DOE/EA-1336

ENVIRONMENTAL ASSESSMENT

OCEAN SEQUESTRATION OF CO_2 FIELD EXPERIMENT

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

March 2001

National Environmental Policy Act (NEPA) Compliance

Environmental Assessment Cover Sheet

Proposed Action: The U.S. Department of Energy (DOE) would participate with a group of international organizations in an experiment to evaluate the dispersion and diffusion of liquid carbon dioxide droplets in ocean waters. The experiment would be conducted in the fall of 2001. If the action is approved, DOE would participate in a series of tests involving the intermittent release of liquid carbon dioxide at a depth of about 2,600 feet (800 meters). The carbon dioxide would be supplied through flexible tubing from a surface vessel to a nozzle attached to a retrievable platform resting on the ocean floor. All testing would be completed within a two-week period. Monitoring of the released carbon dioxide droplets would be accomplished using a combination of remotely operated vehicles controlled from surface vessels, a submersible, and bottom arrays of measurement equipment.

A number of alternative ocean sites were considered for conduct of the proposed experiment. Discharge of liquid carbon dioxide from a surface vessel through tubing to a nozzle attached to a bottom-located platform is preferred. Generally, ocean locations possessing the following characteristics would be appropriate for the experiment: seafloor at about 800 meter depth; weather and surface wave conditions suitable for completing the experiment; proximity to land-based support facilities; and absence of natural resources that would be adversely affected.

Candidate ocean sites within the U.S. territorial waters included several locations offshore from the Hawaiian Islands and in the Gulf of Mexico, off the coasts of Texas or Louisiana. A steering committee comprised of member representatives from participating international organizations would select the final location for the experiment. The currently preferred site is within the Ocean Research Corridor of the Natural Energy Laboratory of Hawai‘i Authority (NELHA) at Ke hole Point, Island of Hawai‘i, approximately 1.2 miles (~1.9 kilometers) from the coast. (See **Note** on continuation page.) This site is described in greatest detail in this Environmental Assessment. However, the characteristics and potential environmental consequences of conducting the experiment within ocean waters outside the Ocean Research Corridor, including locations not within the State of Hawai‘i, are also described.

Type of Statement: Environmental Assessment

Lead Agency: U.S. Department of Energy; National Energy Technology Laboratory (NETL)

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National Environmental Policy Act (NEPA) Compliance

Environmental Assessment Cover Sheet

(continued)

Abstract: DOE's objective in participating in the experiment would be to ensure: (1) that developed information provides improved understanding of the natural processes and of the physical and chemical consequences associated with potential sequestration of carbon dioxide in deep ocean waters; (2) that information is disclosed openly to the public and potential policy makers; and (3) that the U.S. maintains an international leadership role in addressing issues and concerns related to national and global energy and related environmental matters.

The Environmental Assessment (EA) identifies the most notable change from the experiment as a temporary increase in acidity from the dissolution of a cloud of liquid carbon dioxide droplets into seawater. The dissolving plume of carbon dioxide droplets would achieve steady vertical and lateral conditions within one hour (models estimate about 30 minutes) following the start of each release. The resulting carbon-rich seawater could have acidity levels with the potential to affect marine organisms for a maximum of three hours, after which time the action of ocean currents would have reduced the acidity to a level where adverse effects would not be anticipated. Comparative studies indicate that project-related changes in acidity would not persist for sufficient time or at sufficiently reduced levels to substantially affect marine organisms.

Public Comments: DOE encourages public participation in the NEPA process. A draft EA was distributed for public review on August 8, 2000, and comments were solicited through the close of the comment period on September 8, 2000. Due to the preferred site for the experiment off the coast from Ke hole Point, Hawai‘i, the EA was made available for public access at the Kailua-Kona Public Library and the Hilo Public Library on the Island of Hawai‘i and at the Hawai‘i State Library in Honolulu on the Island of O‘ahu. Newspaper notices announcing availability of the draft EA were printed in the <u>West Hawaii Today</u> and <u>Hawaii Tribune-Herald</u> newspapers on the Island of Hawai‘i and in <u>The Honolulu Advertiser</u> on the Island of O‘ahu; collectively, about 85% of the population of the Hawaiian Islands resides on these two islands. In addition, availability of the draft EA was announced on the NETL website and on an internet website established to disseminate information about the proposed experiment. Copies of the draft EA were also distributed to cognizant regulatory agencies and various interested parties. A discussion of feedback received on the draft EA and actions taken to address comments are presented in Appendix G. All comments received from public participation were considered and addressed as appropriate in this final Environmental Assessment for the proposed U.S. Department of Energy action.

Note: On February 26, 2001, subsequent to completing work for preparing a Final Environmental Assessment, the following e-mail communication was received from the Executive Director, NELHA.

> "On February 20th, the Board of Directors of NELHA met in monthly session. During the meeting Peter Young offered a motion for the Board to rescind its 1999 motion to authorize NELHA Staff to work with Pacific International Center for High Technology Research (PICHTR) representatives to negotiate a Facilities Use Agreement. After a second from R. Lim, T. Whittemore called for the question and the motion was carried by the majority."

The communication indicated that the information was from the minutes of that Board meeting and that the minutes are draft only and will not be approved or corrected by the Board until the next meeting. Since the action by the Board of Directors of NELHA does not affect the validity of the analyses of the potential consequences from conducting the proposed experiment at any of the alternative sites, the Environmental Assessment (EA) is being released with this added Note regarding the NELHA action. No additional changes are needed for DOE decision-making.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACM	Acoustic Current Meter
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
C	Centigrade
CDUP	Conservation District Use Permit
CEQ	Council on Environmental Quality
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
cm	centimeters
cm/s	centimeters per second
CO_2	carbon dioxide
COE	U.S. Army Corps of Engineers
CTD	conductivity, temperature, depth probe
CTI	Climate Technology Initiative
CWB	Clean Water Branch (DOH)
CZM	Coastal Zone Management
DAR	Division of Aquatic Resources (DLNR)
dB	decibels
DBEDT	Department of Business, Economic Development & Tourism (State of Hawai‘i)
DIC	Dissolved Inorganic Carbon
DLNR	Department of Land and Natural Resources (State of Hawai‘i)
DOE	U.S. Department of Energy
DOH	Department of Health (State of Hawai‘i)
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
et al.	and others
F	Fahrenheit
FAD	Fish Aggregation Device
FCCC	Framework Convention on Climate Change (United Nations)
FETC	Federal Energy Technology Center (DOE) (now known as the National Energy Technology Laboratory) (NETL)
FY	fiscal year
GHG	greenhouse gas
GtC	billion metric tons (gigatons) of atmospheric carbon
HAR	Hawai‘i Administrative Rules
HDPE	high-density polyethylene

HIBT	Hawaiian International Billfish Tournament
HRS	Hawai‘i Revised Statutes
HURL	Hawai‘i Undersea Research Laboratory
Hz	Hertz (cycles per second)
IEA	International Energy Agency
in situ	In place
IOS	Institute of Ocean Sciences (Canada)
IPCC	Intergovernmental Panel on Climate Change
kg/s	kilograms (2.2 pounds) per second
kHz	kilohertz
km	kilometer(s)
kW	kilowatts
l	liter(s)
m	meters
m^2	square meters
m^3	cubic meters
MARPOL	International Convention for the Prevention of Pollution from Ships
mg/l	milligram(s) per liter
MIT	Massachusetts Institute of Technology
mmol	milli-moles
Pa	micro-Pascals
MMPA	Marine Mammal Protection Act
NASA	National Atmospheric and Space Administration
NEDO	New Energy and Industrial Technology Development Organization
NELH	Natural Energy Laboratory of Hawai‘i
NELHA	Natural Energy Laboratory of Hawai‘i Authority
NEPA	National Environmental Policy Act
NERSC	Nansen Environmental and Remote Sensing Center (Norway)
NETL	National Energy Technology Laboratory (DOE) (formerly known as Federal Energy Technology Center)
NIVA	Norwegian Institute for Water Research
NMFS	National Marine Fisheries Service
NODC	National Oceanographic Data Center
NPDES	National Pollutant Discharge Elimination System
NPSG	North Pacific Subtropical Gyre
NRC	Norwegian Research Council
OGCM	Ocean Global Climate Model
OHA	Office of Hawaiian Affairs (State of Hawai‘i)
OS	U.S. Department of Energy, Office of Science
OSHA	Occupational Safety and Health Administration

p_a	Partial Pressure of CO_2 in the atmosphere
p_m	Partial Pressure of CO_2 in the mixed layer of the ocean
pH[1]	Standard measure of acidity; the negative logarithm (base 10) of the hydronium (H_3O^+) molar activity. The lower the pH (on a scale of 1 to 14), the higher the acidity.
PICHTR	Pacific International Center for High Technology Research
ppm	parts per million
ppmv	parts per million by volume
R&D	Research and Development
RITE	Research Institute of Innovative Technology for the Earth (Japan)
ROV	Remotely operated vehicle
RTV	Remotely operated television
SHPO	State Historic Preservation Office (DLNR)
SMA	Special Management Area
U.S.	United States
USC	United States Code

[1] Pure water has a pH of 7. Normal surface ocean water has a pH of about 8 to 8.5, and deep (800 m) ocean water at the NELHA Ocean Research Corridor site has a pH of about 7.6. Lemon juice has a pH of 2, and most carbonated soft drinks have a pH of about 4.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is proposing to participate, with a group of international organizations, in an experiment to investigate certain scientific and technical aspects of carbon dioxide (CO_2) sequestration in ocean waters (the action proposed by DOE). This Environmental Assessment (EA) describes potential environmental consequences that could result from the experiment, which would consist of releasing small quantities of liquid CO_2 in ocean water at moderate depths in order to test dispersion and dissolution characteristics of carbon dioxide droplets and the evolution of carbon-rich seawater. The experiment would provide information for future use in considering options that might be necessary for effectively managing the build-up of carbon dioxide (a greenhouse gas) in the atmosphere.

If this proposal is approved, DOE would participate as a partner in the *Ocean Sequestration of CO_2 Field Experiment.* The *Field Experiment* would consist of short duration releases of liquid CO_2 during a two-week period in the fall of 2001. It would be conducted by pumping liquid CO_2 from a surface vessel through tubing to a nozzle attached to a platform resting on the seafloor at a depth of about 2,600 feet (800 meters). Ocean sites for the experiment must possess certain characteristics of weather and wave conditions and proximity to land-based logistical support. This EA considers candidate sites for the experiment, including the Natural Energy Laboratory of Hawai‘i Authority's (NELHA's) Ocean Research Corridor, approximately 1.2 miles (~1.9 kilometers) off the western coast of the Island of Hawai‘i, and other generic ocean sites.

During the *Field Experiment*, liquid CO_2 would be injected at low flow rates (i.e., 1.6 to 16 gallons per minute) from a surface vessel to a small discharge platform located on the ocean floor in a series of up to 20 intermittent, controlled-flow tests. Dispersion of the CO_2 into liquid droplets would be achieved using a specially designed discharge nozzle attached to the platform.

The *Field Experiment* would provide information on (1) physical and chemical changes induced in seawater by releasing liquid CO_2 and (2) relationships between release parameters (e.g., flow rate, injection velocity) and the physical dynamics of CO_2 droplets. In addition, sampling of biota and naturally occurring bacteria populations in the vicinity of the discharge nozzle would be conducted to provide insight into potential biological responses resulting from the short-term exposure to CO_2.

This EA identifies and assesses potential environmental and socio-cultural impacts that could result from conducting the *Field Experiment*. A variety of potential sites and concepts for CO_2 injection are discussed; reasonable alternatives for achieving the purpose of the experiment are identified; and alternatives dismissed from further consideration are identified. The potential consequences of a "No Action" alternative are also assessed.

The purpose of the EA is to determine if the action proposed by DOE, which would result in participation in the *Field Experiment,* could cause significant impacts to the environment. If potentially significant environmental impacts are identified, and if they cannot be reduced to insignificance or avoided, then a more detailed Environmental Impact Statement would be prepared and used as the basis for a DOE decision to participate in the *Field Experiment*. If no significant environmental impacts are identified, a Finding of No Significant Impact would be prepared and made available to the public, along with the EA itself, before DOE would proceed with the proposed action.

This study was prepared in accordance with the National Environmental Policy Act (NEPA) of 1969 (42 United States Code 4321 et seq.), the Council on Environmental Quality's Regulations [Title 40, Code of Federal Regulations (CFR), Parts 1500-1508], and the Department of Energy's NEPA Implementing Procedures (Title 10, CFR, Part 1021).

2.0 EXECUTIVE SUMMARY

2.1 INTRODUCTION

2.1.1 PROJECT SUMMARY

This Environmental Assessment (EA) has been prepared by the U.S. Department of Energy (DOE) to provide the results of a study on the potential environmental impacts of an *Ocean Sequestration of CO_2 Field Experiment*. This *Field Experiment* would be conducted from surface vessels in water of about 800 meter depth, either within the Ocean Research Corridor of the Natural Energy Laboratory of Hawaiʻi Authority (NELHA), about 1.2 miles (~1.9 kilometers) off the coast of the Island of Hawaiʻi (see Figure 2-1), or at a suitable alternate site. If approved, DOE would participate as a team member with a group of international organizations in testing certain scientific and technical aspects of CO_2 sequestration in ocean waters.

Through controlled release of fixed amounts of liquid CO_2 totaling a maximum of 40-60 metric tons (44-66 English, or short, tons), the *Field Experiment* would develop information on (1) physical and chemical changes induced in seawater by the release of liquid CO_2 and (2) effects of release rates and nozzle designs on the physical dynamics of a cloud of CO_2 droplets. In addition, sampling of biota and a study of naturally occurring bacteria populations in the immediate vicinity of the discharge nozzle would be conducted and the results would be compared with background information to determine the effects of CO_2 injection on these organisms. Other observations of the behavior of marine biota while the experiment is underway would be performed.

2.1.2 PURPOSE OF THIS DOCUMENT

This study was prepared in accordance with the National Environmental Policy Act (NEPA) of 1969 [42 United States Code 4321 et seq.], the Council on Environmental Quality's Regulations [Title 40, Code of Federal Regulations (CFR), Parts 1500-1508], and the Department of Energy's NEPA Implementing Procedures [Title 10, CFR, Part 1021]. This EA identifies and assesses potential environmental impacts that could result from conducting the *Field Experiment* within NELHA's Ocean Research Corridor, or at an alternative, generic ocean site. The potential impacts of a "No Action" alternative are also identified.

2.2 PURPOSE AND NEED FOR THE *FIELD EXPERIMENT*

The *Field Experiment* would provide data to confirm scientific predictions and to test and refine theoretical models scientists use to predict the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters).

2.3 SUMMARY DESCRIPTION OF THE *FIELD EXPERIMENT*

The *Field Experiment* would consist of a series of tests. Each test would be conducted with a different set of release parameters or physical ambient conditions to obtain a wide range of data for comparison with and calibration of predictive models. The equipment needed to conduct the tests would be mounted on, and deployed from, vessels chartered for that purpose. One vessel would carry the equipment used to release the liquid CO_2. A discharge platform would be carried on the deck of the ship until it is in position for deployment. A test nozzle would be fitted to the end of an outlet pipe on the platform, and the platform's inlet pipe would be connected, using a short length of flexible hose, to one end of coiled tubing through which liquid CO_2 would be pumped from the vessel. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet. The vessel used to deploy the discharge platform and flexible tubing would have good positioning capabilities. That is, the vessel would contain the navigational and mechanical equipment needed to

Figure 2-1. Location Map

remain in a fixed position without using an anchor. Other vessel(s) would transport remotely operated vehicles (ROVs) and a submersible that would be used to collect data during the *Field Experiment*. Instrumentation used for data collection would include ocean current meters, pH meters, video cameras, and other oceanographic tools. Moored systems would be deployed to obtain continuous records of oceanographic variables at fixed locations, while the ROV system and submersible would be used to follow the discharge plume down current.

2.4 SUMMARY DESCRIPTION OF SITES AND ALTERNATIVES

This Environmental Assessment considers the potential effects of conducting the *Field Experiment* at the NELHA Ocean Research Corridor site and at a generic ocean site as well as the effects of No Action by DOE.

- The NELHA Ocean Research Corridor Site, within waters having the requisite depth and other desired characteristics. The site would be approximately 1.2 miles (~1.9 kilometers) from the coast.
- The Generic Ocean Site, within ocean waters having the requisite depth and other desired characteristics outside the NELHA Ocean Research Corridor. This alternative includes sites for a *Field Experiment* that would be in international waters, waters at locations away from the Ocean Research Corridor, and waters away from the Hawaiian Islands.
- The No Action Alternative considers the situation of DOE not participating in the *Field Experiment*. Due to the involvement of an international consortium of sovereign entities, the No Action Alternative would not preclude conduct of the *Field Experiment*.

A number of other alternatives were identified, evaluated, and eliminated from consideration during the conceptual planning phase of the project. These are discussed in Section 4 of this report.

2.5 THE *FIELD EXPERIMENT* SCHEDULE

The *Field Experiment* would be conducted during the fall of 2001. The duration of the experiment would be approximately two weeks.

2.6 COMPARISON OF THE EFFECTS OF ALTERNATIVES

Table 2-1 considers the potential environmental effects of the *Field Experiment* conducted at the NELHA Ocean Research Corridor and at another Generic Ocean Site and also the effects of the No Action Alternative.

Table 2-1. Comparison of the Anticipated Impacts of Alternatives

RESOURCE AFFECTED	*FIELD EXPERIMENT* At Ocean Research Corridor Site	*FIELD EXPERIMENT* At Generic Ocean Site	NO ACTION
Marine Water Quality	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	No or similar effects
Seafloor	Local abrasion of surface due to platform and pipe emplacement and movement.	Local abrasion of surface due to platform and pipe emplacement and movement	No or similar effects
Benthic Marine Life	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	No or similar effects
Deep-Water Pelagic Marine Life	Very small loss of plankton and minor effects on mobile organism communities	Very small loss of plankton and minor effects on mobile organism communities	No or similar effects
Midwater Marine Life	Very minor stress on local plankton populations	Very minor stress on local plankton populations	No or similar effects
Surface-Water Marine Life	No adverse effects	No adverse effects	No or similar effects
Historical and Cultural Resources	No effects on archaeological or historic sites. Native Hawaiian groups believe it would adversely affect cultural values and fishing and other traditional uses	No effects on archaeological or historic sites. Depending upon location, native groups could believe it would adversely affect cultural values and fishing and other traditional uses.	No or similar effects
Air Quality and Climate	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	No or similar effects
Noise	No adverse effects	No adverse effects	No or similar effects
Marine Transportation	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	No or similar effects
Land Use	No effects	No effects	No effects
Aesthetic Resources	No effects	No effects	No effects
Socioeconomic Resources	Inputs of goods and services to Hawai‘i communities; expenditures for goods where test equipment would be manufactured.	Inputs of goods and services to communities; expenditures for goods where test equipment would be manufactured.	No or similar effects
Public Facilities and Services	No effects	No effects	No effects
Public Safety & Health	No effects	No effects	No effects

Note: If, under the No Action Alternative the experiment would be performed without DOE support, then the anticipated impacts would be essentially the same as for the NELHA Ocean Research Corridor site.

3.0 PURPOSE AND NEED FOR AGENCY ACTION

3.1 BACKGROUND

In the past 100 years, the amount of anthropogenic carbon dioxide (CO_2) emitted into the atmosphere has greatly increased, primarily due to expanding use of fossil fuels. Scientists estimate that atmospheric CO_2 has risen from pre-industrial levels of 280 parts per million (ppm) to over 365 ppm (Keeling and Whorf 1998). Barring a major change in the way energy is produced and used, predictions of global energy use in the 21st century suggest a continued increase in carbon emissions and rising concentrations of CO_2 in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) estimated that future global emissions of CO_2 will increase from 7.4 billion metric tons of atmospheric carbon (GtC) annually in 1997 to approximately 26 GtC per year by 2100 (IPCC 1996).

Although historical effects of increased CO_2 levels on global climate remain a topic of debate, there is scientific consensus that doubling atmospheric CO_2 concentrations from present levels could have a variety of serious environmental consequences in the 21st century. There is growing evidence, for example, that higher concentrations of CO_2 and other "greenhouse" gases could be contributing to an observed increase in average global temperatures. A global average temperature increase of even a few degrees could lead to an accelerated rise in sea level, changes in weather patterns, and other atmospheric changes that would impact human health, water resources, land use, and other resources (EPA 2000).

While the long-term solution to this problem must include actions associated with use of fossil fuels (e.g., application of more efficient technologies, reductions in fossil fuel use), these actions could not, on their own, be implemented on a schedule that would quickly stabilize CO_2 levels. The sheer magnitude of the present reliance on fossil fuels and the growing energy demands throughout the world make it inevitable that the United States and other nation-states will continue to rely on fossil fuels for energy well beyond the 21st century. Accordingly, some forms of carbon sequestration — carbon capture, separation, and storage or reuse — could be needed to assist in mitigating global climate change.

Carbon sequestration complements two other approaches to carbon management that are being developed by the U.S. Department of Energy (DOE). The first approach increases the efficiency of primary energy conversion and end-use. DOE sponsors a variety of research and development (R&D) programs to investigate more efficient supply-side and demand-side technologies. These technologies include more efficient fossil fuel-fired power plants, buildings, appliances, and transportation vehicles. DOE also fosters research into methods of producing and delivering electricity and fuels more efficiently. More efficient energy conversion and end-use would result in lower CO_2 emissions per unit of energy service.

The second approach is substituting lower-carbon or carbon-free energy sources for current energy sources. Examples include using lower-carbon fossil fuels (e.g., replacing coal or oil with natural gas) and increasing renewable energy use (such as solar or wind). DOE has major R&D programs to develop more efficient fossil energy utilization and renewable energy technologies.

Carbon sequestration, the focus of the *Field Experiment* discussed in this Environmental Assessment (EA), represents a third approach to carbon management. Most effective over the mid-term, carbon sequestration would complement long-term efforts to improve efficiency and transition toward low-carbon fuels. Increased recognition of the urgency in dealing with the CO_2 buildup has focused more interest on the potential of this approach. In response, DOE has established R&D objectives intended to develop a better understanding of the economics and environmental implications of a variety of carbon sequestration technologies. Successful development and implementation of such technologies would allow the world to continue to benefit from the use of fossil fuels without the adverse side effects that result when CO_2 is emitted into the atmosphere. Federal participation in research on carbon sequestration technologies is important at this early stage in their development because technical uncertainties and lack of profit incentive discourage commitment of private resources.

The United Nations' Framework Convention on Climate Change (FCCC), adopted in 1992, called for industrialized nations to reduce their greenhouse gas (GHG) emissions to 1990 levels by the year 2000. This ambitious goal was viewed as an initial step for developed countries under FCCC, but the overarching objective was to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Some 167 countries, including the United States, have ratified FCCC. The International Energy Agency (IEA) established the Climate Technology Initiative (CTI) in 1995, as part of an effort by industrialized nations to fulfill the demands of FCCC. The Kyoto Protocol, negotiated by the nation-states of the world in December 1997, may be viewed in the same way.

CTI (http://www.climatetech.net/home.shtml) seeks to increase the use of existing and new climate-friendly technologies through international cooperation in research, development, deployment, and information dissemination. One objective of CTI is to enhance international collaboration in greenhouse-gas capture and disposal. In December 1997 at Kyoto, Japan, CTI initiated work on a number of practical research and development projects for CO_2 mitigation. Agencies of the governments of the U.S., Japan, and Norway signed an international project agreement in December 1997 (Appendix A) under the Climate Technology Initiative.

The agreement's contents, and the related project scope, resulted from numerous meetings and discussions among international researchers involved in the study of global climate change mitigation technologies for several years. Original signatory agencies were the National Energy Technology Laboratory of the U.S. Department of Energy (formerly, the Federal Energy Technology Center), Japan's New Energy and Industrial Technology Development Organization, and the Norwegian Research Council (NRC). A steering committee, composed of one member per signatory agency, was established to oversee and coordinate projects funded by participating nation-states. One of those projects, now known as the *Ocean Sequestration of CO_2 Field Experiment*, is the subject of the Proposed Action.

Technical stewardship of activities initiated by each signatory under the agreement is the responsibility of a second-tier group of organizations or agencies that receive monies from member nation-states. The implementing organizations originally consisted of the Massachusetts Institute of Technology (MIT), Japan's Research Institute of Innovative Technology for the Earth (RITE), and the Norwegian Institute for Water Research (NIVA). A group of scientists and engineers from each of the implementing organizations (known as the Technical Committee) share ideas, cooperatively establish scientific and engineering objectives for activities, and track progress of initiated activities.

In 1999, Natural Resources Canada and a Swiss private company (Asea Brown Boveri) joined the international project agreement. The Canadian Institute of Ocean Sciences (IOS) is the implementing organization for Natural Resources Canada. In 2000, membership in the project agreement was increased to include participation by Australia's Commonwealth Scientific and Industrial Research Organization and by Japan's Central Research Institute of Electric Power Industry, which is the research organization for the electric power industry in Japan.

The Pacific International Center for High Technology Research (PICHTR), a non-profit R&D organization based in Honolulu, Hawai'i, was selected and funded by RITE (Japan) to serve as the general contractor for the *Field Experiment*. PICHTR is responsible for organizing experimental infrastructure, securing permits and authorizations, and providing technical and support services over the duration of the project. In addition, PICHTR has initiated numerous public outreach activities.

3.2 PURPOSE OF DOE'S CARBON DIOXIDE SEQUESTRATION PROGRAM

3.2.1 DOE'S PURPOSE

The Agreement signed by DOE in December 1997 was established in accordance with DOE's mandate to work in partnership with stakeholders to support development of technologies that could help solve environmental problems related to energy use. The Agreement is part of DOE's ongoing support of research into energy systems.

The main challenges for research on CO_2 sequestration technologies are to reduce the anticipated cost of sequestration, to establish a portfolio of practical sequestration options, and to identify viable options for sequestration that, in the long term, would be effective and would not create new environmental problems. DOE activities related to CO_2 sequestration focus on five research areas (DOE 1997):

- separation and capture at the source;
- sequestration in stable geologic formations;
- sequestration in the ocean;
- sequestration in terrestrial ecosystems; and
- advanced sequestration concepts using chemical, biological, and other innovative approaches.

A sixth area of research addresses systems analysis, which is a critical tool for assessing the effectiveness of alternative strategies. As shown in Table 3-1, ocean sequestration has, by far, the greatest potential of the four research areas related to sequestration (DOE/FETC 1999). As a point of reference, in 1990 global anthropogenic emissions of carbon amounted to 6.0 billion (10^9) metric tons.

Table 3-1. Carbon Sequestration Reservoirs

Carbon sequestration reservoir	**Carbon Capacity (in 10^9 metric tons)**
Oceans	1,400 – 2 x 10^7
Geologic Structures	300 – 3,200
Terrestrial Systems (forestation and soil)	>100
Fixation or Reuse (advanced concepts)	*Unknown*
Source: DOE/FETC 1999	

DOE has identified areas where the understanding of the science and technologies related to ocean sequestration needs improvement (DOE/OS 1999). Questions such as the following remain unanswered:

- To what extent would ocean sequestration be effective?
- What would be the best way to engineer a cost-effective and environmentally benign system?
- How would the carbon cycle function in the deep ocean?

DOE's carbon sequestration research has identified a range of activities needed to close information gaps. These activities include laboratory studies, small-scale field experiments, and near-field computer modeling to increase understanding of the behavior of CO_2 released into the ocean. In addition, knowledge is needed on the effects of changes in pH and CO_2 concentrations on organisms from mid-water and deep-sea habitats.

3.2.2 PROJECT PURPOSE

The *Ocean Sequestration of CO_2 Field Experiment* would be conducted at a depth of approximately 2,600 feet (800 meters) and would be focused on key information gaps, as identified in Section 3.2.1. The *Field Experiment* would provide data needed to test, validate, and refine existing computer and laboratory models concerning the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters).

The specific objectives of the *Field Experiment* would be to:

- Investigate CO_2 droplet cloud dynamics;
- Examine pH in the plume and on its margins;
- Clarify effects that hydrates might have on droplet dissolution;
- Trace the evolution of CO_2-enriched seawater resulting from CO_2 dissolution;
- Assess potential impacts on bacterial biomass, production, and growth efficiency associated with induced changes in seawater pH in the vicinity of the release; and
- Examine the effect of a range of CO_2 injection velocities and injector configurations (e.g., orifice size, number of injectors) on the performance of the system and on physio-chemical effects.

The *Field Experiment* would allow a real-world evaluation of computer model predictions and a refined understanding of the small-scale physics governing the evolution of liquid CO_2 released in the deep ocean. Reliable results obtained from these computer models would represent a very valuable input to the general effort to understand the feasibility and potential consequences of ocean sequestration of CO_2.

3.3 NEED FOR THE ACTION

Global climate change is an issue with many implications for the inhabitants of the planet, and it presents a complex challenge. The potential for climate change, and the response of the nation-states of the world to such change, could dictate fundamental shifts in the methods by which energy is generated and used. In the long-term, options that help to mitigate climate change, such as carbon sequestration, could be essential to preserving or improving the quality of life of the world's inhabitants.

3.3.1 DOE NEED FOR ACTION

The President's Committee of Advisors on Science and Technology recognized the importance of carbon sequestration research and recommended increasing the U.S. Department of Energy's budget for such research (President's Committee 1997). The Committee also recommended that a larger, science-based sequestration program be developed with a focus on providing a science-based assessment of the prospects and costs of CO_2 sequestration. The Committee recognized that this scientific focus would represent long-term research and development that would not be conducted by industry alone.

Among the opportunities for carbon sequestration are the following:

- Cost-effective CO_2 capture and separation processes;
- Geologic storage;
- Enhancement of natural processes in terrestrial and ocean sinks; and
- Chemical or biological fixation or reuse.

Approaches to test technologies in all of the above areas are at an early research stage. As noted in Table 3-1, the world's oceans provide the greatest possible sink for carbon. Additional research is needed to establish answers to critical technical and environmental questions regarding the feasibility, capacity, and long-term viability of enhancing the natural process of CO_2 storage in the ocean. Improved understanding of the basic processes and process chemistries are needed before practical, achievable technology performance and costs can be estimated.

3.3.2 DOE DECISION

The decision to be made by DOE is whether to participate in the *Field Experiment* proposed to be conducted in 2001 at a site that possesses the requisite characteristics of depth, weather and wave regime, proximity to land-based support facilities, and absence of potentially adversely affected sensitive natural resources. Candidate sites exist within the Natural Energy Laboratory of Hawai'i Authority's Ocean Research Corridor and at other ocean locations. The DOE decision will be based on the potential consequences, identified in this Environmental Assessment, of conducting the proposed experiment within the Ocean Resource Corridor or at another ocean site.

3.4 SCOPING ACTIVITIES

3.4.1 SCIENTIFIC LITERATURE

DOE reviewed the experimental concept for a field test of ocean sequestration of CO_2 at the outset of the program to identify the potential environmental effects that would need to be investigated and discussed. This review included a thorough analysis of the scientific literature.

Some examples of scientific literature reviewed in order to identify potential environmental consequences of the *Field Experiment* include Auerbach *et al.* (1997), Caulfield *et al.* (1997), and Alendal *et al.* (1998). Additional examples are included in Section 12.0 (References).

3.4.2 ENVIRONMENTAL QUESTIONNAIRE

The Department of Energy's National Environmental Policy Act (NEPA) Implementing Procedures (10 CFR 1021) require careful consideration of the potential environmental consequences of all proposed actions during the early planning stages. DOE must determine at the earliest possible time whether such actions require either an Environmental Assessment or an Environmental Impact Statement, or whether they qualify for categorical exclusion. To assist in making this determination, an Environmental Questionnaire must often be completed to provide information that can support determination of the appropriate level of NEPA review.

A NEPA Environmental Questionnaire for land-based implementation of the *Field Experiment* was completed in August 1998. The information supplied on the Questionnaire indicated that an Environmental Assessment would be the appropriate level of review. DOE reconsidered this determination when the focus of the *Field Experiment* changed to a vessel-based alternative. Although the latter would have fewer potential effects than the shore-based alternative, DOE reaffirmed its decision to prepare an Environmental Assessment.

3.4.3 PUBLIC OUTREACH PROGRAM

As the general contractor, the Pacific International Center for High Technology Research (PICHTR) developed and initiated an extensive public outreach program for the *Field Experiment*. The outreach program was developed to inform environmental groups and other local stakeholders about the *Field Experiment* and to provide a mechanism for concerns to be identified and addressed. Activities included contacting the media, hosting one-on-one meetings, holding a public scoping meeting (Section 3.4.4), and establishing a website (www.co2experiment.org). The public outreach effort was divided into several phases, which are specifically defined in Appendix B.

3.4.4 FORMAL SCOPING

PICHTR arranged and conducted a public scoping meeting for a *Field Experiment* within the Ocean Research Corridor. The meeting took place on October 14, 1999, from 6:30 p.m. to 9:00 p.m. at the Kealakehe Intermediate School cafeteria in Kailua-Kona. About 30 members of the public attended. The purpose of the meeting was to explain the project and to gather questions and concerns from the public. Topics discussed at the meeting included the rationale for selecting NELHA's Ocean Research Corridor as a potential site of the *Field Experiment*, impacts that the proposed project might have on marine organisms, sensitivity of the *Field Experiment* to native Hawaiian cultural issues, possible effects on public access to and along the shoreline, and opportunities for public input.

3.5 SCOPE OF THE ENVIRONMENTAL ASSESSMENT

The scope of the Environmental Assessment was determined after reviewing the objective and purpose of the proposed project, the extent of testing that would be performed, activities that would need to be performed to implement the proposed experiment, the proposed setting for the project, and other available technical and environmental information related to the proposed project.

Factors considered in establishing the scope of the Environmental Assessment included the following: air, water, wastewater, noise, health and safety (including accidents), transportation, hazardous and non-hazardous wastes, environmentally sensitive resources, ecology, cultural resources, and land use. The key issues for the proposed action were determined to be: ecological protection, water quality, cultural values, transportation, and seafloor protection.

4.0 ALTERNATIVES, INCLUDING THE PROPOSED ACTION

4.1 INTRODUCTION

As discussed in Chapter 3, DOE is supporting research in many areas that may lead to lower levels of anthropogenic CO_2 emissions to the atmosphere. One of these areas involves ocean sequestration. This Environmental Assessment covers an experiment (the "*Field Experiment*") that has been proposed as a means to expand knowledge of the behavior of CO_2 released into the ocean at moderate depth, which is considered appropriate for testing ocean sequestration.

Theoretical calculations and laboratory experiments have made significant progress in defining chemical and physical limitations that would constrain any future ocean sequestration scheme (e.g., Wadsley 1995, Shindo *et al.* 1995, Aya 1995, Masutani *et al.* 1995). This work has shown that some key uncertainties cannot be resolved without field experimentation. Tests involving the release of extremely small amounts (i.e., a few kilograms) of CO_2 have helped to confirm and extend theoretical and laboratory results (Brewer *et al.* 2000). However, several scientific questions remain that can only be answered through larger *in situ* releases.

Scientists first conceptualized the *Ocean Sequestration of CO_2 Field Experiment* in a definitive way in 1996 and 1997. At that time, the concept involved a *Field Experiment* that would most likely use shore-based facilities with a pipeline extending seaward to the required water depth. However, a vessel-based test was recognized as having advantages if technical difficulties could be overcome.

This chapter defines alternatives considered for impact analysis. Section 4.2 discusses concepts that were initially considered but dismissed from detailed consideration as reasonable alternatives. Section 4.3 describes the vessel-based experiment conducted in NELHA's Ocean Research Corridor or in a generic site outside the Ocean Research Corridor. Section 4.4 describes the "No Action" alternative, which would result if the U.S. Department of Energy does not provide funding for the *Field Experiment*.

4.2 CONCEPTS DISMISSED FROM DETAILED CONSIDERATION

4.2.1 PHASE I: INITIAL SCREENING OF EXPERIMENT CONCEPTS

The *Ocean Sequestration of CO_2 Field Experiment* would produce information needed to calibrate and refine predictive models describing the behavior of CO_2 released at a moderate ocean depth appropriate for sequestration. Since release parameters represent a fundamental input to the predictive models, the *Field Experiment* would be best conducted under as wide a range of conditions as can be practically achieved. Key aspects of the release conditions that need to be examined include (1) how the nozzle design will affect the size distribution of droplets, (2) the interactions among droplets near the nozzle, (3) the possibility of hydrate formation, and (4) the potential effects of hydrates, if formed. Many of these have been explored in laboratory experiments, but tests in the open ocean would be needed to verify and extend laboratory results. This would require placing instruments near the nozzle to measure physical and chemical changes induced by the release of the CO_2, direct observation of CO_2 droplets, and indirect measurements of the CO_2 plume.

Evaluating the effects of ambient dispersal of the discharged CO_2 would be important to understanding the way in which CO_2 would be assimilated into the ocean environment at a depth of about 2,600 feet (800 meters). Many field experiments have been conducted to measure horizontal and vertical mixing in near-surface waters (e.g., Okubo 1971, Jenkins 1985). Fewer data are available to describe mixing at the depths where CO_2 would have to be released for effective sequestration.

In order to achieve the desired objectives (Section 3.2.2), the scale of the *Field Experiment* would need to be sufficient for effective monitoring by available instrumentation. This means the release rates should be in the range of 1.6 to 15.8 gallons per minute (0.1 to 1.0 kilograms per second). The depth of the release would need to be sufficient to allow the CO_2 in the rising droplets to dissolve before reaching the depth at which the CO_2 changes into vapor (approximately 1,375 feet, or 420 meters). In addition, the duration of testing at a defined set of conditions would need to be sufficient to attain a steady state around the discharge nozzle and to provide sufficient additional release time for making meaningful measurements. Computer models predict (see Section 5.2.1.4) that a steady state would be achieved within about thirty minutes, and a minimum of one hour would be needed to take measurements after achieving steady state conditions. Consequently, operational plans would consist of two-hour release periods, with close monitoring being carried out before, during, and after the release.

4.2.1.1 Carbon Dioxide Delivery System Concepts Considered

CO_2 could be delivered to the discharge nozzle in any of several ways. These include (i) from a land-based facility through a pipe laid along the bottom, (ii) from a vertical pipe attached to an oil platform, (iii) through a conduit from a surface vessel, and (iv) from a submerged tank. The advantages and disadvantages of these delivery concepts are discussed below.

4.2.1.1.1 Bottom-Mounted Pipe from Shore-Based Facility

A pipe constructed along the bottom from a shore-based facility to a release point would be the least technologically challenging of the options. The CO_2 could be handled onshore and any trouble-shooting of the delivery system could be conducted before the start of the *Field Experiment*, thereby minimizing time researchers would need to spend at the site. Offsetting these advantages would be the fact that a pipeline would need to negotiate a high-energy nearshore environment. Also, the potential would exist that construction activities or a pipe failure could adversely affect nearshore resources. The inability to readily access the release nozzle after deployment would be another drawback to this concept.

4.2.1.1.2 Platform-Mounted Pipe

Several oil drilling and oil pumping platforms reach to a depth of about 3,000 feet (900 meters). Some platforms float with anchoring tendons tied to the seafloor; other platforms have a central spar extending to the bottom. An advantage of a platform-mounted pipe would be that small diameter pipes already extend from the platforms to various depths, thus potentially simplifying construction. A disadvantage would be that the multitude of support structures surrounding the release pipe could produce perturbations in the flow regime and greatly complicate use of the ROVs that would carry video cameras and instruments needed to monitor the behavior of the CO_2.

4.2.1.1.3 Vessel-Mounted System

CO_2 delivery from a vessel would allow flexibility in the location of the release and in the ability to readily access the small platform on which the test nozzles would be mounted. This concept would possess technical challenges related to (i) design of CO_2 delivery tubing with the required strength and flexibility and (ii) maintaining accurate vessel position during the *Field Experiment* in order to ensure a fixed release point for the duration of each test.

4.2.1.1.4 Submerged Tank

CO_2 delivery from a submerged tank lowered to the seafloor would avoid all piping except for a short riser extending upward from the tank on which the discharge nozzle(s) would be mounted. Disadvantages include the fact that the entire volume of CO_2 could be released into the ocean in the event of a tank failure. Another complicating factor would be the relatively difficult engineering problems associated with designing a tank capable of withstanding both high internal pressures, when the tank would be filled with CO_2 on the surface, and high external pressures, when the tank would be on the seafloor.

4.2.1.2 Delivery System Concepts Eliminated from Further Consideration

After reviewing the advantages and disadvantages of these four concepts, the platform-mounted pipeline and the submerged tank approaches were eliminated from consideration. While the platform-mounted pipeline had originally appeared promising, excessive safety risk would be created when operating research vessels and submersibles near an oil-drilling platform, and the quality of scientific monitoring data would be suspect due to perturbations in water currents and flow regimes around the platform's support structures. Similarly, the reliability of a system supplying CO_2 from a submerged tank could not be assured, and the potential would exist for release of an entire tank load of liquid CO_2 in the event of a rupture. Thus, these concepts were eliminated from further consideration.

4.2.2 PHASE II: DETAILED SCREENING OF EXPERIMENTAL CONCEPTS

After the initial screening, two delivery system concepts remained as viable candidates for the experiment: (1) a bottom-mounted pipe from shore-based facility and (2) a vessel-mounted system. These design concepts were explored in more detail and evaluated further during a second stage of screening. The results of this effort are summarized in Section 4.2.2.1 for a bottom-mounted pipeline and in Section 4.2.2.2 for a vessel-mounted concept.

4.2.2.1 Bottom-Mounted Pipeline Concept

4.2.2.1.1 Possible Locations

Possible locations for an onshore facility using a bottom-mounted pipeline for the *Field Experiment* were evaluated in considerable detail in 1997 (Adams *et al*. 1997).[2] The analysis concluded that, in principle, near-field tests of nozzle, droplet cloud, and overall plume behavior could be tested at any of a number of ocean sites where hydrographic conditions would be representative of potential ocean sequestration sites. The report noted greater limitations on far-field tests, which could be influenced by site-specific patterns of ocean currents and turbulence.[3] The Adams *et al.* study identified several characteristics that would enhance suitability of a *Field Experiment* conducted using a shore-based facility and a bottom-mounted delivery pipe. Some of these characteristics were noted as being reduced in importance if the *Field Experiment* were conducted from a vessel.

The 1997 review by Adams *et al.* identified several candidate sites as having the requisite characteristics for a land-based *Field Experiment*. These included the northern shore of St. Croix in the U.S. Virgin Islands, Punta Tuna in Puerto Rico, and Ke hole Point in Hawai'i. Each location was evaluated with respect to the required length of the CO_2 delivery pipe, surface currents, waves, wind speeds, the magnitude of bottom currents, and bottom conditions.

Consideration of potential locations for the experiment continued in 1998, with efforts focusing on two sites. One site was near the NASA facility on Cooper's Island at the eastern edge of Bermuda.

[2] The study was not intended to identify the very best place in the world to conduct the experiment. Rather, the goal was to identify locations where the activities could be conducted with reasonable ease and where they would have a high probability of producing scientifically valid results.

[3] In this context, the near field would comprise a zone where initial jet-momentum and gravity effects due to differential buoyancy (e.g., liquid CO_2 droplets, dense carbon rich water) would be strong. The dissolution of the dispersed phase (pure CO_2) should take place within the near field. Typical time scales of a few hours and spatial scales of a few hundred meters would be expected for these experiments. The far field would be the zone where the dissolved carbon would be further transported via advection (currents) and dispersion (turbulent diffusion). In simple terms, the far field would be defined as a size and time scale that exceeds the near field.

The other site was in the Ocean Research Corridor off Ke hole Point on the Island of Hawai‘i. Both sites were evaluated with respect to such factors as the difficulty of laying a pipeline from the shoreline to the potential release location, the suitability of oceanographic conditions, weather, the availability of support from local institutions, and implementation costs. The analysis showed that both locations had strengths and weaknesses relative to one another and concluded that either would be suitable for the *Field Experiment*.

4.2.2.1.2 Conceptual Design for Bottom-Mounted Pipeline

The test facilities required for a bottom-mounted pipeline would consist of four primary components: (1) refrigerated CO_2 storage tank; (2) a pump and metering system; (3) aboveground and submerged conduit; and (4) a moored nozzle array. Each of these is discussed briefly below.

- CO_2 Storage Tank. A single, refrigerated, storage tank would be installed a short distance inland from the shoreline to hold the CO_2 that would be required for the experiment. CO_2 typically is stored in tanks at about 20 to 22 bar[4] and -4°F (about -20°C). The storage tank would require a 3-phase electrical hook-up, consume about 25 kW, and might need to be installed on concrete pads. The liquid CO_2 would be purchased, and a refrigerated storage tank would be leased from a local firm. The storage tank system would consist of standard equipment that has safely been used for years by many industries and businesses, such as food and beverage companies and hospitals.
- Pump and Metering System. A pump would be needed to further pressurize liquid CO_2 extracted from the tank to compensate for pressure losses due to flow through the pipeline and valves, discharge losses through the nozzles, and density head (i.e., the added hydrostatic pressure at the bottom of the sea and the pressure due to differences in densities of the two liquids). Pressurizing CO_2 to a level equal to 70 bar or greater would preclude the possibility of CO_2 boiling in the conduit due to heat transfer from the warm (about 27°C during the summer) surface waters. The flow control and monitoring devices would consist of conventional hardware.
- Aboveground and Submerged Conduit. Conducting the *Field Experiment* from shore-based facilities would involve pumping pure liquid CO_2 through a small steel pipeline from the refrigerated storage tank on the shore to a discharge platform located at a depth of about 800 meters. The length of the pipeline would vary with location.[5] The conduit would rest on the seafloor. The candidate pipe (~1.5-inch internal diameter) would be a product manufactured for offshore oil and gas applications. The coiled pipe would be fabricated from alloy steel.
- Moored Nozzle Array. Specific designs have not been developed for the type of nozzle array that would be used with a bottom-mounted pipeline. However, some basic characteristics are known. A common manifold would be needed to feed the CO_2 into one of two or three different nozzles. The common manifold would need to be connected to the conduit by a swivel joint that would allow it to be disconnected from the pipe. Each nozzle would likely consist of a vertical riser (pipe) about 20 centimeters (cm) in diameter that ends in a blind flange with 10 to 60 small holes (discharge ports). This arrangement would generate an ensemble of CO_2 droplets. Submerged, electrically actuated valves would be needed to select a specific nozzle for testing.

4.2.2.1.3 Construction Activities for Shore-Side Facilities Needed for a Bottom-Mounted Pipeline

Construction of the shore-side facilities needed to use a bottom-mounted pipeline for the *Field Experiment* would involve the following activities:

- Grading of the selected site;
- Installing a temporary office trailer;

[4] One “bar” is nearly equal to normal atmospheric pressure at sea level, or 14.5 pounds per square inch.

[5] At NELH, for example, the pipe would need to have a length of about 1.9 kilometers (6,340 feet).

- Building several concrete equipment pads;
- Installing a temporary refrigerated tank to store liquid CO_2;
- Installing a pumping system to inject CO_2 through the submerged pipeline;
- Installing instruments; and
- Connecting the facilities to existing power and water systems.

A level outdoor area between 5,000 square feet (0.12 acres or 465 square meters) and 10,000 square feet (0.23 acres or 929 square meters) would be needed. A square plot of land with dimensions of 100 feet (30 meters) by 100 feet would be appropriate. Due to the relatively short duration of the experiment, mobile (i.e., easily removable and transportable) facilities would be employed wherever possible. The two major components that would be located in the outdoor area would consist of an office trailer with restroom and stairs [~ 3.7 meters x 17 meters (12 feet x 56 feet)] and a refrigerated CO_2 storage tank [~ 3 meters x 18 meters (10 feet x 60 feet)].

The liquid CO_2 pump and motor, valves, and flow rate meter would be mounted adjacent to the storage tank, probably on a concrete pad or wooden platform, and possibly with a roof for rain protection. The pump controller would be installed next to the pump in a weatherproof box with redundant controls in the trailer. The pump and motor footprint would be relatively small [~ 1 meter x 1 meter (3 feet x 3 feet)]. A concrete pad for the pump and other equipment might be necessary if the ground is not adequately hard and level. An insulated steel pressure pipeline would be installed above ground and follow the most direct path to the shoreline take-off point of the submerged conduit. The onshore section of the underwater power and signal cable would also follow this path.

4.2.2.1.4 Construction Activities for Bottom-Mounted Pipeline

Several factors would affect pipeline installation, including the physical character of the offshore area through which the pipeline would pass, the wave environment, and current fields. Several different techniques for deploying the pipeline were considered:

- Pulling spooled pipe and cables from shore;
- Laying pipe and cables from a ship moving toward shore; and
- Laying pipe and cables from a ship moving away from shore.

Pulling the pipe from a spool on shore was considered the most feasible approach. In this case, the bottom-mounted pipeline that would be used to deliver pressurized, liquid CO_2 to the injection nozzles would be a continuous steel conduit about 1.5-inch (3.8 centimeters) in diameter. Such a pipeline could probably be obtained on a single spool. Even filled with a gas, candidate CO_2 delivery pipelines would not be buoyant in seawater. Thus, a small-diameter (e.g., 4-inch, or 10 centimeter) high-density polyethylene (HDPE) conduit would need to be attached to the CO_2 delivery pipeline as it would be unreeled from a spool on the shoreline and pulled out to sea during deployment.[6]

Just like the CO_2 delivery pipeline, the HDPE conduit would be air-filled since its purpose would be to provide a significant amount of removable buoyancy. In fact, the HDPE conduit would need to be sufficiently buoyant to attach a power cable, which would also be on a reel. The pipeline bundle would be deployed as follows:

- All pipe reels would be secured on a concrete pad onshore, and a "launching ramp" would be installed over the shoreline cliff to control pipe curvatures.

[6] Spools containing 1,000-foot lengths of HDPE would be available for this type of conduit. These lengths could be joined together thermally, which would provide a significant advantage over similar operations using "traditional" 40-foot straight sections. This benefit would be complicated by the need for a more extensive shoreline working area, with about 8 HDPE pipe spools, the CO_2 delivery pipe spool, and the power cable reel stored next to one another.

- A tugboat would be positioned in shallow waters immediately offshore; the CO_2 discharge nozzle structure would be onboard.
- The coiled tube, the power cable, and the HDPE line would be simultaneously unspooled and tied together to form a buoyant bundle, which would be passed on to the tugboat by an auxiliary small craft.
- The end of the CO_2 delivery pipe would be connected to the CO_2 discharge nozzle structure, and the tugboat would pull away from the shoreline. The weight of the CO_2 discharge nozzle structure would provide the principal holding point for the buoyant bundle.
- The tugboat would continue moving away from the shoreline toward the site for the experiment until the bundle would be completely unspooled and floating on the water surface, with the shore end held under tension for proper alignment. The HDPE pipe sections would be fused together quickly, requiring only that pulling operations would be held for about ten minutes at a time.
- Once the pipeline achieves full extension, the tugboat would hold position until acceptably low (e.g., less than one knot) surface currents would exist. Seawater would then be pumped into the pressurized HDPE pipeline, causing it to sink slowly to the seafloor. The tugboat would adjust the line tension and position to control the touchdown path of the bundle. The bundle would progressively sink to the seafloor starting at the shoreward end of the assembly.
- To complete the deployment, a small crane on board the tugboat would lift the CO_2 discharge nozzle structure overboard into the water using a wire rope connected to an onboard winch. The discharge nozzle assembly and final length of pipeline would be lowered slowly under tension to the seafloor. Upon touchdown on the seafloor, the wire rope would be released and the entire assembly would be in place.
- Deployment of the pipeline and the CO_2 discharge nozzle structure would be expected to take just a few days.

If a shoreline cliff or topographic discontinuity should be encountered, a short, separate, shoreline section of pipeline might need to be installed to safely clear the shoreline. For the bottom-mounted pipeline, a self-anchoring pipeline (i.e., one that simply lies on the bottom with no permanent anchors), which would avoid the complications and costs associated with even the least obtrusive anchoring procedure, would be satisfactory. However, this advantage would need to be weighed against the possibility that pipeline damage near the shoreline could result from large swells that might be produced by an unusual storm.

4.2.2.1.5 Post Test/Site Clean-Up

The pipeline infrastructure deployed for this alternative would be removed immediately upon completion of the *Field Experiment*. Removal would proceed by reversing all deployment steps until the bundle floats at the ocean surface. Then, the bundle would be depressurized, pulled onto the shoreline, and cut into pieces for transport by truck to a landfill for disposal. Because of the proposed pipeline deployment method, no permanent structures would be placed on the seabed. Consequently, the only trace of the experiment that would remain following re-flotation and removal of the pipeline could be a small amount of surface abrasion of the seafloor.

4.2.2.1.6 Summary of Bottom-Mounted Pipeline

In summary, the shore-based alternative would be the least technologically challenging of the options and was extensively considered in defining the experimental methodology. The CO_2 would be handled onshore and any trouble-shooting of the delivery system could be conducted before the start of the *Field Experiment*, thereby minimizing time researchers would be needed at the site. Offsetting these advantages would be the fact that the pipeline would need to negotiate a high-energy, nearshore environment. Also, the potential would exist that construction activities or a pipe failure could adversely affect nearshore resources. The inability to readily access the nozzles following deployment of the pipeline would be another notable drawback to this alternative.

4.2.2.2 Vessel-Based Concept

While the characteristics needed for the release point using a vessel-based concept are essentially the same as for a land-based alternative, the flexibility that could be provided by ships means that many more locations would have suitable physical characteristics. Implementation of a vessel-based experiment would also involve a shorter overall duration than a land-based alternative. However, vessel-based experiments require more restrictive limits on weather and sea state than the land-based methods, due to a longer exposure time at sea while the complicated positioning, deployment, and recovery operations are completed.

In general, site characteristics required for a vessel-based *Field Experiment* would include:

- Water depth of approximately 2,600 feet (800 meters);
- Weather and wave regime that would allow research vessels to maintain position during the *Field Experiment* and not cause undue delays that might prevent completion within the limited time that the ships would be available;
- Proximity to (and availability of) land-based support facilities needed for research vessels and associated scientists; and
- Absence of particularly sensitive natural resources in the potentially affected area.

Examples of locations meeting these requirements include several sites offshore from the Hawaiian Islands, an offshore Norwegian site, and in the Gulf of Mexico offshore from Texas or Louisiana.

4.2.3 PHASE III: ELIMINATION OF THE BOTTOM-MOUNTED PIPELINE CONCEPT

4.2.3.1 Consideration of Bermuda and Hawai‘i Sites

After considering all technical factors (see Section 4.2.2.1.1) related to possible locations for a bottom-mounted pipeline at Bermuda and Hawai‘i, the Natural Energy Laboratory of Hawai‘i Authority’s (NELHA’s) Ocean Research Corridor at Ke hole Point, Hawai‘i, was determined to possess the most favorable characteristics for the *Field Experiment*, regardless of whether it were conducted from land-based facilities with a pipeline following the seafloor, as was then thought most likely, or from a vessel.

A deciding factor in this determination was the fact that the relatively high deep-water temperature found to exist off Bermuda would preclude the ability to properly investigate the potential for (and possible effects of) hydrate formation if the *Field Experiment* would be conducted at that location. In order to thoroughly assess the technical and environmental implications of CO_2 sequestration in ocean waters, the *Field Experiment* would need to produce scientific data at depths where temperature conditions could potentially result in hydrate formation. Also, the superior weather and sea-state conditions expected at the NELHA location were factors that supported the choice of a Hawai‘i site. In addition, the existence of an approved Ocean Research Corridor and the available oceanographic and environmental characterization data, as well as the *Field Experiment*’s compatibility with these established uses, were considered positive for the Hawai‘i site.

In September 1999, PICHTR filed a formal application to conduct the *Field Experiment* within NELHA’s Ocean Research Corridor. The NELHA Board approved the request at its October 19, 1999 meeting.

4.2.3.2 Elimination of NELHA Bottom-Mounted Pipeline Concept

In March 2000, after considering the relative merits of land-based and vessel-based alternatives for delivering carbon dioxide, the vessel-based concept was determined to be the preferred approach for conducting the *Field Experiment* and efforts to further consider a land-based experiment were suspended. PICHTR informed NELHA of this determination in April 2000.

The decision to suspend further studies of a land-based alternative was based on several considerations. Confirmation that the experiment could be successfully conducted using a vessel was an important factor in this decision. However, the information that had been obtained through the public outreach program and scoping conducted for the project was equally important. Those efforts made it clear that public concerns existed regarding use of a bottom-mounted pipeline that could have potential for adversely affecting nearshore resources. More specifically, for a land-based experiment at the NELHA location, public concern existed about possible impacts on traditional Hawaiian fishing and gathering activities, on historic properties within the existing archaeological preserve, on nearshore biota because of construction activities or pipeline failure, and on freedom of access along the shoreline. While mitigation measures could be implemented to address these concerns, practical mitigation measures would not be likely to completely eliminate all public concerns about the bottom-mounted pipeline. Hence, the bottom-mounted pipeline concept at NELHA's Ocean Research Corridor was eliminated from consideration.

This Environmental Assessment describes the potential environmental effects of the alternatives that remain under consideration for implementation as a result of the proposed action. They are:

- Vessel-Based *Field Experiment* at NELHA's Ocean Research Corridor site,
- Vessel-Based *Field Experiment* at a generic ocean site, and
- The No Action Alternative.

These alternatives are described in Sections 4.3 through 4.4 below.

4.3 VESSEL-BASED *FIELD EXPERIMENT*

This section of the Environmental Assessment (EA) describes the alternative for conduct of the *Field Experiment* from a vessel. Section 4.3.1 briefly describes the general characteristics and purposes of the NELHA Ocean Research Corridor site alternative. Section 4.3.2 briefly describes a more generic ocean site not in the NELHA Ocean Research Corridor. Section 4.3.3 identifies the basic equipment that would be employed and the types of activities that would occur during the *Field Experiment*, and Section 4.3.4 describes the sequence of events anticipated during the *Field Experiment*. The termination phase of the *Field Experiment*, during which the at-sea release system and the monitoring systems would be removed from the ocean, are described in Section 4.3.5.

A draft experimental plan for the *Field Experiment*, which includes more detailed descriptions of the anticipated experimental and monitoring activities, schedule, and contingency provisions, is presented in Appendix C. This plan was formulated through collaboration among the principal scientists in charge of the experiment and professional biological oceanographers with extensive experience investigating the marine ecosystems of the Hawaiian Islands. The *Field Experiment*, because of its planned short duration and low release rates of CO_2, would not provide adequate foundation for a comprehensive investigation of environmental impacts. However, some preliminary studies directed toward evaluating how some biota might respond to the releases are planned (see Section 5.3.2.1.1).

4.3.1 THE NELHA OCEAN RESEARCH CORRIDOR SITE

The Natural Energy Laboratory of Hawai‘i Authority (NELHA) Ocean Research Corridor includes 2,940 acres of ocean waters and submerged lands located on Conservation Lands offshore from Ke hole Point (Figure 4-1). The State of Hawai‘i Department of Land and Natural Resources

Figure 4-1. NELHA Ocean Research Corridor

(DLNR) issued a Conservation District Use Permit (CDUP HA-1862) to NELHA authorizing use of the Ocean Research Corridor, and NELHA has been continuously carrying out research activities consistent with this permit since it was issued in 1986. The permit authorizes activities within the Ocean Research Corridor that include the following:

> *"… temporary and permanent ocean research, alternative energy and mariculture research and commercial mariculture and energy activities and facilities; immediate construction and development of three ocean water pipelines and use of portions of two parcels of land for pipeline and utility easements, pump stations and road improvement and maintenance activities on and offshore of Ke hole Point."*

The *Field Experiment* would be consistent with these uses and, as related in Chapter 6, DLNR has determined that a Conservation District Use Permit would not be needed to conduct the vessel-based experiment. Moreover, the site is not in any wildlife sanctuary and is well removed from the shoreline and surface-water biological communities. Other factors that make the Research Corridor site appropriate for the *Field Experiment* include reliably calm seas and winds, easy access to deep water, local project participants and the excellent scientific research facilities available in Hawai‘i.

4.3.2 GENERIC OCEAN SITE

Potential locations for a vessel-based *Field Experiment* that would be beyond the Ocean Research Corridor, outside of Hawaiian or U.S. waters, or outside the territorial waters of any nation-state, are treated as a class rather than individually. These locations are analyzed in this Environmental Assessment as a "Generic Ocean Site."

Section 4.2.2.2 describes the characteristics that would be required for a vessel-based *Field Experiment*. As previously discussed, potential ocean sites considered for the *Field Experiment* in U.S. Territorial waters include sites further offshore from the Hawaiian Islands than NELHA's Ocean Research Corridor and sites in the Gulf of Mexico offshore from Texas or Louisiana. Although these sites meet most of the required characteristics, the anticipated wind and weather conditions at each site would be more severe than in the Ocean Research Corridor, and they would pose more difficult conditions for deployment and recovery of the discharge system, as well as for vessel positioning during tests.

4.3.3 PROPOSED EQUIPMENT

The equipment needed to conduct a vessel-based *Field Experiment* would be mounted on, and deployed from, ocean-going vessels chartered for the purpose. Figure 4-2 schematically illustrates the overall configuration of the experiment, which has been specifically tailored to the scale, duration, and scientific purpose of the proposed *Field Experiment.* Figure 4-3 is a diagram of the type of vessel most likely to be used.[7]

4.3.3.1 Carbon Dioxide Delivery Vessel

One vessel would carry the equipment used to release the liquid CO_2. This vessel would have good positioning capabilities, which means that it would have navigational and mechanical equipment needed to remain in a fixed position without use of an anchor. The equipment mounted on the vessel would consist of the following:

- A standard refrigerated CO_2 storage tank system of the type widely used by food and beverage companies and hospitals. The deck-mounted tank would keep the CO_2 at a pressure of 20 to 22 bars and -4°F (about -20°C).

[7] If conducted within the Ocean Research Corridor or at another ocean site near the Hawaiian Islands, the experiment could use vessels already based in Hawaiian waters or ones whose schedule would bring them through Hawai‘i during the expected time window for the experiment (fall of 2001). The choice would depend upon vessel availability and cost. Because of this, a detailed description cannot be provided at this time.

Figure 4-2. General Methods Used in the *Field Experiment*

Figure 4-3. Typical Vessel and Deck-Mounted Equipment.

- A pump, metering system, and high-pressure hose capable of delivering the liquid CO_2 from the storage tank into tubing through which the CO_2 would be transported to the discharge platform and nozzle on the seafloor.
- A reel holding approximately 3,940 feet (1,200 meters) of 1.5- to 2-inch (3.81 to 5.08 centimeter) outside diameter, coiled tubing,[8] a control cabin with hydraulic power pack, and a deck-mounted container housing controls for the other equipment.

A discharge platform, similar to one shown in Figure 4-4 would be carried on the deck of the ship. When the vessel would be in position for deployment, a test nozzle would be fitted to the end of the outlet pipe, and the inlet pipe would be connected to the end of the coiled tubing. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet (800 meters). The platform would be about six or seven feet wide by thirteen feet long (2 meters by 4 meters) and would weigh approximately 11,000 pounds (5 metric tons). The discharge platform would consist of the following:

- A flat, steel structure that would provide sufficient tension to the tubing during deployment to minimize drifting due to currents.
- A vertical steel pipe connected to the CO_2 supply tubing by a short, flexible hose secured by chains. The connection would also include a swivel joint to minimize torsion forces in the tubing.
- A trumpet-shaped guide to prevent kinking in the CO_2 supply line.
- Four pointed, steel legs to minimize horizontal movements on the hard seabed, which can have a slope of as much as 30 degrees.
- A discharge pipe to which the test nozzle would be attached; the discharge pipe would extend outward and upward from the side of the platform.
- Anti-backflow devices, such as a check valve, to prevent seawater from entering the pipe and causing hydrate blockages.

The platform may also be equipped with electric heaters to 'melt' any hydrates that form, transponders, and other small pieces of scientific equipment.

4.3.3.2 Other Support Vessels

Other vessels would be used to support the *Field Experiment*. These would include up to two mother ships for the remotely operated vehicles (ROVs) or submersibles that would be used to collect data during experimental tests (see Figure 4-5). In addition, a small boat would probably be chartered to carry scientists and samples between the research vessels and the shore. Small chemical and physical sensors, as well as ROV transponders, would be placed temporarily on the seafloor during the *Field Experiment*.

4.3.4 PROPOSED TEST SEQUENCE

The *Field Experiment* would consist of a series of test sequences, with each individual test designed to observe and evaluate the behavior of liquid CO_2 in seawater as release parameters vary under known physical conditions. Since nozzle design would influence the initial characteristics of the CO_2 droplets for a given release rate, varied nozzle designs would be used to widen the range of practical release parameters. Table 4-1 summarizes the most important characteristics of the planned tests. The currently proposed experimental plan is provided in Appendix C.

[8] The leading candidate would be a product manufactured for offshore oil and gas applications. The continuous, coiled tubing would be fabricated from alloy steel. All tubing would be tested at pressures greater than or equal to 6,000 pounds per square inch (414 bar) before shipment. Since the planned operating CO_2 pressures would be less than or equal to 80 bar, the safety factor would be greater than 5.

Figure 4-4. Discharge Platform

Figure 4-5. Type of ROV Used for Monitoring in the *Field Experiment*

Table 4-1. Preliminary *Field Experiment* Matrix

Duration of Each Test Release (approximate)	Two Hours.
CO_2 Flow Rates	1.6 and 15.8 gallons per minute (0.1 and 1.0 kg/s)
Number of Nozzle Designs Tested	2
Ambient Conditions	Conduct tests at range of current speeds, if possible
Number of Tests	12 to 20
Total Amount of CO_2 Released	Approximately 10,500 to 15,500 gallons (40 to 60 metric tons)
Source: Pacific International Center for High Technology Research (PICHTR)	

Tests would only be conducted when weather and sea conditions allow vessels to maintain their positions within a designated area. The relatively high frequency of moderate seas and calm winds in the lee of the Big Island make it particularly well suited for the *Field Experiment*.[9] Based on equipment requirements, the preferred surface current for conducting tests would be 2 knots (about 1 meter per second) or less.

The vessel deploying the platform would maintain station while the coiled tubing would be extended for a single experimental test series. In general, this means that the vessel would be stationary above the platform for periods ranging from 8 hours to several days. Radioactive substances would not be used in any of the experiments.

4.3.4.1 Deployment

Before the discharge platform would be lowered from the ship, one of the specially designed nozzles would be attached to the end of the CO_2 discharge pipe. Each nozzle would likely consist of a vertical riser (pipe) about 8 inches (20 centimeters) in diameter that ends in a blind flange with 10 to 60 small holes for release ports.

When prepared for deployment, the platform and attached coiled tubing would be slowly lowered into the water. The weight of the platform would result in a virtually vertical descent of the assembly.[10]

While deploying the platform, the ship would maintain station within a radius of approximately 80 feet (25 meters) over the platform's intended resting-place on the bottom. After the platform reaches the bottom, additional tubing would be deployed until approximately 650 to 1,000 feet (200 to 300 meters) of tubing would be laid on the seafloor. Laying out this additional tubing would provide an unobstructed space immediately above the discharge platform so that observers would have a clear

[9] A 3.28-foot (1 meter) wave height with periods from 4 seconds upward is deemed representative of the conditions that would be experienced during deployment and testing.

[10] Given the typical differences between surface and bottom currents, the maximum deflection in the tubing would be approximately 10 feet (3 meters) over the 2,600-foot (800 meter) length of tubing between the surface and the discharge platform.

view of the CO_2 plume. In addition, the ROVs or submersibles would be able to maintain a safe separation from the vertical segment of the tubing.[11]

The platform would be retrieved from the seafloor to change the discharge nozzle, perform maintenance on the nozzle or discharge platform instrumentation, or correct any operational problems. A maximum of 10 deployments of the discharge platform would be anticipated, but the most likely number of deployments would be fewer than half that amount.

4.3.4.2 Carbon Dioxide Release

Following proper placement of the discharge platform on the bottom, the CO_2 release through the nozzle being tested would begin. The design of each nozzle would generate a unique assemblage of CO_2 droplets at each release rate. As indicated in Table 4-1, the CO_2 would be released from the nozzle at flow rates ranging from about 1.6 gallons per minute (0.1 kilograms per second) to 15.8 gallons per minute (1.0 kilograms per second). Typically, each test sequence would be conducted over the course of a few days. However, unusual weather or other factors could prolong the duration of a test sequence.

Following each release, two distinct regimes of CO_2 behavior would result. The first regime would consist of rising droplets of liquid CO_2, with some droplets covered with hydrate films. The release rate and the design of the nozzle would largely control both the size and shape of the droplets and the extent of hydrate formation. The planned flow regimes and nozzle designs would be established to control the formation of “slush.”[12]

The second regime would result as the buoyant droplets rise after being released from the injection nozzle. The droplets would gradually dissolve in seawater, because the natural concentration of inorganic carbon in ambient seawater is orders of magnitude below the solubility limit for liquid CO_2. As discussed in more detail in Chapter 5, at the release rates planned for the *Field Experiment*, the vertical rise of the liquid CO_2 droplets would cease within 1,000 feet (~300 meters) from the nozzle.

The dynamics of the ascending droplets would be complex, with some seawater being entrained upward by the momentum of the rising droplets. CO_2-enriched water along the edges of the rising plume would sink as dissolved concentrations of carbon in it increase. This relatively dense, carbon-rich seawater would stop sinking when sufficient mixing with lighter ambient seawater would bring the mixture to a neutrally buoyant equilibrium. Then, the carbon-rich water would drift with the current while being diluted further by turbulence. The predicted behavior of the discharge plume is discussed in Section 5.2.1.4.

4.3.4.3 Monitoring

During each test, staff on the vessel deploying the platform would: operate and monitor the CO_2 pump system and nozzle flow rate; maintain the vessel’s position; and interface with project administrators and the ships from which the ROVs would operate.

The crew and staff of the vessel or vessels deploying the survey systems would: make ocean measurements; control and monitor the system location, provide feedback concerning the behavior of the release and the condition of the discharge platform; visually monitor the behavior of megafauna near the test release; and conduct related tests and measurements. Sampling bottles would be deployed and retrieved from the research vessels to collect water and sediment for chemical and biological (bacterial) analysis. Conductivity, temperature, and depth (CTD) measurements from the

[11] ROVs or submersibles would collect data during the *Field Experiment*. The vessel deploying the platform would not remain directly overhead while these instrument systems are operated to avoid the possibility of becoming entangled with the tubing or cables or collision with the ship itself.

[12] Slush in this context is an ice-like mixture of seawater and CO_2 where the two are bonded closely together.

research vessel would supplement the data obtained from small sensors moored temporarily on the bottom and from the mobile survey systems (ROVs and submersible).

The CO_2 droplets would be visible and tracked directly using video equipment. Dissolved carbon in the carbon-rich water plume would not be visible and would need to be monitored indirectly. Since CO_2 would increase acidity (lower pH) of the seawater as it dissolves, the plume would be distinguished from normal seawater by measuring the pH. Non-toxic tracers, such as fluorescent dyes, might be added to the CO_2 to facilitate optical monitoring.

Instruments mounted on mobile survey systems and instrument arrays moored temporarily on the seafloor would be used to monitor ambient conditions. The ROV instrument package would probably include video, conventional salinity, temperature, and pH probes. The instrument package might also include a modified Acoustic Doppler Velocimeter (ADV).

Data collected during each test would be used to produce detailed maps of the parameters under scientific investigation (e.g., pH, temperature, and salinity) and of the current fields. The mobile video systems and video lamps would provide flow images of the CO_2 droplet evolution over time. The ADV would obtain point measurements of fluid velocities for use in evaluating turbulence within the discharge plume. Small transponders on the seafloor would be used to track the underwater position of the mobile systems.

Data obtained on CO_2 droplet cloud dynamics, effects of hydrate films on droplet dissolution, and three-dimensional mapping of the dispersing, CO_2-enriched seawater would be used to assess the physical and chemical effects of CO_2 sequestration in ocean water.

To assess potential impacts of CO_2 sequestration on environmental health, variations in bacterial biomass, productivity, and growth efficiency would be determined and compared to water column pH. Measurement of nutrients (dissolved and particulate organic carbon and organic nitrogen) would be conducted for corollary analyses. These measurements would identify changes in substrate availability that could alter bacterial activity during injection of CO_2. The analyses of bacterial cycling rates would be combined with an analysis of the variation in bacterial genetic diversity to interpret stresses that might arise from pH changes. This information would provide a better understanding of the effect of water column acidification on the lowest levels of marine food chains.

Data would also be collected to confirm that the experiment preserves the water uses that the Water Quality Standards (HAR 11-54) for the State of Hawai‘i are intended to protect. The specific monitoring program that would be conducted (which is outlined in Appendix C) has been developed in consultation with the Department of Health, Clean Water Branch.

4.3.5 POST TEST/SITE CLEAN-UP

Because of the deployment method planned, the discharge platform, nozzle, and tubing would be removed from the seabed as soon as the test releases are completed. The small instrument packages and transponders that would be deployed around the test area would also be retrieved.

4.3.6 LOGISTICAL SUPPORT

One of the advantages of a vessel-based experiment would be that the vessels provide portable operations platforms. The specific types of required logistical facilities needed to support the vessels would depend on the location of the experiment and on the specific research vessels that would be used. However, the differences between conducting a vessel-based *Field Experiment* at different ocean sites would be minor.

4.4 NO ACTION ALTERNATIVE

Under the “No Action Alternative,” DOE would not participate in conduct of the *Field Experiment*, wherein DOE would be one party in an international agreement for collaboration to investigate the technical feasibility and to improve the understanding of potential environmental effects of ocean sequestration of CO_2.

No Action by DOE would result in withdrawal from the Project Agreement for International Collaboration on CO_2 Ocean Sequestration (see Appendix A), which would eliminate any role for the United States in effectively contributing to the direction of the *Field Experiment*. No Action would eliminate any official role for the U.S. government in ensuring that the *Field Experiment* would be conducted in a manner that (1) fully protects the interests of the United States and (2) fully and effectively communicates information to the public and to potential policy makers on the implications of both the *Field Experiment* and ocean sequestration of CO_2 as a viable option for controlling global climate change. Selection of the No Action Alternative would also convey a lack of commitment by the United States to an international study directed at evaluating potential solutions to global environmental problems and would diminish the role of the United States as a key leader in addressing important environmental issues.

Since DOE is a relatively minor financial contributor to the Agreement, providing only about 22% of the funding, the other parties to the Agreement could either provide the incremental funding needed to conduct the *Field Experiment* in the absence of DOE or abandon plans for the *Field Experiment*. If the other participants provide the U.S. share of funding for the Agreement, the environmental consequences would be identical to those established for the *Field Experiment* in this Environmental Assessment. The other parties to the Agreement would need to agree on a course of action in the absence of participation by DOE.

4.5 COMPARISON OF ALTERNATIVES

Table 4-2 compares potential environmental effects of the Vessel-Based *Field Experiment* at both NELHA's Ocean Research Corridor site and a Generic Ocean site and of the No Action Alternative.

Table 4-2. Comparison of the Anticipated Impacts of Alternatives

RESOURCE AFFECTED	*FIELD EXPERIMENT* At Ocean Research Corridor Site	*FIELD EXPERIMENT* At Generic Ocean Site	NO ACTION
Marine Water Quality	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	No or similar effects
Seafloor	Local abrasion of surface due to platform and pipe emplacement and movement.	Local abrasion of surface due to platform and pipe emplacement and movement	No or similar effects
Benthic Marine Life	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	No or similar effects
Deep-Water Pelagic Marine Life	Very small loss of plankton and minor effects on mobile organism communities	Very small loss of plankton and minor effects on mobile organism communities	No or similar effects
Midwater Marine Life	Very minor stress on local plankton populations	Very minor stress on local plankton populations	No or similar effects
Surface-Water Marine Life	No adverse effects	No adverse effects	No or similar effects
Historical and Cultural Resources	No effects on archaeological or historic sites. Native Hawaiian groups believe it would adversely affect cultural values and fishing and other traditional uses	No effects on archaeological or historic sites. Depending upon location, native groups could believe it would adversely affect cultural values and fishing and other traditional uses.	No or similar effects
Air Quality and Climate	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	No or similar effects
Noise	No adverse effects	No adverse effects	No or similar effects
Marine Transportation	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	No or similar effects
Land Use	No effects	No effects	No effects
Aesthetic Resources	No effects	No effects	No effects
Socioeconomic Resources	Inputs of goods and services to Hawai‘i communities; expenditures for goods where test equipment would be manufactured.	Inputs of goods and services to communities; expenditures for goods where test equipment would be manufactured.	No or similar effects
Public Facilities and Services	No effects	No effects	No effects
Public Safety & Health	No effects	No effects	No effects

Note: If, under the No Action Alternative the experiment would be performed without DOE support, then the anticipated impacts would be essentially the same as for the NELHA Ocean Research Corridor site.

5.0 AFFECTED ENVIRONMENT & ENVIRONMENTAL CONSEQUENCES

This chapter discusses effects of the alternatives described in Section 4. Section 5.1 contains an overview of the most relevant features of the environments that might be affected. Sections 5.2 through 5.13 discuss anticipated environmental impacts on natural and human resources. Section 5.14 discusses Environmental Justice issues as required by Executive Order 12898. Section 5.15 summarizes pollution prevention measures that would be employed.

The discussion concentrates on the key resources that have the potential to be affected by the *Field Experiment*. These include ocean water quality, benthic and pelagic biota, traditional cultural resources, and recreational and commercial uses of the ocean waters near the experiment. Factors likely to be affected to a lesser degree by the proposed activities are discussed in less detail. These include ocean navigation while the experiment is underway, health and safety, and historic and cultural sites. The analysis considers both normal operation and possible accident scenarios.

5.1 AFFECTED ENVIRONMENT

This section outlines the relevant factors for the Ke hole Point Ocean Research Corridor site that could be affected by the proposed action (Section 5.1.1) and reviews the most significant differences that would be expected at a Generic Ocean site (Section 5.1.2). A brief examination of the key concepts and models relevant to ocean sequestration of CO_2 is presented in Appendix D.

5.1.1 AFFECTED ENVIRONMENT AT THE NELHA OCEAN RESEARCH CORRIDOR SITE

The discharge platform for the *Ocean Sequestration of CO_2 Field Experiment* would be deployed onto the seafloor within the Natural Energy Laboratory of Hawaiʻi Authority's (NELHA's) Ocean Research Corridor, approximately 1.2 miles (~1.9 kilometers) offshore from Ke hole Point at a depth of about 2,600 feet (800 meters; Figure 5-1).

The following sections outline the key natural marine resources that have the potential to be affected by the *Field Experiment*. Section 5.1.1.1 reviews the primary physical and chemical characteristics of the marine environment that would interact with the *Field Experiment*. Sections 5.1.1.2 through 5.1.1.5 describe the biological resources that have the potential to be affected by the *Field Experiment*.

5.1.1.1 Physical and Chemical Environment

Factors within the Ocean Research Corridor relevant to ascertaining environmental effects include seabed characteristics, general oceanographic features of the overlying water column, and prevailing ocean currents throughout the water column. Each is discussed briefly below.

5.1.1.1.1 Seabed Characteristics

This site for the experiment lies on a slope of about 25º to 30º. Video taken in August 1999 by a remotely operated vehicle near the *Field Experiment* site indicates a seafloor composed primarily of coarse sand with occasional rock outcrops. The rocky outcrops appeared in the video to be projecting as much as 2 feet (60 centimeters) from the sediment surface.

Figure 5-1. Setting at the Ocean Research Corridor Site

5.1.1.1.2 General Oceanographic Conditions

The water column is typical of the tropical Pacific Ocean, with low levels of nutrients and a clearly stratified water column. The U.S. National Oceanographic Data Center (NODC) has 17 profiles in its database containing oceanographic data from the general vicinity (NODC 2000; Search Area, 19º - 20º N latitude; 156º - 156º20 W longitude), collected by various oceanographic research vessels between 1949 and 1979 (Figure 5-2).

As part of the preparation for the *Field Experiment*, total dissolved inorganic carbon (DIC) and acidity (pH) were measured off Ke hole Point during August 1999 (Figure 5-3). The data show depletion (due to efficient utilization by phytoplankton populations) of inorganic nutrients (represented by silicate, phosphate and nitrate in Figure 5-2), which is typical in surface waters. Relatively high pH (8.1) is found in surface waters where photosynthesis acts to increase pH. Lower pH values (approximately 7.6) are found at the 2,600-foot (800-meter) depth planned for the experiment, where no photosynthesis acts to increase pH. NELHA has monitored the intake water collected from about 2,000 feet (600 meters) water depths for several years. The pH values from that ongoing monitoring agree with the data collected for this study.

Data for Ke hole Point indicate presence of a surface-mixed layer between 300- and 650-foot water depths (about 100 to 200 meters) and confirm the presence of a primary thermocline (zone in which temperature decreases rapidly with depth) occurring at depths of 650 to 1,300 feet (about 200 to 400 meters). A persistent oxygen minimum layer occurs between 2,000 and 2,300 feet (approximately 600 to 700 meters). However, oxygen levels at these depths do not drop near the anoxic conditions that can occur in more equatorial ocean environments that have high levels of primary productivity (e.g., Riley and Chester 1971, 117).

5.1.1.1.3 Ocean Currents

In August and September 1999, several current meters were deployed on two temporary moorings near the Ocean Research Corridor site to measure ocean currents. On one mooring, Norwegian researchers provided an Acoustic Doppler Current Profiler (ADCP) and a single-point Doppler current meter (NIVA 2000). The ADCP recorded values for each 40-minute interval and provided information on the horizontal current velocities in the overlying water column (to minimum water depths of about 850 feet, or 250 meters) at intervals of about 20 feet (6 meters). The single-point Doppler current meter collected measurements at the seafloor site every 10 minutes. On the other mooring, Japanese researchers fitted three-dimensional Acoustic Current Meters (ACM) at three different depths through the water column, to sample the local current field at a high frequency (every minute).

Generally, the current speed was observed to increase from the seafloor vertically (Figure 5-4). Average speeds near the seafloor were about 0.08 knots (4 centimeters per second [cm/s]). During the 38 days the current meters were on station, the longest period during which the current speed was greater than 0.2 knots (10 cm/s) was 1 hour, while the average period during which currents were faster than 0.2 knots was 40 minutes. The current speed (averaged repeatedly over periods of 10 minutes) never exceeded about 0.4 knots (20 cm/s). An earlier current-meter deployment for a much longer duration (between June 1980 and April 1981) produced data that show essentially the same characteristics (Frye, Leavitt, and Noda 1981).

The currents off Ke hole Point are greatly influenced by the tidal flows and change direction frequently. By combining the speeds and directions for different water depths over time, the net transport at each water depth from which measurements were obtained can be estimated. The results of these estimates are presented in Table 5-1.

Figure 5-2. General Oceanographic Variables Near the Ocean Research Corridor Site

Figure 5-3. Dissolved Inorganic Carbon and pH at the Ocean Research Corridor Site

Figure 5-4. Ocean Current Speed and Water Depth

Surface currents can be significantly higher than those measured at the deep seabed site. The U.S. National Data Center reports data from a current meter deployed near the Ocean Research Corridor at a depth of 98 feet (30 meters) for a period of about 20 days in August 1968 and recording speeds every 15 minutes (NODC 1968). The average surface current speed during that period was 0.70 knots (36 cm/s), with a maximum speed of 1.6 knots (82 cm/s) recorded during one 15-minute period.

Table 5-1. Speed and Direction of Ocean Currents

Water Depth (feet) **Net Transport Direction**	**2,460** **SSE**	**1,640** **W**	**984** **NNW**
Average Velocity (Knots)	0.08	0.11	0.2
Residual Speed (Knots)	0.03	0.002	0.1
Net Transport Per Hour (Feet)	180	13	620
Net Transport Per Day (Feet)	4,300	300	15,000
Net Transport Per Week (Nautical Mile)	5	0.3	17
Source: NIVA 2000.			

Both anecdotal and scientific evidence indicate that upwelling (i.e., the vertical transport of water toward the surface) occurs from depths as great as 1,000 feet along the coast off Ke hole Point. However, as discussed below, there is no indication that upwelling normally occurs in water below that depth. This is why it is necessary to pump nutrient-rich water from greater depths to the surface for use by NELHA's tenants. A number of studies have examined the variability of deep-water parameters off Ke hole Point, including currents (Sundfjord and Golmen 2000; Maeda *et al*. 1999), temperatures (Nihous and Vega 1998), and nutrients such as phosphates, nitrates, and silicates (Price *et al*. 1988). These studies have concluded that at depths between 600 and 800 m offshore of NELH there is significant variability in the deep ocean currents, particularly with respect to their horizontal direction. However, none of the inferred water motions documented in these studies corresponds to upwelling from these depths.

A very unusual event occurred off Ke hole Point starting on the afternoon of Monday, December 13, 1999. At that time the seawater intake of NELHA's 40-inch pipeline (which is at a depth of approximately 600 meters) became very cloudy. The temperature stayed just below 6° C, indicating that the change was not caused by shallow seawater intrusion. The following day, when NELHA's pumps were started scientists also noticed an increase in turbidity in the seawater from the 18-inch pipeline, which is located about 800 meters south of the larger pipe and draws water from approximately the same depth. Water from this pipe never became as turbid as the water from the larger pipe, but was more turbid than the surface water, which is unusual. An analysis of the suspended solids that were causing the turbidity indicated that they were typical of those found on the underwater slope, with a high number of shallow water sediments.

Scientists at NELH originally thought that the extreme turbidity in the seawater from 600-meter depth was caused by some *in situ* event. However, the Volcano Observatory seismologist who they contacted reported no significant seismic events, and there was no evidence of a tsunami on the nearby tide gauges. The turbidity remained above normal for several weeks.

At the same time that NELH was experiencing increased turbidity in the seawater that it draws from a depth of 600 meters, American Divers was working with its two one-man submersibles off Kailua Bay, O'ahu. On December 13-16, 1999 the seawater at a depth of 1,400 feet (~425 m) was so turbid that they had to cancel a planned dive. The seawater was clear from the surface to a depth of about 1,200 feet (~365 m), then became very cloudy as they went deeper. While the crew of the submersible was reporting turbidity at depth, the boat crew on the surface observed what they characterized as strong "upwelling" currents that made it difficult to maneuver the boat. The boat crew guessed that a strong current heading toward the island might be stirring up the bottom as it ran up the slope. However, since the reports of unusual happenings from the submersible focused on the turbidity rather than strong currents, it is not clear that the two observations are related.

No completely satisfactory explanation of these events has been given. This was the only time that the deep seawater pumped up at NELH has lost clarity. Were such turbid conditions to occur during the conduct of the *Field Experiment*, they would be completely unacceptable for testing the release of CO_2 because visual observations of the droplet cloud would become impossible. Also, such an event must correspond to fairly strong deep water mixing, which would 'drown' any pH signal from carbon-enriched seawater. No CO_2 release testing would be conducted under such conditions.

5.1.1.2 Species of Particular Concern

Species of particular concern that may pass through the proposed study site off Ke hole Point include the following marine turtles and marine mammals. An asterisk denotes a species listed by the U.S. Fish and Wildlife Service as threatened or endangered.

- Green turtle (*Chelonia mydas agassizii*)*
- Pacific Hawksbill turtle (*Eretmochelys imbricata bissa*)*
- Olive Ridley turtle (*Lepidochelys olivacea*)*
- Loggerhead turtle (*Caretta caretta*)*
- Leatherback turtle (*Dermochelys coriacea schlegelii*)*
- Hawaiian Monk Seal (*Monachus schauinslandi*)*
- Humpback whale (*Megaptera novaeangliae*)*
- Finback whale (*Balaenoptera physalus*)*
- Blue whale (*Balaenoptera musculus*)*
- Bryde's whale (*Balaenoptera edeni*)
- Right whale (*Eubalaena glacialis*)*
- Sperm whale (*Physeter macrocephalus*)*
- Sei whale (*Balaenoptera borealis*)*
- Spinner dolphins (*Stenella longirostris*)
- Spotted dolphins (*Stenella attenuata*)
- Rough-toothed dolphin (*Steno bredanensis*)
- Bottlenose dolphin (*Tursiops truncatus*)
- Striped dolphin (*Stenella coeruleoalba*)
- Risso's dolphin (*Grampus griseus*)
- Melon-head whale (*Peponocephala electra*)
- Pygmy killer whale (*Feresa attenuata*)
- False killer whale (*Pseudorca crassidens*)
- Short-finned pilot whale (*Globicephala macrorhynchus*)
- Killer whale (*Orcinus orca*)
- Pygmy sperm whale (*Kogia breviceps*)
- Dwarf sperm whale (*Kogia simus*)
- Cuvier's beaked whale (*Ziphius cavirostris*)
- Blainville's beaked whale (*Mesoplodon densirostris*)

The threatened Newells' shearwater (*Puffinis auricularis),* and the endangered dark-rumpled petrel (*Pterodroma phaeopygia sandwichensis)* may also forage in the project area.

Species of concern to the sport-fishing community include representatives from several families including (but not limited to) snappers (*Lutjanidae*), pomfrets (*Bramidae*), jacks (*Carangidae*), dolphins (*Coryphaenidae*), mackerels and tunas (*Scombridae*), swordfishes (*Xiphiidae*), and billfishes (*Istiophoridae*).

5.1.1.3 Seafloor Marine Life (Depth range: 650 to 6,000 feet; ~200–1,900 meters)

The seafloor at a depth of 2,600 feet (800 meters) consists primarily of coarse sand with occasional rock outcrops for a distance of several miles around the Ocean Research Corridor site (Section 5.1.1.1.1). Such moderately deepwater habitats typically harbor complex sediment assemblages of microbes, meiofauna, macrofauna, and megafauna. Deposit-feeding and suspension-feeding polychaetes, bivalves, echinoderms, and crustaceans typically constitute most of the sediment-dwelling macro-organisms (Gage and Tyler 1991). Foraminifera and bryozoans may be abundant (Agegian and Mackenzie 1989). Macro-organisms dwelling on hard substrates include a variety of sponges, crinoids, deep-sea corals and other sessile cnidarians (Gage and Tyler 1991, Western Pacific Regional Fishery Management Council 1979). Organisms captured on video during the ROV examinations of the Ocean Research Corridor site in 1999 are listed in Table 5-2. Additional observations of benthic life, collected by researchers during submersible dives in October 2000, are presented in Appendix E.

Commercially and recreationally exploited species living and feeding on the seafloor at this depth potentially include the following:

- The deep-water shrimp, *Heterocarpus laevigatus*, with a depth range of 1,500 to 3,000 feet (about 450-900 meters, King 1987, Tagami and Ralston 1988);
- At least three species of snappers, *Etelis coruscans*, *Etelis carbunculus*, and *Pristiopomoides filamentosus*;
- Deep-sea precious corals, including pink (*Corallium secundum*, depth range 1,300 to 5,000 feet or 400-1,500 meters), gold (*Gerardia* sp., depth range 1,000 to 1,300 feet, or 300-400 meters), and bamboo (*Lepidisis clapa*, depth range 1,100 to 1,600 feet or 330-490 meters) corals (Western Pacific Regional Fishery Management Council 1979).

Commercially significant deep precious coral beds do occur on the west side of Hawai‘i (e.g., off Kawaihae; Grigg 1976). However, the nearest known beds are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (300 to 490 meters) (R. Grigg 2000, personal communication). Because deep-sea benthic species are distributed at similar depths on the slopes of all the main Hawaiian Islands, only a very small proportion of the total habitat of any of these species could conceivably be found near the Ocean Research Corridor site (Chave and Jones 1991). Scientists who have reviewed the videos taken from the submersibles investigating the area where the experiment would be conducted have not identified any precious corals.

Portions of the deep seafloor on the western slope of Hawai‘i and on similar slopes of other main Hawaiian Islands have been quantitatively studied between water depths of 650 to 6,000 feet (200-1,800 meters). These studies show that benthic megafauna is characterized by a low abundance of organisms (mean = 8 individual organisms per 1,000 square feet) and patchy distributions (Chave and Jones 1991, Chave and Malahoff 1998). Inspections of seafloor videotapes suggest that the habitat and biota at the Ocean Research Corridor site are typical of the slopes of the main Hawaiian Islands. The megafaunal species richness (75 reported species) of the ‘Alenuih h Channel is of the same order as the species richness on seamounts in the north central Pacific ($\leq$ 128 species reported) (Wilson and Kaufmann 1987). Checklists of deep-water organisms from the ‘Alenuih h Channel and the slopes of the Hawaiian Islands in general can be found in Chave and Jones (1991) and Chave and Malahoff (1998).

Table 5-2. ROV Observations of the Ocean Research Corridor Site, August 5, 1999

Time from Start	Biological Observation	Geological Observation
0:13:20	Nettastoma sp. (fish)	Basalt talus
0:14:00	*Beryx decacactylus* (fish)	
0:18:30	Small white sponges (max. density $7/m^2$ in one area	
0:21:15	Synaphobranchid eel, 2 shrimp, 4 small fish,other small midwater animals	
0:23:00	3 tan ophiuroids (brittle stars); small white sponges (max. density $0.1/m^2$), fish	
0:25:00		Fine sediment, many mounds and burrows
0:27:30	Clumps of white sponges, fish	
0:42:00		Fine sediment, sheet flow with sand patches
0:43:00	Small fishes	
0:44:30	Red Corallimorphus sp. *Asterodiscides tuberculosus* (sea star); 2 fish, Sergestes sp (shrimp); octopus	P hoehoe flow
0:46:00	3 Corallimorphus sp; *Paelopatides retifer* (sea cucumber)	On boulder
0:47:20	Gadid fish	Sheet flow
0:48:00	Godiasterid seastar	
0:51:00	Fish; brown anemone	
0:53:00	Shrimp; prawns	Fine sediment
0:55:00	Morid fish	Sand talus
0:57:30	Tan ophiuroids	Sheet flow
0:58:30	Crab	Line, anchor, cable
1:00:00	Red polychaete	Fine sediment; sheet flow
1:03:00	Tan ophiuroid; animal	
1:04:00	*Aristeus semidentatus* (shrimp); 6 tan ophiuroids; elopid fish	
1:05:00		Fine sediment; mounds; burrows
1:06:00	Hormathiid sp 2 (anemone); 3 Corallimorphus sp	Sand, talus

Source: Dr. E. Chave, Hawai‘i Undersea Research Laboratory, University of Hawai‘i at M noa

Several general characteristics of the deep-sea benthos in the Ocean Research Corridor area are relevant to predicting potential effects. First, deep-sea species typically are very broadly distributed, making it virtually certain that species occurring on the deep slope off Ke hole Point are distributed throughout the main Hawaiian Islands. Second, the seafloor near the Ocean Research Corridor site is a relatively high-energy environment by deep-sea standards; consequently, the benthos within the area is likely to be relatively well adapted to withstand water currents and mobile sediments. Because of low food availability and low temperatures in the deep ocean, deep-sea species typically have low metabolic rates (e.g., Gage and Tyler 1991). These low metabolic rates would be expected to allow deep-sea benthos to withstand CO_2 or oxygen stress for longer than species with higher metabolic demands. At the same time, deep-sea species also generally are characterized by low rates of growth, reproduction, and population recovery (Gage and Tyler 1991, Smith 1994). Thus, any effects resulting from the *Field Experiment* would tend to persist longer than effects in shallow-water settings.

No Federally listed endangered or threatened species (see Section 5.1.1.2) are known to occur at the deep seafloor near the experimental site or on the deep western slope of the Island of Hawai‘i.

5.1.1.4 Midwater Marine Life (Depth range: 650 – 3,300 feet, ~200 – 1,000 meters)

Below about 650 feet (200 meters), plankton biomass declines almost exponentially with increasing depth down to about 6,600 feet (2,000 meters) (Barnes and Hughes 1999). Organisms in this relatively poorly studied region depend on the mixed surface waters above for virtually all of their food. Some organisms in the upper half of this layer migrate to surface waters to feed at night; others feed on migratory animals or on organic material that sinks from surface waters.

In these very clear waters, sufficient light exists for very low levels of photosynthesis down to perhaps 1,100 feet (350 meters), though very little photosynthesis occurs below 500 feet (150 meters) and the effectiveness of color vision disappears below about 1,300 to 1,500 feet (400-450 meters). Below 1,500 feet (450 meters) animals see only a faint glimmer of light from above, and bioluminescence becomes common. Virtually no sunlight penetrates beneath this zone. Other environmental gradients in this zone include: (*i*) a decrease of temperature from about 80º F (27° C) at the surface in summer to about 40º F (5º C) at the bottom, (*ii*) an oxygen minimum zone between 2,000 and 2,300 feet (600 and 700 meters), and (*iii*) an increase in hydrostatic pressure of about 15 pounds per square inch (1 atmosphere) every 33 feet (10 meters).

Densities of vertebrates are very low at these depths, though some species of large, surface-associated fishes, marine mammals, and sea turtles may forage here. The most ubiquitous and visible organisms are the mesopelagic micronekton, which are composed primarily of small fishes, shrimps, and squids. The region off Ke hole Point may contain somewhat higher biomass of these animals than waters to the north or south because of the periodic formation of a cyclonic eddy centered a few tens of kilometers to the west of the Point. Such cyclonic flows may cause an upwelling of relatively nutrient rich waters from below the mixed layer (i.e., to a maximum depth of approximately 1,000 feet, or 300 meters) and stimulate primary production (Allen *et al.* 1996). These do not affect the water below that depth.

Reid *et al.* (1991) describe a ‘mesopelagic-boundary community’ found in Hawaiian waters at bottom depths of approximately 1,300 to 4,000 feet (400 to 1,200 meters). This community is composed of fourteen species of fishes (Argentinidae, Astronesthidae, Neoscopelidae, one species each; Sternoptychidae, four species; Myctophidae, seven species), five shrimps (*Gnathophausia longispina, Janicella spinicauda, Opophorus gracilirostris, Pasiphaea truncata, Sergia fulgens),* and four squids (*Chiroteuthis imperator, Abralia astosticta, Abralia trigonura, Iridoteuthis iris).* The mean biomass of the mesopelagic-boundary community sampled off O‘ahu was strongly dominated by shrimps (Reid *et al.* 1991). As the name implies, the offshore edge of this community marks the transition between Hawaiian and open-ocean midwater communities. The size of this midwater habitat greatly exceeds that of any other habitat in all of the Hawaiian Islands.

Federally listed endangered or threatened species that may occasionally occur in waters of this depth include Green (*Chelonia mydas agassizii)*, Pacific Hawksbill (*Eretmochelys imbricata bissa)*, Olive Ridley (*Lepidochelys olivacea),* Loggerhead (*Caretta caretta),* and Leatherback (*Dermochelys coriacea schlegelii)* sea turtles, as well as the Hawaiian Monk Seal (*Monachus schauinslandi*). Humpback whales (*Megaptera novaeangliae*) winter in Hawaiian waters; Finback (*Balaenoptera physalus*), Blue (*Balaenoptera musculus*), Right (*Eubalaena glacialis*), and Sperm (*Physeter macrocephalus*) whales are rarely sighted or detected by hydrophones in Hawaiian waters (Tomich 1986).

5.1.1.5 Surface Ocean Marine Life (depth: 0 – 650 feet, 0-200 meters)

The most abundant and the only ubiquitous organisms of the surface waters are planktonic organisms including, most prominently, bacteria, algae (phytoplankton), protozoans, and zooplankton (Karl 1999). Common zooplankton types in coastal Hawaiian waters include copepods, chaetognaths, appendicularians, shrimps, amphipods, pteropods, and a variety of other invertebrates, as well as larval fishes. Many of these organisms migrate to waters below the thermocline during the day. The clear blue offshore waters in Hawaiʻi result from the very low densities of phytoplankton that are found in the oligotrophic waters of the North Pacific central gyre. Chlorophyll-a concentrations at the surface are low (about 0.1 micrograms/liter) in the waters off Ke hole Point. However, photosynthetic rates in the recurrent cyclonic eddy to the west of the Point have been found to be as much as two-thirds higher than in surrounding waters because of the presence of upwelled nutrients (Allen *et al.* 1996). Important phytoplankton taxa include prochlorophytes, coccolithophorids, flagellates, dinoflagellates, and diatoms.

A considerable diversity of fish exists in the nearshore waters around Ke hole Point, but the vast majority of these are directly associated with the shallow seabed. The surface waters above the Ocean Research Corridor site are the habitat of numerous pelagic fishes in a number of families, including tunas, jacks, billfishes, swordfishes, and dolphin fishes. Pelagic fishes are generally highly mobile and, while they may occur in large schools, they have overall very low average densities.

North of Ke hole Point, bathymetric contours diverge from the coastline. This defines an underwater ridge extending offshore. The local fishing community knows these waters as "The Grounds." The area is famous for excellent fishing, especially when there is a prevailing Kohala (north running) current. The attribution of good fishing conditions to nutrient upwelling from great depths is unsubstantiated in the scientific sense, though it might be worth investigating in future research. At any rate, the Grounds near Ke hole Point seem to be an area of intense mixing within the surface layer with the formation of small-scale eddies. Such conditions apparently can lead to good fishing.

As previously mentioned, several threatened and endangered marine species can occur in the open ocean off Ke hole Point. The Humpback whale occurs routinely in the waters around the main Hawaiian Islands during the winter months (Marine Sciences Group 1986). Blue, Right, Finback, and Sperm whales also occur rarely in Hawaiian waters (Tomich 1986). The monk seal is endemic to Hawaiʻi, but is largely restricted to the northwest Hawaiian Islands. No records of monk seal sighting near the Ocean Research Corridor site have been discovered.

The five species of sea turtles mentioned above (all endangered or threatened) have been reported in Hawaiian waters, but there are no known breeding or nesting areas for these turtles near Ke hole Point, the land nearest to the Ocean Research Corridor site (Marine Sciences Group 1986). Sea turtles are commonly sighted in the nearshore waters off Ke hole Point and have been seen by divers sleeping under overhanging outcrops on the coastal seabed.

5.1.2 AFFECTED ENVIRONMENT AT A GENERIC OCEAN SITE

Other possible locations for conducting the *Field Experiment* are discussed in Section 4.2.2.1.1. Evaluations of those locations concluded that, in principle, the *Field Experiment* could be tested at any of a number of ocean sites where hydrographic conditions would provide an environment with characteristics representative of potential ocean sequestration sites.

Consideration has also been given to locations where the *Field Experiment* could be performed from an ocean vessel outside the NELHA Ocean Research Corridor. As described in Section 4.2.2.2, these alternate locations would have the following specifications:

- Water depth of approximately 2,600 feet (800 meters);

- Weather and wave regime that would allow the research vessel to maintain position while the *Field Experiment* is being conducted and would not cause undue delays that might prevent the *Field Experiment* from being completed within the limited time that the ship would be available.
- Proximity to (and availability of) land-based support facilities needed for the research vessels and associated scientists.
- Absence of particularly sensitive natural resources.

A detailed description of the existing environment for a "generic" 2,600-foot (800-meter) site cannot be provided. The specifications required for such a site, however, suggest that environmental factors would be similar to the Ocean Research Corridor site in most respects. The general water-column characteristics of surface mixed zone, thermocline, and oxygen minimum zone would be similar for many tropical, open-ocean sites, although differences in nutrient levels and oxygen partial pressure would be expected at sites where primary productivity would be higher.

As described in Section 5.1.1.3, the benthic life of the deep seabed where the discharge would occur is similar over large geographic areas. If the generic ocean site were to be a tropical or semi-tropical location, similar taxonomic composition (at the generic level and above) and abundances would be expected. Mid-water and surface communities would probably exhibit more differences from the Ke hole site than the deep-water and benthic fauna. However, these differences would not be likely to change the overall nature of the environmental response.

5.1.3 NO ACTION ALTERNATIVE

As explained in Section 4.4, "No Action" means that the U.S. Department of Energy (DOE) would not participate in an international agreement covering the *Field Experiment*. Foreign government agencies participating in the agreement, however, have tentatively committed significant funds to the investigation and could increase their involvement to offset withdrawal by DOE. Since DOE does not have regulatory control over the *Field Experiment*, increased involvement by the other participants in the agreement would allow the *Field Experiment* to proceed, even in the absence of DOE action. Thus, the environmental effects of the "No Action" alternative range from no effects (if withdrawal from the agreement would result in cancellation of the *Field Experiment* by the other participants) to the same effects as those described in this Environmental Assessment.

5.2 WATER QUALITY EFFECTS

The release of liquid carbon dioxide (CO_2), the cornerstone of the *Field Experiment*, would produce a temporary and localized effect on water quality. The anticipated behavior of the carbon-rich plume and the resultant water quality changes are described below.[13]

5.2.1 EXPERIMENT-PHASE EFFECTS ON MARINE WATER QUALITY

Mathematical models, laboratory tests, and oceanographic measurements indicate that the principal effect of the *Field Experiment* would be the creation of a cloud of liquid CO_2 droplets and the subsequent dispersal of CO_2-enriched seawater. The primary goals of the *Field Experiment* would be to verify scientific principles and to provide data that can be used to improve the accuracy of existing predictive models. As discussed in Appendix D, several groups have been developing different approaches to modeling these complex processes. In the following discussion, the evaluation of potential impacts is based on the computer programs of Alendal *et al.* (1998). This model is fully three-dimensional and has benefited from more than two years of development.

[13] In reading the discussion for Section 5.2, it is important to remember the earth's oceans are the natural sinks for carbon dioxide, removing from circulation at least 7.3 <u>billion</u> tons of CO_2 annually.

The base case in computer simulations by Alendal *et al.* consists of a discharge rate for CO_2 of about 16 gallons per minute (1 kilogram per second), an initial droplet radius of 0.28 inches (7 millimeters), and a typical deep-water current of 0.1 knots (5 cm/s).[14] The model calculates the size distributions of the CO_2 droplets in the near field, as well as pH distribution in the near- and far-field.[15] Alendal *et al*.'s model predicts that after about 25 minutes the discharge plume would reach a stable size in the vertical and lateral directions, but would continue to lengthen in the down-current direction.

Liquid CO_2 injected by the *Field Experiment* would exist in three different forms: (i) droplets of liquid CO_2 with density lower than seawater; (ii) hydrates on the surface of CO_2 droplets; and (iii) CO_2 dissolved in seawater. The physical and chemical effects predicted by modeling for each form of liquid CO_2 are discussed separately below.

5.2.1.1 Droplet Phase of the Plume

When liquid CO_2 discharges under pressure through a nozzle, distinct droplets (similar to those from a water sprinkler) would be created. Because these droplets would be less dense than the surrounding seawater, the CO_2 droplets would rise from the discharge nozzle; thus, they would not affect the deep seafloor. Subsequent processes would dissolve and disperse the droplets, preventing them from reaching surface waters. The released carbon dioxide would be at essentially the same temperature as the ambient water. Consequently, no detectable cooling of the seawater surrounding the discharge platform would be expected.

Figure 5-5 shows a vertical cross-section of the predicted behavior of the droplet cloud for the base case (i.e., minimal hydrate formation). Here, the droplet cloud would be expected to persist for a distance of approximately 100 feet (30 meters) down current and to be about 200 feet (60 meters) high (thick). The width of the droplet cloud would expand from the size of the nozzle at the injection point to about 60 feet (18.5 meters) at 100 feet (30 meters) down current. Though CO_2 is colorless, water clarity within the droplet cloud would be reduced (CO_2 has a different refractive index than seawater, so the droplets would be visible). Discharge experiments that were carried out in a high-pressure vessel simulated the deep-water discharge (Masutani *et al.* 2000a, Masutani, *et al.* 2000b). Pictures of the droplet cloud generated in these experiments (Figure 5-6) provide a sense of the way the droplets in the *Field Experiment* would appear.

5.2.1.2 Formation of Hydrate Coating

Under certain conditions, CO_2 at the droplet surface can form solid complexes of water and carbon dioxide known as "hydrates." When hydrates coat a droplet, the droplet is partially isolated from the surrounding water; this isolation slows the overall dissolution process. Although pure hydrates have a slightly higher density than seawater, their effect on the net buoyancy of coated droplets can only be significant with extremely small initial droplets, for which the surface-to-volume ratio is large. Initial droplet size, in turn, is primarily controlled by the way CO_2 is released. During the *Field Experiment*, the CO_2 would be released in such a way that droplets would remain buoyant even with a hydrate coating. Thus, these droplets are not expected to impact the seafloor.[16]

[14] The average deep-water current measured in August and September of 1999 at the Ocean Research Site was 0.08 knots (4 cm/s) (Section 5.1.1.1.3).

[15] For a definition of "near-field" and "far-field," see Section 4.2.2.1.1 (footnote 3).

[16] If unexpectedly large quantities of hydrates began to form on the droplets, the smallest could settle onto the seafloor, most likely falling close to the injection platform. The hydrates themselves would be unlikely to directly impact seafloor biota. Upon dissolution, hydrates would form small clouds of relatively dense, CO_2-rich, seawater that would be dispersed by mixing near the seafloor. Unexpectedly large quantities of hydrates would be readily visible, and the experiment would be modified if any such contingency develops.

Figure 5-5. Time Evolution of the Liquid CO_2 Droplet Cloud (Base Case)

Figure 5-6. Laboratory Generation of Liquid CO_2 Droplets

Figure 5-7 shows how the droplet cloud would behave if droplets corresponding to the same initial conditions as in Figure 5-5 were to develop a hydrate shell. In this case, dissolution would be slowed, which would allow the buoyant droplet cloud to rise further before fully dissolving in seawater.

The expected plume in this hydrate-coating scenario would be 400 feet (120 meters) high and have a down-current extent of 200 feet (60 meters). Thus, the formation of hydrates would cause the near-field plume to be larger than a droplet cloud generated without hydrate formation. Since the same amount of CO_2 would be discharged in both scenarios, the average concentration of droplets (and, therefore, their effect on pH after they dissolve) would be lower in the larger droplet cloud. This relationship (i.e., the larger the affected volume, the smaller the magnitude of the effect) would be true for all of the scenarios described herein.

5.2.1.3 Dissolution

The droplets and hydrates would ultimately be unstable and would dissolve in the deep seawater within 30 minutes of their release. The key chemical reactions of this process would be as follows:

a. CO_2(droplets) $CO_{2(aq)}$

b. $CO_{2(aq)} + H_2O$ H_2CO_3

c. H_2CO_3 $H^+ + HCO_3^-$

d. HCO_3^- $H^+ + CO_3^{2-}$

As indicated by the equations, droplets would first dissolve into the water (a), react with water to form carbonic acid (b), rapidly dissociate partially both to bicarbonate and carbonate anions, and generate free acid, or protons (H^+) (c and d). Although a dissolved droplet would not be visible to the naked eye, the water containing the carbon dioxide could be distinguished from the rest of the seawater principally by a lowered pH (Stumm and Morgan 1981). A threshold of pH = 6.5 was chosen as the level below which acute effects on biota could occur as a result of exposure times of the approximate duration expected from the experiment. This threshold was based on experimental and field studies of the relationships between pH and marine life (Section 5.3.1.2, below). These dissolution reactions would have no substantial effect on the levels of dissolved oxygen in the affected seawater (C.S. Wong. 2000, Personal Communication).

Surface seawater has a typical saturation value of 33 mmol/l for total dissolved inorganic carbon (Teng *et al*. 1996). This corresponds to a pH of 4.88. Saturation value increases, and the corresponding pH value at saturation decreases, with increasing water depth. Degassing can occur only when the saturation value has been exceeded. The computer models (described in the following sections and in Appendix D) used to predict the behavior of the CO_2 released for the *Field Experiment* indicate that pH values well above 5 would be reached within 6 feet of the release point. Because of this, a sudden release of CO_2 into the atmosphere, similar to the dramatic and tragic release from Lake Nyos (Cameroon, Africa) that occurred in 1986 (Holloway 2000), would not be possible in the *Field Experiment*.

5.2.1.4 Advection, Dispersion, & Diffusion: The Spatial & Temporal Extent of the Plume

Deep-water currents would carry the CO_2-enriched seawater away from the site (termed advection). Turbulent eddies would mix the water with the surrounding seawater, dispersing it (also sometimes called "turbulent diffusion"). Finally, relatively slow molecular processes would mix the water through diffusion. Since molecular diffusion would be too slow to be relevant in the short time frame considered for this experiment, this analysis concentrates on the effects of advection and dispersion.

Figure 5-7. Time Evolution of the Liquid CO_2 Droplet Cloud (with Hydrate Formation)

As described in Section 5.1.1.1.3, the seafloor currents at the NELHA Ocean Research Corridor site vary between 0 and 0.4 knots (0–20 cm/s). Currents faster than 0.2 knots (10 cm/s) do not persist longer than about one hour. Figure 5-8, Figure 5-9, and Figure 5-10 depict the behavior of the released CO_2 with a constant current of 0.1 knots (5 cm/s).[17] The predicted extent of the discharge plume created in this process and the implications of these calculations for marine water quality are discussed below.

Figure 5-8 shows the base case, which assumes no hydrates have formed. Figure 5-9 depicts the horizontal extent of the base-case plume after the discharge has been underway for one hour, which is the maximum time for which graphical computer output has been obtained. As can be seen in Figure 5-8, the only significant change to the plume after the first half-hour would be an increase in its downstream length. Because of this dynamic stability in the plume, the plume from a two-hour discharge would be about twice as long as the plume produced by a one-hour discharge; all other dimensions would be about the same.

Using this line of reasoning the Alendal *et al.* model predicts that the approximate volume of water subject to pH levels of 6.5 or lower at the moment a two-hour discharge has ended (the time at which this water volume would be greatest) would be 1,200 feet long, 60 feet wide, and 100 feet high (360 meters by 18.5 meters by 30 meters). This represents a volume of about 260,000 cubic yards (200,000 m^3). If this plume contacted the seafloor at its maximum width for its entire length, it would have a footprint area of 8,000 square yards (6,660 m^2).

The plume would persist for a time after the discharge has ended, drifting with the ocean currents and dissipating with the natural processes of turbulent dispersion. Even using very conservative assumptions (including low rates of turbulent dispersion) to model the further dispersion, calculations indicate that the plume would be dispersed to the point where the entire volume would contain seawater with pH values higher than 6.5 less than three hours after the discharge has stopped. Assuming, for simplicity, that the 0.1-knot (5 cm/s) current persists during this three-hour period, the plume would be transported 1,800 feet (approximately 550 meters) downstream. Assuming further that the plume would remain unchanged until the end of this three-hour period, then the plume could affect a total seafloor area of about 4 acres (0.14% of the Ocean Research Corridor).[18] For the entire *Field Experiment*, a maximum of eight such maximum rate, 2-hour discharges would be possible. Assuming each discharge would affect a different area of the seafloor (i.e., that there would be no overlap between tests in the sequence), a total of about 33 acres could be affected.

This high-end estimate assumes that the maximum amount of CO_2 under consideration would actually be used <u>and</u> all of the CO_2 would be used for tests at the maximum release rate (1 kilogram/second). In reality, less than the maximum amount of CO_2 would probably be used and substantial amounts would be likely to be used for tests at lower release rates (which would produce less change in pH; see Appendix C for current plans). Because the model does not fully account for all of the factors that would tend to disperse the plume, the model almost certainly overstates the affected area. Thus, the actual effect would be less than indicated here.

Figure 5-10 shows the modeled plume if hydrate formation on the surface of the CO_2 droplets would slow the dissolution rate of the droplets by 50%.[19] The principal differences between this "with-hydrates" scenario and the base case previously described would be a greater plume thickness (height) (approximately 200 feet, or 60 meters). In either case, the affected volume would be the

[17] Note: The average current measured was 0.08 knots (4 cm/s).

[18] In reality, the plume would shrink over this entire three-hour period. This means that the area actually affected would be far less.

[19] A 50% reduction would be consistent with estimates made using theoretical models and with experimental results.

Figure 5-8. Time Evolution of the pH Field (Base Case)

Figure 5-9. Horizontal Plume Cross Sections, 1-25 Meters Above Ocean Floor (Base Case)

Figure 5-10. Time Evolution of the pH Field (with Hydrate Formation)

same, (200,000 m^3), implying that hydrate formation would reduce the seafloor area affected relative to the base case (i.e., would reduce the area subject to a pH of less than 6.5). Section 5.3 uses the larger area predicted by the base case (33 acres) to assess potential effects on marine life on the seafloor. Eight releases of this size[20] would produce an affected volume of 2 million cubic yards (about 1.6 million cubic meters). Overall, the model predicts that the pH levels of 6.5 or less would be expected to persist for no more than three hours after the CO_2 release has stopped the plume is while drifting down current to a distance of about 1,800 feet. The pH would return to ambient conditions everywhere (pH 7.6) in about 12 hours.

5.2.1.5 Other Water Quality Effects

Other activities carried out during the *Field Experiment* would include standard oceanographic investigations of the carbon dioxide plume's characteristics. These activities would include temporary deployment of instrument packages and one or two remotely operated vehicles (ROVs) or submersibles to measure key parameters. The U.S. National Oceanographic and Atmospheric Administration has determined that use of these instruments creates no potential for significant environmental effects, including effects on water quality (15 CFR 970.701a). Research vessels would be equipped with U.S. Coast Guard-approved marine sanitation devices (33 CFR 159) to preclude unauthorized discharges of sanitary wastes. Research vessels would comply with U.S. Coast Guard regulations (33 CFR 151) and other applicable Federal and State of Hawai‘i laws and regulations for the management of bilge and ballast water to minimize pollution and the introduction of non-indigenous or exotic species into waters at the site of the experiment.

As discussed in Section 5.2.1.1, the CO_2 droplets would cause a temporary, localized effect on water clarity within 100 to 200 feet of the release point. In addition, marker dyes, used to track the CO_2-enriched seawater plume, would contribute a localized effect on water clarity near the release point. Two types of dye are under consideration for use during some of the releases, rhodamine-WT and disodium fluorescein (trade name uranine). For many years scientists and engineers have used both of these tracer dyes in freshwater and seawater systems to track parcels of water. Either dye would create a visible color in the seawater within at most 300 to 500 feet of the discharge point. Beyond this distance, the dye would be diluted to where it would be only detectable using specific sensors designed for that purpose. The absence of potential for toxic effects from these dyes is discussed in Sections 5.3.1.3 and 5.3.2.1.4. Because the effects on water clarity caused by the CO_2 droplet cloud and by the tracer dyes would both be localized and temporary, they would not have a substantial effect on seawater quality.

5.2.1.6 Relationship to Applicable Water Quality Standards

For waters regulated by the State of Hawai‘i, which includes waters within the Ocean Research Corridor, the State of Hawai‘i Department of Health (DOH) has determined that the release of CO_2 into Class A waters constitutes an activity subject to HAR Section 11-54 (Water Quality Standards) and Section 11-55 (Water Pollution Control). DOH has indicated that due to the research nature of the experiment and to the fact that releases would be intermittent and of short duration, the State DOH may waive the requirement for a National Pollutant Discharge Elimination System (NPDES) permit if certain conditions are met (see Section 7.2.1). If the requirement is not waived, an NPDES permit and zone of mixing permit would be needed from the Department of Health.

The waters in which the proposed experiment would be conducted are classified by the State Department of Health as "oceanic waters".[21] HAR §11-54-06 (c) establishes water quality standards

[20] Only eight releases would be possible with the amount of CO_2 available in the operational plan at the maximum discharge rate (16 gallons per minute) and duration (2 hours). The actual number of planned tests (12-20) would result in tests of shorter duration or lower release rates.

[21] Oceanic waters are defined as all marine waters outside of the 183 meter (600 feet or 100 fathom) depth contour.

for these waters. These standards cover total nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, chlorophyll a, turbidity, dissolved oxygen, temperature, salinity, and pH.

The only one of these that the proposed experiment has the potential to affect is pH. The regulations stipulate that "pH Units - shall not deviate more than 0.5 units from a value of 8.1" (which is the pH typical of surface waters). Because the existing pH at the depth of the proposed experiment (7.6) is already at the extreme lower end of the range allowed by this standard, the water most affected by the proposed release would not comply with this standard. This would be true even if the allowable change was measured from the existing pH of 7.6.

HAR §11-54-04 establishes basic water quality standards for all State waters. It requires all waters to be free of substances attributable to domestic, industrial, or other controllable sources of pollutants. Named pollutants include:

- Materials that will settle to form objectionable sludge or bottom deposits;
- Floating debris, oil, grease, scum, or other floating materials; substances in amounts sufficient to produce taste in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to produce objectionable color, turbidity or other conditions in the receiving waters;
- High or low temperatures; biocides; pathogenic organisms; toxic, radioactive, corrosive, or other deleterious substances at levels or in combinations sufficient to be toxic or harmful to human, animal, plant, or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water;
- Substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life;
- Soil particles resulting from erosion on land involved in earthwork, such as the construction of public works; highways; subdivisions; recreational, commercial, or industrial developments; or the cultivation and management of agricultural lands.

As discussed in Section 5.2, the pH reduction that would accompany the release of CO_2 would cause only localized, short-term excursions outside the normal range. These would not substantially interfere with the uses that the standards are designed to protect.

HAR §11-54-01.1 states that it is the general policy of the state to prevent the degradation of water quality. This "antidegradation rule" states that *"…the quality of waters whose quality are higher than established water quality standards shall not be lowered in quality unless it has been affirmatively demonstrated to the director that the change is justifiable as a result of important economic or social development and will not interfere with or become injurious to any assigned uses made of, or presently in, those waters."* The environmental analyses conducted for this report indicate that the proposed experiment would not interfere with or become injurious to any assigned uses made of those waters in any substantial way.

If the State Department of Health were to decide not to waive the requirement for an NPDES permit, the Department has indicated that a "Zone of Mixing Permit" as provided for in HAR §11-54-09 would also be required. As used in these regulations, "zones of mixing" means limited areas around outfalls and other facilities to allow for the initial dilution and assimilation of *waste* discharges. Zones of mixing are normally used for the assimilation of domestic, agricultural, and industrial wastes. They are not normally associated with scientific experiments where the purpose of the experiment is to cause a temporary perturbation in water quality for the purpose of establishing the ocean's assimilative capacity.

Because the discharges normally governed by the regulations are wastes, the regulations require that these discharges (1) be determined to be necessary and (2) receive the best degree of treatment or control possible. The proposed *Field Experiment* is consistent with both of these provisions. First, for reasons described in Section 2.2, the experiment is needed in order to better understand basic physical processes that affect the assimilation of CO_2 in the deep ocean. Second, the experimental plan (see Appendix C) calls for the use of the lowest release rate and smallest total release volume that is believed necessary if the scientific objectives are to be met. Thus, the proposed action is consistent with these regulations.

5.2.2 ACCIDENT SCENARIOS (REASONABLE WORST CASE)

The flexible steel discharge tubing planned for use during the *Field Experiment* would be designed to withstand the stress of repeatedly lowering and raising the approximately 5-metric ton discharge platform, the internal pressure of the liquid CO_2, and the external, hydrostatic pressure in the deep sea. The tubing would be designed to be coiled and uncoiled up to 150 times (JMC 2000. Personal Communication). Nonetheless, while unlikely, the possibility of a tubing failure cannot be completely discounted.

If a failure were to occur, it would most likely happen at a point of greatest stress. In practice, this means the tubing would be most likely to fail either at the top or at the bottom; failure would also be most likely to occur while the platform is being raised or lowered or if the tubing were to become snagged on a protuberance from the seafloor.[22]

The important variables in evaluating the effect of a tubing failure would be the depth at which the break occurs and the amount of CO_2 that could potentially escape. While design of the tubing has not been finalized, the tubing would likely have an internal diameter of approximately 1.5 inches (3.81 centimeters). The volume of CO_2 contained within a 3,600-foot length of tubing with a 1.5-inch diameter would be 325 gallons (1.25 cubic meters).[23]

Failure Near the Surface. If the tubing would rupture at or near the surface (i.e., if the tubing develops a leak without being completely severed), the CO_2 would escape as a gas due to sudden depressurization. The rapid ascent of bubbles to the sea surface would probably prevent much CO_2 from entering the seawater. Hence, this scenario would have little potential to affect water quality. Once in the atmosphere, the CO_2 would rapidly disperse.

If completely severed at the surface, the tubing would fall to the seafloor. In reality, most of the liquid CO_2 in the tubing would vaporize, rise to the surface, and then vent into the atmosphere. Little CO_2 would dissolve into the water during this process. Once the broken end of the tubing would sink below 1,500 feet (450 meters), hydrostatic pressure would be sufficient to keep any remaining CO_2 that escapes in a liquid state. The tubing would move erratically during the fall, thereby dispersing the CO_2 over a large volume of water. Because of these forces, the CO_2 released in the event of such an accident would have little effect on water quality.[24]

Failure Near the Bottom. If the tubing were to fail near the bottom, the most CO_2 that could be released would be the entire volume of CO_2 (325 gallons) in the tubing. In reality, the pressure inside and outside the break would quickly equalize and less would escape. Such a failure could release, over a relatively short period of time, about the same volume of CO_2 as would normally be released during 15-20 minutes of a planned test at the maximum discharge rate contemplated.

[22] Video of the seafloor near the study site revealed numerous patches of rocky outcrops, many appearing to rise 1 to 2 feet above the sediments. If the surface vessel that deployed the platform were to move substantially to either side of a designated location, the tubing could become stuck on a rock and, in effect, anchor the vessel. This could cause the tubing to break.

[23] The tubing length used, 3,600 feet, accounts for the 2,600 feet of vertical distance needed to reach the ocean floor plus the 1,000 feet of tubing that would lie on the ocean floor.

[24] Even if an assumption is made that all CO_2 in the tubing would dissolve in the surface layer with no subsequent release to the atmosphere, the maximum dimensions of the parcel of water that would experience a pH = 6.5 would be no more than 30 meters (100 feet) on a side. Even this parcel would be very short-lived; nowhere would pH remain below 6.5 for longer than 17 minutes, and the affected parcel could travel no further than 440 feet (133 meters) before being completely dissipated by turbulent mixing.

The impacts on water quality would depend upon many factors, including whether or not the broken tubing would remain attached to the platform and the extent to which hydrate formation around the break would restrict the rate of release. However, in any event, the water quality effect would only be a fraction of the modeled situation presented in Section 5.2.1. The probability of these failures is not known. Such an experiment has not been conducted, and yet the handling and transport of liquid CO_2 is commonplace worldwide. No specific statistics for failure of such marine transport and handling systems were available for this study.

5.2.3 CLOSURE/TERMINATION-PHASE EFFECTS ON MARINE WATER QUALITY

The activities that would take place during the closure/termination phase of the *Field Experiment* would not affect water quality. The discharge platform, pipe, and monitoring instrumentation would be removed with no further activities anticipated at the site. These activities would have no measurable effect on water quality.

5.2.4 WATER QUALITY EFFECTS AT A GENERIC OCEAN SITE

Differences between the predicted effects of conducting the *Field Experiment* within the NELHA Ocean Research Corridor at Ke hole Point or at another location would probably arise mostly from differences in the ocean current regime at the sites. Higher currents and levels of turbulence would disperse the discharge plume more rapidly, while lower current speeds and turbulence would have the opposite effect. Hydrographic conditions selected for the experiment would need to be below levels that could pose operational problems. Therefore, any generic ocean site selected for the experiment would possess a current regime similar to that at the NELHA Ocean Research Corridor site. Generally, then, the effects on water quality at a generic ocean site would be quite similar to predictions made for the Ocean Research Corridor site.

5.2.5 WATER QUALITY EFFECTS OF NO ACTION ALTERNATIVE

If the *Field Experiment* was not conducted due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no changes in existing water quality would occur. If the *Field Experiment* was conducted without DOE participation, then the water quality effects would be similar to those presented for the Ocean Research Corridor.

5.3 EFFECT ON MARINE RESOURCES

The primary environmental effects of the *Field Experiment* would be on the marine biological resources near the *Field Experiment* site. Section 5.3.1 provides a general overview of the project elements that have potential to affect marine biological resources. Section 5.3.2 discusses the effects of conducting the *Field Experiment* at the NELHA Ocean Research Corridor site. Section 5.3.3 briefly examines how these effects might differ at a generic ocean site. Section 5.3.4 describes the anticipated effects on marine biological resources under a No-Action decision by DOE.

The *Field Experiment* would not be expected to have a substantial adverse affect on the North Pacific Humpback whales (*Megaptera novaeangliae*). Additional discussion on Humpback whales is presented in Section 7.1.6. The absence of potential effects on sea turtles is discussed in Section 7.1.5.

5.3.1 PROJECT ELEMENTS WITH POTENTIAL TO AFFECT MARINE BIOTA

This subsection summarizes key aspects of the *Field Experiment* that have the potential to cause environmental effects. Section 5.3.1.1 describes the direct effects anticipated to result from emplacement of the discharge platform and tubing. Section 5.3.1.2 outlines the state of knowledge regarding the interaction between lowered pH levels in ocean water and marine life. Section 5.3.1.3 describes the characteristics of the oceanographic monitoring equipment that would be used for the

Field Experiment, and Section 5.3.1.4 considers the scale of, and probable results from, accidental releases of CO_2 that could result from equipment failure or operational errors.

5.3.1.1 Area Subject to Abrasion from the Discharge Platform and Tubing

The discharge platform (Figure 4-4), measuring about 7 by 13 feet (approximately 2 by 4 meters) and weighing 5 metric tons, could be lowered onto the seafloor as many as 10 times, though the current experimental plan calls for only two such deployments (see Appendix C). During each landing, the platform would likely leave an imprint in the seabed if it lands on soft substrate. The preliminary platform design incorporates a pointed leg at each corner. This configuration, which is intended to help affix the platform to the steeply sloping seafloor, would minimize the area over which the platform would contact the bottom. If all four legs would land on bare substrate each time the platform would be deployed, the contact area for 10 deployments would be minimal, probably no more than 40 square feet (4 square meters). Even if the platform unexpectedly landed on soft bottom during each of the 10 deployments so that the entire bottom rested on the seafloor, the contact area would be no more than 860 square feet (80 square meters), which would be too small to have a substantial deleterious effect on the benthos.

The tubing laid on the seafloor during each deployment of the platform would affect a larger area. Figure 4-2 shows the general methods that would be used for deployment of the tubing and discharge platform. Figure 5-11 illustrates the worst-case estimate of the area that would be impacted. Tubing could extend approximately 1,000 feet (300 meters) away (as measured horizontally) from the platform. This horizontal displacement would keep the vertical segment of the tubing (i.e., the part that extends through the water column from the surface vessel to the seafloor) well clear of the space in which the ROVs and submersibles would operate. Figure 5-11a shows the situation after complete deployment of the platform.

While the vessel used for the deployment would have very good position-keeping capability, the vessel would not remain perfectly motionless for the entire duration of each deployment. The experimental design specifies that the vessel would remain within 80 feet (25 meters) of a desired position. Combined with the length of tubing that would rest on the seafloor, this position-keeping capability would define the maximum sector across which the tubing could sweep. This sector (with the platform as its center and the length of tubing on the seafloor as its radius) is sketched in Figure 5-11b. A seabed area of about 1.84 acres (0.06% of the Ocean Research Corridor) could be impacted.

However, the vessel and platform would probably not be in precisely the same location each time the platform would be deployed (although they are likely to be close). Thus, the tubing could affect a different part of the seafloor during each deployment of the platform. Assuming that absolutely no overlap would exist between successive deployments of the platform and tubing (a highly unlikely assumption) and that a maximum of 10 deployments would be made, then loose rocks could be displaced and mounded sediments could be disturbed over a maximum seafloor area of 18 acres (0.62% of the Ocean Research Corridor seafloor).

5.3.1.2 Mechanism Through Which Lowered pH Could Affect Marine Life

Injection of very large amounts of anthropogenic CO_2 into seawater over a long period could affect the rate of deposition or loss of calcium carbonate by organisms. The *Field Experiment* would involve far too small a release and far too short a time to cause such chronic effects. Organisms that live at the depth where the *Field Experiment* would be conducted are accustomed to an environment where calcium carbonate is stable. The temporary depression of pH caused by the *Field Experiment* CO_2 release would briefly produce chemical instability, but the relatively slow process of carbonate dissolution would not be substantially affected.

Figure 5-11. Benthic Impact Area Estimate

The kind of short-term CO_2 release planned for the *Field Experiment* would theoretically be capable of affecting development, reproduction, and survival of marine organisms through physiological effects of acidosis. The potential for such acute effects is discussed below. Studies of the effects of increased CO_2 levels on marine organisms have only been recently initiated and few data are available. Most prior research into the effects of depressed pH on marine organisms has concentrated on the effects of acid discharge from industrial outfalls and the release of acidic wastes from barges. Auerbach *et al.* (1997) reviewed available laboratory studies on the effects that lowered pH can have on different sorts of marine life. Figure 5-12 presents a summary of these laboratory studies.

Perhaps the best available natural analog to a release of anthropogenic CO_2 in the deep sea are the plumes of hydrothermal fluid emanating from vents on the Hawaiian seamount L ‘ihi, located about 20 nautical miles southeast of the Island of Hawai‘i. The fluids venting from L ‘ihi contain CO_2 concentrations as high as 18 parts per thousand (by weight) at a depth of about 3,300 feet (~1000 m; Karl *et al*., 1988; Sedwick *et al*., 1992).

Over a period of two weeks in 1997, injection of CO_2 into the deep-sea water near Hawai‘i by Pele’s Vents (located on L ‘ihi) was on the order of 340 to 5,500 short tons (McMurtry 1998). This mass is a minimum of 6 times the amount that would be injected over the course of the *Field Experiment*. There are no known reports of substantial adverse effects on marine organisms in the water column as a consequence of the L ‘ihi vents, where animals passing through the vent field in the water column above the vents would not be adapted to the high CO_2 levels, and where the pH would be as low as the pH likely to be experienced in the *Field Experiment*. Moreover, this is true even though the release from the L ‘ihi vents occurs over very long periods of time and is accompanied by other factors that are even more inimical to biological activity.

The existence of naturally occurring releases of large amounts of dissolved carbon in deep hydrothermal vents of volcanic origin on L ‘ihi may prove very useful in future evaluations of the potential chronic environmental effects of ocean sequestration of CO_2. However, the lack of a pure phase (liquid CO_2) at release points on L ‘ihi would eliminate strong buoyancy effects, the role of hydrate formation, the influence of dissolution kinetics, and other processes that are the objects of study for the *Field Experiment*. Also, there would be a lack of necessary experimental control, because the venting occurs sporadically at variable flow rates and at multiple sites.

A critical assumption of this analysis is the pH at (and below) which marine metazoans would begin to die after a brief exposure. Information on this subject is limited. In a study of the effects of CO_2 concentration on two echinoid and one gastropod species, Shirayama *et al.* (1999) reported very low mortality relative to controls at pH levels ranging from approximately 6.5 to 7.8. Significantly, no experimental organisms died during the first week of exposure to any of the reduced pH levels in this range (i.e., to an exposure period that would be much longer than any produced by the *Field Experiment*).[25]

In a study of the effect of pH on eggs, larvae, juveniles, and adults of flounder (*Paralichthys olivaceus*), Kita *et al.* (1999) reported that the younger life stages were the most sensitive. Approximately 40% of flounder larvae were found to survive exposure to 6.5-pH seawater for 6 hours, and about 20% survived exposure to 6.5-pH seawater for 24 hours. Auerbach *et al.* (1997) used literature data to report on the effect of pH and exposure time on a variety of holo- and meroplanktonic organisms; no mortality was predicted for those organisms after a 24-hour exposure to seawater with pH as low as 5.7. Mortality did not occur in the copepod *Temora longicornis* after 24-hour exposure to acidified seawater until the pH was reduced below 6.0 (Grice *et al.* 1973).

[25] The report notes that, at the highest acidity concentrations, the echinoderms appeared to be paralyzed for some time prior to death (after about 2 weeks). The report does not state either the length of time between initial exposure to decreased pH and the onset of paralysis or the response that might result if conditions returned to normal in less than two weeks.

Figure 5-12. Biological Mortality Due to pH Exposure

Taken as a whole, the data suggest exposure to seawater with a pH as low as 6.5 for periods of time less than 24 hours would not result in substantial levels of mortality for marine macrofauna and plankton. The data do suggest that water with pH levels below 6.5 would have some potential to harm certain marine organisms if they are exposed for a sufficient period of time. The limited studies also suggest that exposures to the greatest pH depression that would be produced by the fastest discharge rate over the time that a CO_2 plume would persist (a few hours) would have the potential to harm (including kill) some marine organisms. Unfortunately, insufficient data exist to establish precise dose-response relationships.

5.3.1.3 Experimental Monitoring Devices

The other activities carried out during the *Field Experiment* would include standard oceanographic investigations of the discharge plume characteristics. These activities would include deployment of seafloor-moored instrument packages, ROVs, and submersibles to measure the key parameters of the discharge. The U.S. National Oceanographic and Atmospheric Administration has, through many years of conducting and observing such activities, determined that they have no potential for significant environmental effects (15 CFR 970.701a).

The tracer dyes planned for use in the *Field Experiment* are non-toxic at the concentration levels anticipated (<5 mg/l at a distance of 3 feet from the release point). Extensive testing of the dyes using a variety of aquatic organisms showed no toxic effects at concentrations below 10 mg/l (Keystone Corporation 2000).

5.3.1.4 Mechanism Through Which Accidental Releases Could Affect Marine Life

Accidental releases of CO_2, either on the sea surface or at the seafloor, would be of very short duration and cause only minor perturbations on surface or deep seawater. Accidental releases would not be expected to cause adverse impacts.

5.3.2 EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.3.2.1 Anticipated Seafloor Effects

The planned *Field Experiment* could potentially affect deep seafloor communities through (i) direct CO_2 effects, (ii) disturbance from repeated platform emplacement, (iii) seafloor scour by the CO_2 delivery tubing, and (iv) other miscellaneous effects. All of these effects would be localized.

5.3.2.1.1 Direct CO_2 Effects on the Seafloor

As discussed in Section 5.2.1.4, small patches of seafloor near the platform could be subjected to pH levels below 6.5. Some mortality of benthic organisms dwelling within these patches would be likely, but they would be very difficult to detect due to the low densities and the high spatial variability characteristic of deep-sea sediment assemblages (Gage and Tyler 1991). Mortality on similar spatial scales frequently occurs naturally in deep-sea communities due to mounding and digging activities of seafloor animals (Kukert and Smith 1992). A potential for a seafloor impact from the *Field Experiment* would be created from the formation of plumes of CO_2-enriched seawater with pH $\leq$ 6.5. Conservative plume-dispersion calculations previously outlined in Section 5.2.1.4 indicate that the plume from a test at the highest planned release rate could produce pH levels below the 6.5 threshold over a seafloor area of about 4 acres (0.14% of the Ocean Research Corridor) for one test, and 33 acres (1.12% of the Ocean Research Corridor) for the entire *Field Experiment*.

The same conservative calculations show that the maximum time during which any seafloor organism would be exposed to pH of that magnitude would be three hours. The evidence presented in Section 5.3.1.2 from Auerbach *et al.* (1997) indicates that this exposure could stress some organisms but would be unlikely to be lethal. Shirayama *et al.* (1999), on the other hand, have reported toxicity to megafaunal organisms from such an exposure. Marine biologists recognize that they have imperfect knowledge of the precise pH dose-response characteristics of the organisms that populate the seafloor at the depth of the planned *Field Experiment*. Moreover, deep-sea communities that would be affected are characterized by very low rates of recolonization because of the low food availability at the deep seafloor (Smith and Hessler 1987, Kukert and Smith 1992).[26] Finally, while the seafloor area that the conservative modeling and assumptions indicate could experience pH $\leq$ 6.5 during an experimental release would be tiny from the perspective of the total area of similar habitat that is present in the region, several tens of acres would be involved.[27]

When all factors are considered, the CO_2 released during the *Field Experiment* would not be likely to have a substantial effect on benthic fauna. However, in view of the uncertainty inherent in any research endeavor, one or more of the following actions could be implemented if needed to provide additional protection against unanticipated adverse effects:

- Monitor the actual behavior of the plume of seawater having a reduced pH if any substantial plume characteristics that were not predicted by preliminary modeling studies should be identified;
- Monitor acute effects on animals near the CO_2 release point during the course of the experiment;
- Include in the experimental protocol provisions to modify the release (with respect to rate, timing, current speed, location, or other factors) in response to any unanticipated adverse effects.

The feasibility and specific methods of implementing these actions are being developed by the project team in collaboration with the State of Hawai‘i Department of Health as well as with other State and Federal agencies. The draft experimental plan describing these protocols and monitoring activities is presented in Appendix C.

One aspect of the work undertaken to monitor benthic ecosystem response to the *Field Experiment* discharge is a component of the existing *Field Experiment* scientific program. Coffin, *et al.* (1999) are developing the means to determine how the basic metabolic processes in ambient bacterial populations at the site would be affected by the CO_2 discharge. The work would include measuring ratios and abundances of naturally occurring carbon isotopes[28] (^{13}C and ^{14}C) in bacteria at the site before and after the *Field Experiment*, as well as laboratory culturing of the bacteria and measurement of how their growth rates vary with changes in pH. The object of these experiments would be to obtain information about how this very basic level of the ecosystem would be affected. Sampling and testing activities were conducted at the Ocean Research Corridor site and at other sites in the Hawaiian Archipelago during October 2000. These measurements would be repeated in conjunction with the *Field Experiment.*

5.3.2.1.2 Seafloor Effects of Repeated Platform Emplacement

As discussed in Section 5.3.1.1, the total area that could be physically impacted by 10 deployments of the discharge platform would range from 5 square yards (4 square meters) to 100 square yards (80 square meters). Complete recovery of the disturbed patches to background levels of faunal abundance and diversity could take a number of years. However, disturbance on this scale would not cause any long-lasting negative impacts to any of the seafloor fauna at the population or species level.

[26] Depending on their shape and size, areas that would experience 100 percent mortality could require on the order of 5-30 years to achieve full recovery.

[27] Seafloor species living at the depth of the planned experiment typically occur over depth ranges between 1,300 and 4,000 feet (400-1,200 meters; Gage and Tyler 1991). If the western side of the Island of Hawai‘i has an average slope of 22^o between these depths, the total seafloor habitat within this depth zone between M hukona and Ho‘ p loa, an alongshore distance of 67 miles (108 kilometers) is about 85,000 acres (345 square kilometers). Thus, even using conservative assumptions, the total area that could be impacted by the plume would be less than 0.04% of available similar seafloor habitat on the west side of Hawai‘i alone. The species found at this depth range on the western slope of Hawai‘i are also almost certainly found throughout the main Hawaiian archipelago (Chave and Jones 1991).

[28] Radioactive substances would not be used in any of the experiments.

5.3.2.1.3 Seafloor Scour by the Injection Tubing

As discussed in Section 5.3.1.1, an area of about 18 acres (8 hectares) of seafloor could be impacted by the maximum number of possible deployments of the platform and tubing. Movement of the tubing on the seafloor would adversely affect animals living on hard substrates. Video taken near the study site revealed few, if any, organisms attached to the rocks. Organisms that might be expected to occur on such substrates include non-hermatypic corals, sponges, and ascidians. Such organisms could be completely or partially destroyed by the movement of the tubing, or they could receive partial or complete protection from irregularities in the rock surface. Organisms with temporary or no attachments such as crinoids, echinoids, ophiuroids, holothurians, and decapods could be damaged, killed, or simply dislodged by the movement of the tubing.

Movement of the tubing could also affect animals living on or in soft sediments. Macrofauna could be damaged, killed, or simply dislodged by the movement of the tubing. Some infauna (predominantly small polychaete worms, peracarid crustaceans, and mollusks) could be damaged or killed by sediment disruption caused by the movement of the tubing; others would merely be temporarily dislodged.

Another potential effect of tubing movement would be the leveling of small-scale sediment features created from movement, feeding, and defecation by sediment-dwelling animals. Such features often persist in the deep sea because of the sluggish currents found at depth, and may provide locally important habitat diversity for infaunal invertebrates. The obliteration of such features is a commonly reported effect of trawling, which impacts vast tracts of the seafloor in many regions of the world's oceans.

Complete recovery of hard and soft substrate fauna following tubing disturbance would likely require months to several years. Because tubing disturbance would not cause complete defaunation of the area impacted, recovery rates would likely be more rapid than if the seafloor were completely denuded.

5.3.2.1.4 Miscellaneous Effects

Other activities during the *Field Experiment*, such as the emplacement and operation of the acoustic net and instrument packages, the collection of seafloor samples for bacteria, introduction of tracer dyes, and the operation of the ROV or submersible, are routinely conducted during research programs throughout the oceans. The instrument mooring anchors would occupy a very small area and would be composed of non-toxic materials (concrete or iron). After the instrument packages are retrieved at the end of the *Field Experiment*, the remaining anchors would provide hard-substrate outcrops, which could harbor colonizing benthic organisms. These activities would not have a substantial effect on seafloor communities.

5.3.2.2 Anticipated Deep to Midwater Effects

5.3.2.2.1 Direct Deep to Midwater pH Effects

Invertebrate zooplankton have no means of detecting or avoiding the plume of reduced-pH water that the *Field Experiment* would produce and thus could be affected by testing. As previously discussed, a pH of 6.5 may be considered as the threshold above which no effect would be anticipated; a pH below 6.5 could stress or kill some zooplankton if exposure is sufficiently long. The volume of the plume having a pH below 6.5 (200,000 m^3) represents the maximum size of the zone of potential effect for one discharge; this volume would be about 2 million cubic yards (1,600,000 m^3) for eight discharges. The maximum exposure time would be three hours.

The greatest concentrations of zooplankton generally occur within 800 feet (250 meters) of the surface. Copepods have sometimes been observed in high concentration at depths of 1,300 to 2,300 feet (400 to 700 meters; Davis and Wiebe 1985, Longhurst 1985, Beckman 1988). At the expected depth of the bulk of the plume (2,300 to 2,600 feet, or 700 to 800 meters) zooplankton density would be expected to be very low.

Combining the small likelihood that the reduced pH would be of sufficient magnitude and duration to adversely affect zooplankton with the fact that the zooplankton density at the affected depth would be very low, the likelihood of substantial adverse effects on these animals would be minimal.

Some studies have indicated fish and nektonic shrimp react to and avoid water with sub-lethal pH levels (Portman 1970, Davies 1991). If these results are typical of organisms at the *Field Experiment* site, then the *Field Experiment* should harm few fish and nektonic decapods because they would reverse direction upon encountering the plume. Scientists do not know if squid have the same ability to detect low pH water. Investigations by Shirayama *et al.* (1999) indicate that fish that would swim very near to the discharge nozzle, where pH levels would be low, and remain for a time, would probably be killed.

Between July and September 1986, soon after the operation of the 40-inch deep-water intake pipe began at NELH, a total of 29 stingrays were found at the facility intake sump at the discharge of the pipe (T.H. Daniel 2000, Personal Communication). No stingrays have been found in the sump since this initial period. The rays are believed to be a well-known species (*Plesiobatis daviesi*), which has commonly been observed in similar water depths (700 m) by deep diving submersibles throughout the Hawaiian Islands (D. Chave, 2000, Personal Communication). If such stingrays are present at the *Field Experiment* site, they might be affected if they do not move from the vicinity of the release point or if they are attracted to the carbon-rich plume.

Species of concern to the sport-fishing community include representatives from several families including, but not limited to, <u>snappers</u> (Lutjanidae, discussed below in this section), <u>pomfrets</u> (Bramidae, including monchong-*Taractichthys steindachneri* and *Eumegistus illustris*), <u>jacks</u> (Carangidae, including *halahala Trachiurops crumenopthalamus*, *lai-Scrombroides sancti-petri, kamanu- Elegatis bipinnulatus, ulua- Caranx cheilio, and ulua kihikihi- Alectis ciliaris*), <u>dolphins</u> (Coryphaenidae, including *mahi-mahi- Coryphaena lippurus and Coryphaena equisetis*), <u>mackerels and tunas</u> (Scombridae, including *ahi- Thunnus albacares, ahi palaha- Thunnus alalunga, aku- Katsuwonus pelamis, akule- Trachiurops, kawakawa- Euthynnus affinis, ono- Acanthocybium solandri, opelu- Decapterus pinnulatus*,and *po`onui- Thunnus obesus*), <u>swordfishes</u> (Xiphiidae, such as the *a`uku- Xiphins gladius*), and <u>billfishes</u> (Istiophoridae, including *a`u- Makaira nigricans and Makaira indica*).

The depth ranges are not precisely known for many of the species of interest to local anglers, but depth data for several species from time-depth recorders and observations are available and are discussed below. The centers of distribution of the families listed above occur well above the CO_2 release depth. Some species may occasionally descend to a depth at which they might encounter the plume, but it is unlikely that the experiment would result in any substantial mortality to these sport-fishes. The depth is simply too great and the persistence of sub pH 6.5 water too short.

- Block *et al.* (1992) found that blue marlin fish equipped with depth and temperature transmitters exhibited a preference to remain in the surface mixed layer (above the thermocline). One fish was found to remain near the surface in 81º F (27° C) water during daylight hours and make numerous dives between 160 and 330 feet (50 and 100 meters) at night.
- Studies using ultrasonic depth telemetry recorders off the west coast of Hawai‘i on yellowfin tuna (*Thunnus albacares)*, skipjack tuna (*Katsuwonus pelamis*), blue marlin, and striped marlin, suggest that these species limit their vertical movements to remain in waters within 14ºF (8ºC) of surface water temperatures (Brill *et al.* 1993, 1998). Brill *et al.* (1998) reported that five tagged yellowfin tuna remained shallower than 330 feet (100 meters) 80% of the time and shallower than 400 feet (125 meters) 90% of the time. A similar study found that blue and striped marlin spent

85% of the time at depths shallower than 300 feet (90 meters) and limited their descent to a maximum depth of <560 feet (170 meters; Brill *et al.* 1993).

- Bigeye tuna and swordfish reportedly forage routinely to depths as great as 1,600 feet (500 meters) (Carey 1990). This water depth would be above the expected upper margin of the area affected by the *Field Experiment*.
- Six species of *lutjanids* (snappers) are found in Hawaiian waters. These include *uku* (gray job fish or gray snapper; *Aprion virescens*), gindai (also known as *ukiuki* or Brigham's or flower snapper; *Pristipomoides zonatus*), *to`au* (blacktail snapper; *Lutjanus fulvus*), *ta`ape* (blue striped snapper; *Lutjanus kasmira*), *ehu* (squirrelfish snapper; *Etelis carbunculus*), and the Spotted rose snapper (*Lutjanus guttatus*). These fishes are found above 1,000 feet (300 meters; Haight 1989). Hence, they would not be expected to encounter waters with depressed pH.
- Similarly the deep snappers and other bottom fish such as *ula ula* (*onaga* or long red tail snapper; *Etelis coruscans*), *opakapaka* (pink snapper; *Pristipomoides microlepis*), *kalekale* (Von Siebold's snapper; *Pristipomoides sieboldii*), and the *hapu'upu'u* (the Hawaiian grouper; *Epinephelus quernus*) are not generally found in water depths deeper than 1,000 feet (Fresh Island Fish Company 2000; DLNR-DAR 2000).

The deep-scattering layer is composed primarily of species that migrate to surface waters at night and to depth during the daytime (the aforementioned snappers are generally associated with the seafloor, not the open water that would be above the platform). The deep-scattering layer occurs between 300 and 1,600 feet (100-500 meters). The daytime depth of different species is determined by their center of distribution and swimming speed. Swiftly swimming animals would be able to descend to deeper depths during the day than the slowly swimming species that exist in the same depth range at night. Throughout much of the world's oceans, the deep-scattering layer is composed largely of euphausiids, sergestid shrimps, small bathypelagic fishes, squids, and copepods. The *Field Experiment* would not affect water visited by organisms found in the deep-scattering layer.

5.3.2.2.2 Threatened and Endangered Species

The threatened or endangered species in the vicinity of the planned *Field Experiment* would all be air-breathers (reptiles and mammals) that are not normally found at depths that would experience changes in water quality. Even if they were to reach such depths, their need to return to the surface to breathe would severely limit the time during which they would be exposed to reduced pH. In addition, because they are air breathing, CO_2 would not be exchanged across their respiratory membranes. The pH levels of the *Field Experiment* would not be expected to be caustic to their body surfaces because of the relatively low expected acidity and persistence. Hence, they would be very unlikely to be affected unless the CO_2 droplets would be directly ingested or the animals exposed their eyes very close to the nozzle.

5.3.2.2.3 Deep to Midwater Tubing Effects

The vertical segment of tubing that would pass through the deep-to-midwater zone would result in effects similar to those created by a Fish Aggregation Device (FAD) mooring line. The tubing would not be expected to have a deleterious effect on marine organisms.

5.3.2.2.4 Other Deep to Midwater Effects

Other effects could result from the movement of a remotely operated vehicle (ROV) or submersible within the study area and the use of acoustical navigational aids. Procedures and techniques for these types of activities have been used without any apparent negative effects during the course of thousands of oceanographic investigations.

5.3.2.3 Surface-Layer Effects

5.3.2.3.1 Direct CO_2 Effects on the Surface Layer

As planned, the experimental injection of CO_2 would not be expected to cause any measurable changes in pH or CO_2 concentrations at depths shallower than about 1,600 feet (500 meters). Thus, no impacts on biota or habitats in the surface layer of the ocean, 0 to 650 feet (0-200 meters), would be expected. Coral reefs and reef fish communities (including such species as *uhu*- Scaridae species, *Lauwiliwilinukunuku-'oi'oi- Forcipiger Longirostris*, and many others) would not be affected by the *Field Experiment*. Similarly, nearshore ecosystems familiar to divers and hosting such species as manta rays (*Manta birostris*) would be too remote from the *Field Experiment* site to have the potential to suffer any adverse effects.

5.3.2.3.2 Other Surface Layer Effects

The various operations conducted in the surface layer, 0 to 650 feet (0-200 meters), during the experiment (e.g., running support vessels, platform lowering and raising, ROV or submersible operation, transponder nets) would be similar, or identical, to oceanographic research operations repeatedly conducted in Hawaiian waters. No unusual (or measurable) impacts to the biota or habitats of the surface ocean would be expected to result from these activities. Concern has been expressed regarding the potential effects of ships and transponders on dolphin activity. The auditory systems of sonar using Odontoceti are adapted for the high ultrasonic frequencies that these animals employ for echolocation. The auditory system of these animals is necessarily robust in that, within milliseconds of producing loud sounds, they receive and process very faint echoes (Au *et al*. 1997, Richardson *et al*. 1995). Responses by cetaceans to the vessels used in this study would not be expected to differ from their response to other similarly sized vessels in Hawaiian waters. It is possible that the activities carried out for the *Field Experiment* could attract dolphins to the site, thereby slightly increasing their normal density in the area.

Collision with the ships or discharge pipe would be more likely to cause harm to these organisms. Pipe collision would be relatively unlikely especially for the sonar capable Odontoceti. Ship collision is a known source of mortality for sea turtles and marine mammals, but usually only when the ships are underway. Spotters will be on duty during the ship transits to help minimize the potential for such collisions.

5.3.2.4 "Worst-Case" Accidental Release

The nature of possible accidental releases is discussed in Section 5.2.2. The potential biological impacts are discussed below.

5.3.2.4.1 "Worst-Case" Accidental Release from Tubing Rupture at the Surface

In the worst case scenario of a rupture or break in the tubing at or near the ocean's surface, nearly all of the CO_2 would vaporize into the atmosphere[29] and have virtually no effect on pH or marine biota.

5.3.2.4.2 "Worst-Case" Accidental Release from Tubing Rupture Near the Seafloor

If the tubing fails near the seafloor, the entire volume of CO_2 in the tubing could rapidly discharge. Due to the relatively small volume of CO_2 that would be contained in the tubing, the effects would be much more limited in scale than those previously described for planned tests.

[29] This would not constitute discharge of a regulated air pollutant.

5.3.2.4.3 Other Accidents

The risks and potential impacts from other accidents (e.g., associated with vessel, ROV and submersible operation) would be similar to those potentially resulting from any of many research expeditions conducted regularly in Hawaiian waters.

5.3.2.5 Response to Accidental Releases

Shipboard personnel would be briefed on the characteristics and risks associated with the high pressure CO_2 system. At the first indication of an unintentional release, the CO_2 holding tank would be secured and remedies to the situation would be implemented, as appropriate. If any spills of petroleum products occur from vessels used for the *Field Experiment*, the U.S. Coast Guard would immediately be notified.

5.3.2.6 Summary of Effects on the Ecosystems in the NELHA Ocean Research Corridor

The overall impact of the *Field Experiment* on the ecosystem of the area would be extremely small. Traces of CO_2 would be expected to be undetectable in the water column within 12 hours; evidence on the deep sea floor would disappear within months to a few years. Some mortality of midwater organisms may result from CO_2 effects (pH below 6.5) within a total volume of water of 1.6 x 10^6 m^3. This entire impacted volume would be below a water depth of 500 m (i.e., it would be restricted to the deep ocean where biomass levels are extremely low). Because of the open and dynamic nature of pelagic ecosystems, it is expected that any measurable effects on the midwater biota within the NELHA corridor would dissipate to undetectable levels within hours. No impacts whatsoever would be expected for the fishing “Grounds” off Ke hole Point, nor to any nearshore habitats (e.g., coral reefs).

Impacts to the seafloor from the *Field Experiment* would be more persistent than those in the water column, with seafloor community recovery possibly requiring years. The potential seabed area impacted within the NELHA corridor would be so small that no significant impacts to the general ecosystem are conceivable. For example, the ranges of species and populations of all seafloor organisms potentially impacted by the *Field Experiment* would include slope regions on many (most likely all) of the Hawaiian Islands, so the chances of significant population or species level stress would be miniscule. There is no ecological evidence that anticipated small disturbances to the NELHA corridor ecosystem, such as would result from the *Field Experiment,* would result in permanent (or long-term) ecosystem changes.

5.3.3 GENERIC OCEAN SITE

5.3.3.1 Differences in Marine Biota

As discussed in Section 5.1.2, other ocean locations with the required characteristics for the *Field Experiment* would be likely to have benthic communities similar to those within the Ocean Research Corridor.

5.3.3.2 Differences in Potential Effects

Differences between predicted effects at the Ocean Research Corridor site and those at a generic ocean site would probably arise mostly from differences in the ocean current regime. Higher currents and levels of turbulence would disperse the discharge plume more rapidly, while lower current speeds and turbulence would have the opposite effect. Hydrographic conditions selected for the experiment would need to be below levels that could pose operational problems. Therefore, it is probable that the current regime at a generic ocean site would be similar to the Ocean Research Corridor. Generally, then, the effects on marine life at an alternate ocean site would be quite similar to those predicted in Section 5.3.2.

5.3.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no changes in existing marine life, such as those that could be created by conduct of the experiment, would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on marine life would be similar to those presented for the Ocean Research Corridor.

5.4 EFFECTS ON HISTORIC AND CULTURAL RESOURCES

5.4.1 NELHA OCEAN RESEARCH CORRIDOR SITE

5.4.1.1 Existing Historic and Archaeological Remains at *Field Experiment* Site

The bottom area on which the platform and about 1,000 feet (300 meters) of tubing would rest during the course of each test was explored in August 1999 using a video camera mounted on a remotely operated vehicle. Images were captured for approximately one hour and covered essentially the entire area that would be potentially affected by the *Field Experiment*. No physical historic or cultural remains of any kind were visible within the survey area. The absence of such remains is not surprising, particularly in view of the great depth and the absence of any folklore or other information that might indicate the presence of a shipwreck. It is also consistent with findings of other NELHA studies.[30]

5.4.1.2 Existing Historic and Archaeological Features on Land in the Ke hole Area

Although the project would not have a visible physical impact on the land in the Ke hole area, several archaeological and historic features deserve mention because they are in the *ahupua'a* immediately inland. These include the M malahoa (the old Government Road) and *ala loa*, now referred to as *Ala Kahakai* trails. Various trails led from Ke hole to Hual lai Mountain. Some of the trails had large blue rock stepping-stones. Previous oral interviews with area residents also tell of burial sites in the area, but these have not yet been located.

Stories note the presence of a fishpond known as *Pa' iea* in the Ke hole area, but it is thought to have been destroyed by lava flows, especially the flow of 1801. The following narrative by Kihe (in *Ka H k o Hawai'i* translated by Maly) describes some of the cultural features of the area:

> "It was at Ho'on that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one of the canoe landings of the place. Today it is where the light house of America is situated. Pelek ne is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *p hoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today."

Translations completed by Kumu Pono Associates (1998) include documents that tell of the traditional significance of this area. These include the writings of J.W.H. Isaac Kihe and John Ka'elemakule, portions of which are cited throughout this part of the report. These were native authors writing in Hawaiian newspapers between 1907 and 1929.

Other compilations of oral histories include *A Social History of Kona: Volumes I and II* (University of Hawai'i Ethnic Studies Program, 1981). That report documents the results of the Ethnic Studies Program's oral history project in Kona. Its emphasis is on the general experiences of the individuals interviewed. While it provides little specific information on issues relating to shoreline access or historic sites, it does provide insights into land use and economic activity during the early part of the

[30] It should be noted that many Hawaiian elders consider the ocean itself as a cultural, as well as a physical and biological, entity.

20th century. The interviews highlight the importance of fishing to native residents of the Kona coast during that time.

5.4.1.3 Anticipated Effects on Historic and Cultural Sites

The Historic Preservation Division of the State Department of Land and Natural Resources (SHPD), the Office of Hawaiian Affairs (OHA), and Hui M lama were contacted during preparation of this Environmental Assessment. Copies of the correspondence are reproduced in Appendix G. The SHPD agreed that the *Field Experiment* would not have any effects on historic properties; it offered no discussion on cultural properties. Hui M lama, another native Hawaiian organization that was contacted, did not provide comments.

5.4.1.4 Methodology Followed in Identifying Traditional Uses and Rights

While there is general agreement that the proposed experiment is unlikely to affect physical remains, public comments on the Draft EA for the project indicated concerns that it might adversely affect other resources important to native Hawaiians. This possibility had not been discussed in the Draft EA because it had been believed that the offshore location would prevent any substantial effects on such resources.

In order to address the questions that had been raised, a cultural impact assessment analysis was prepared to determine the nature and extent of these possible effects (Social Research Pacific, Inc., November 14, 2000). The assessment used an ethnohistorical approach, with the primary emphasis placed on oral interviews with individuals who could share knowledge about traditional uses of the project area. While the primary method of obtaining information was through the oral interviews, literature was also reviewed to identify issues of known historic and cultural significance. This study is reproduced here as Appendix F.

Consistent with State Environmental Council guidelines for conducting cultural impact assessments, efforts were made to contact individuals and organizations which have expertise concerning the types of cultural resources, practices and beliefs found within the vicinity of Ke hole (these include the *ahupua'a* of Makalewena, Mahai'ula, Haleohi'u, Kalaoa, 'O'oma, and Kohanaiki). Efforts were made to select individuals who specifically had knowledge of the proposed project area; this included six *k puna* from the Island of Hawai'i. Oral interviews (7 formal and 7 informal) were conducted with informants who possessed historical knowledge about the area and/or who could recommend bearers of cultural information, and a follow-up meeting was held with *k puna* in response to requests made during the initial round of contacts. Documentary research, particularly on the location of cultural and historical uses of the area, was conducted on O'ahu and Hawai'i.

Since the project area is located in the ocean, and since a major objective of the study was to identify traditional fishing sites (as requested by the State Historic Preservation Officer), efforts were made to interview *k puna* who had been fishermen in these waters.[31] All of the *k puna*, except for Eddie Ka'ana'ana who is from the village of Miloli'i, have been fishing in the area since they were children. The significance of the interviews with the *k puna* is that these are men who are still actively using the waters in and around the project area for their fishing activities.

Both formal and informal interviews were conducted; these took place between September 28 and October 24, 2000. The goals of the formal interviews were to:

- Identify traditional uses of the project site and surrounding area;
- Identify traditional fishing sites in the project area;

[31] Selection of people to interview was done primarily by locating individuals and families of Hawaiian ancestry, who had lived in the Ke hole area and/or had knowledge about the waters off Ke hole Point. The Office of Hawaiian Affairs (OHA) was first contacted for recommendations of individuals to interview. Interviews with *k puna* on Hawai'i were identified and arranged for by Mr. Kep Maly.

- Identify cultural features (other than ocean-bound) in the area;
- Identify stories, legends, and beliefs that may describe traditional uses of the area; and
- Obtain information on if and how the proposed project might affect traditional practices in the area.

The formal interviews began with personal introductions. The interviewers then solicited recollections and narratives of the traditions and uses of the area. The interviewers followed this with a summary description of the proposed experiment (including a map of the project area). The final portion of the interviews entailed questions and answers directed at the interviewer about the project. This allowed the interviewer to elicit responses directed towards determining whether the individuals participating in the interviews felt the proposed experiment would cause specific cultural impacts.

In addition to formal interviews, discussions and informal interviews were held with individuals and groups who provided names of Hawaiian *k puna* and/or knowledgeable community residents. Among these were individuals who have knowledge about the proposed project and shared their views, not necessarily based on personal experience in the area, but based on knowledge and interest in the general cultural traditions and practices of Hawaiians. Many of the individuals in this group had previously expressed their concern or outright opposition to the proposed experiment.

5.4.1.5 Traditional Uses Identified Through the Research and Interview Process

The information gathered through the investigation is summarized below. For clarity, the discussion is divided into three types of "traditional uses" that informants recalled or verified from the area: (i) deep sea fishing, (ii) *ko'a* – traditional fishing grounds or stations, and (iii) Ke hole Point.

5.4.1.5.1 Deep Sea Fishing

All of the *k puna* recall fishing from Ke hole out to the deeper ocean. It is an area where both traditional and modern types of fishing continue to the present day. The fishermen described <u>ahi</u> grounds extending from K holo to Ke hole. The following are among the findings:

- The traditional fishing grounds extended well beyond the 1+ mile marker shown on a 1981-82 Loran marker map. They indicated that *"…the main current heads north…these are where the <u>aku</u> grounds are…north side of the island. This area was once both <u>aku</u> and <u>ahi</u> grounds. Hawaiians used to go fishing way out…maybe about 5-6 miles, and would judge their whereabouts by the clouds. If you weren't with an experienced navigator, you'd be dead out there."*
- Fish are much less abundant today than they were in the first half of the 20th century. Whereas they were once easy to find, now fishermen must look hard. Moreover, when they find the fish, they are generally in smaller numbers than was once the case.
- Writings from the Kona elder, John Ka'elemakule (1854-1935), tell of the importance of deep-sea fishing in the early 20th century. Among the important fishing practices of Kekaha were *aku* fishing, *ahi* fishing, and fishing for *' pelu* with nets. This type of fishing was done at the *ko'a ' pelu* (*' pelu* fishing station or grounds) that was not too far out from shore. The famous *ko'a lawai'a* (fishing ground) of Kekaha, known by the name "Haleohi'u" was beyond that.

5.4.1.5.2 Ko'a – Traditional Fishing Grounds or Stations

Ko'a are fishing grounds or stations out at sea, and knowledge about them is passed on through generations of fishermen. There are several within the Ke hole region still used by fishermen. The following narrative from Kihe (October 11-18, 1923) as translated by Maly (Kumu Pono Associates, March 1998), describes the *ko'a* off Ke hole.

> "It is not a large place, this point, Ke hole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (*ka wili-au*) that flow with the passing current…And there in front of this point, is deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (*muliwai*), and then flow out. It is on that side, that you will find the *ko'a* (fishing stations) for *aku*, *ahi*, *k hala*, *pakapaka*, and such. Among these *ko'a* are *Pao'o, ' pae, Kahakai*, *Kapapu*, *Kanaha-ha*, *Kaluahine*, *Kanukuhale*, *Kaho'owaha*, *Honu*, *Muliwai* (from where one peers upon the dirt of H ena, Kohala) and *Kaihuakala*, Maui…There are many other *ko'a*, but these that I've mentioned, are the famous *ko'a*. There are many deep *ko'a* all in a line, from the Point of Ke hole to the Point of Upolu and the *heiau* of Mo'okini in Kohala."

These same *ko'a* were referenced by the *k puna* during the oral interviews. They indicated that more than one *ko'a* could be used while using the fishing grounds in the Ke hole area. Some of the fish mentioned (e.g., *pelu* and *weke la'o*) are typically caught close to shore. Other, larger fish are generally further out. The *k puna* indicated that the *ko'a* out there [is] the *ko'a weke*. The *k puna* indicated that they did not want any desecration in that particular area.

Along with knowledge about when and where to fish, the *k puna* interviewed shared some of their traditional methods of attracting and replenishing fish. They indicated that they always used fresh bait; they never used *pilau* (stink bait or rotten bait) for catching fish. They stressed how important it was to eat fresh food and to show the same courtesy to the fish. They noted that they would traditionally feed the *ko'a* (i.e., leave food offerings at them) on a regular basis to keep the fish "at home." These *ko'a* extended from near shore at Ke hole to Honok hau and were located as far as two miles from shore. The fishermen indicated that they were careful to *ho'oma'a*, or let the grounds rest, as a means of being careful that they did not take too much from the sea.

Fishing using both traditional and modern methods remains common in the nearshore area to the present day. While these nearshore fishing grounds are far from the site of the proposed experiment, the persons interviewed expressed concern that deep currents would cause the *Field Experiment* to affect shoreline areas.

5.4.1.5.3 Ke hole Point

According to the *k puna*, Ke hole translates as: *Ke* (the), *hole* (water banging together). holehole means "water banging together," where two currents blend together. They said that the area is very seldom calm, usually it is "bubbling/boiling," and that the naming of Ke hole is after this unique current. The special current off of Ke hole Point that causes the "boiling" is referred to as *Lelewai*, and *Ho'on* is the calm place to the right of this current. The importance of Ke hole's unique currents is captured in the following excerpt from Kihe:

> *"It is not a large place, this point, Ke hole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current…And there in front of this point, is deep waves where this current swirls."*

Maly uses the following story of Ka-Miki to further illustrate the importance of Ke hole's unique currents:

> "…the bonito lure fishing grounds which extended from Kaulana to *Ho'on* , fronting Ke hole, which is the source of the supernatural currents *Ke-au-k* (the current which strikes), *Ke-au-k na'i* (the current of smooth waters), and *Ke-au-miki* (the current which pulls out to deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by *M k lei*."

The *k puna* also recounted stories of canoes often coming into the long-buried *P 'aiea* fishpond to avoid the current. According to the *k puna*, currents were also very significant in determining which place to fish. The location of *‘ pelu*, for example, could be determined by the current/undercurrent. They reported that the “white current” approximately 100 yards off Ke hole Point is where *‘ pakapaka*, *‘ula ‘ula*, and *kumu* are found.

The *k puna* also correlated specific currents with the availability of fish. They said: “*If the current’s not right, you can sit there 2 to 3 hours and nothing will happen. When the current starts to move however, you’re only given about 1½ hours to fish and its plenty good at that time.” “Kona kai m ‘oki ‘oki”* (the streaked sea of Kona) are current lines from Kekaha. The *k puna* spoke of the black current lines that appear off of Ke hole, saying that these lines reflect the shape of the seafloor. They said that when you see an upwelling in the current, that’s when the nutrients reach the surface and attract feeding fish. Hawaiians traditionally observed these currents both by watching the waves from markers on shore and from out at sea.

In addition to influencing where they fished and how they reached the fishing grounds, the currents sometimes determined where they could come back to shore as well. The following description of *Ho‘on* indicates that it offered a place of refuge when the waters became too rough:

> “*Ho‘on* was the place where calm waters mix…its about ¾ to a mile out to sea, the place where the waters mix. We had a song for Kona that we used to sing when fishing out there. We went down to *Ho‘on* because we couldn’t come back in. We were stuck there for about 4-5 hours and the captain said that we should get back before dark fall [when the lights go out…during the war period]. *Ho‘on* is a quiet area, so it was used as a waiting grounds before trying to go back into shore.”

In addition to the deep-sea and *ko‘a* fishing described above, several other types of subsistence activities related to fishing took place off and near the shores of Ke hole. These included shellfish collecting (Kona crabs, *‘ pihi*, *wana*), *limu* gathering, and gathering salt from salt pans along the shoreline. Some of these practices, such as gathering salt and *limu*, continue today. Some practices have been abandoned due to lesser availability of and/or access to resources and for other reasons.

In addition to oral histories from individual sources, documentation exists on traditional fishing rights in the area; these were established during Kamehameha III’s rule. The *konohiki* fishing rights granted use of the area extending from the beach to the outer edge of the reef, or one geographic mile seaward. Kamehameha III also recognized traditional deep sea fishing grounds (*ko‘a*), in waters up to 1,800 feet (MacKenzie 1991).[32] A number of traditional and current fishing sites are located in the Ke hole area. Many of these sites have been previously documented (see the writings of J.W.H. Isaac Kihe and John Ka‘elemakule cited in this study).

5.4.1.6 Additional Contacts With Native Hawaiians

During the interview process it became apparent that, despite the extensive informational effort that had been undertaken and the numerous articles that had appeared in local newspapers, many of the *k puna* did not understand exactly what activities the project would entail. In an effort to improve understanding, representatives of the project team met with native Hawaiian families (traditional and customary practitioners) — *kama‘ ina* of the Kalaoa-Ke hole Fisheries and Adjacent Lands (Kekaha Region, North Kona District, Island of Hawai‘i) on December 7, 2000.[33]

[32] The analysis conducted for this report focused principally on the area seaward (*makai*) of the shoreline. The traditional Hawaiian concept of *ahupua‘a* encompasses both land and sea areas. In this instance, DOE believes that expanding the scope of the analysis to include a detailed analysis of land-based resources is not needed for a full understanding of potential effects.

[33] Participants included *Kama‘ ina*: Valentine K. Ako, Elizabeth Ako, Lily Ha‘anio-Kong, Isaac & Tammy Harp, George Kinoulu Kahananui Sr., Robert Ka‘iwa Punihaole Sr., Annie Coelho, Hanohano Punihaole-Kennedy, and David Kahelemauna Roy. Gerard Nihous, Ph.D. (PICHTR), Jeff Summers (Department of Energy), and Perry White (Planning Solutions, Inc.) represented the experimental team. Because the meeting was intended primarily to afford individuals already familiar with the cultural investigations for the experiment an opportunity to obtain additional information and to

The project team began the meeting by providing the detailed overview of the proposed experiment that participants had requested. They also responded to questions that were asked by the *kama‘ ina*. Key points made by the *kama‘ ina* participants in the meeting are summarized below. Strong objections to the proposed experiment being conducted in the vicinity of the Kalaoa-Ke hole fisheries were voiced throughout the proceeding.

- Participants reiterated (1) their knowledge of traditional and customary practices; (2) the on-going use of the Kalaoa-Ke hole Fisheries; and (3) their recommendation that the proposed *Ocean Sequestration of CO_2 Field Experiment* not be conducted at the Kalaoa-Ke hole location.
- Those present indicated that they understand concerns regarding global warming, but said that measures that reduce CO_2 generation are preferable to efforts to accommodate continued CO_2 emissions at present or higher levels.
- They said that the three primary factors that make Ke hole suitable for the proposed experiment (access to deep waters, predictable calm seas and winds, and good logistical access) exist elsewhere as well, making it unnecessary to carry out the work where it might affect the Kalaoa-Ke hole Fisheries. It was strongly suggested that the experiment be relocated to an area that was distant from population areas and active fisheries. The Johnson or Wake Island vicinity, or other areas that had already been "desecrated," were suggested as possible alternatives.
- They reiterated that the Kalaoa-Ke hole Fisheries (which they characterized as extending from the shore to six and more miles at sea) are of traditional and customary significance and said that they are cultural resources that are highly valued by the native families of the lands. They also said that the fisheries are not only of past traditional and customary value, but remain the most significant small boat fishery in Hawai‘i today.
- One of those present described the fisheries and ocean as a part of a sacred landscape, a feature of religious significance, dedicated to Kanaloa and other *akua* that he calls upon.
- Those present expressed concern that the effects of the experiment on the fisheries could not be established with enough certainty for them to be comfortable. They cited the unpredictable effects of the strong and variable currents in the area and concerns about potential impacts on the micro-organism-plankton life forms that are the foundation of the entire food chain (fish to human consumers). By the close of the meeting, the *kama‘ ina* participants remained dissatisfied with the explanations and skeptical about the proposed experiment. They asked who would be responsible if something went wrong, and what could possibly be done to fix it? The project team explained the care that was being taken to begin with the smallest releases and proceed to the highest flow rate only if monitoring showed that it was not having an unexpected adverse effect, but this did not fundamentally change the belief of the *kama‘ ina* who were present that the potential threats outweigh the value of the experiment.

5.4.1.7 Summary of Potential Effects on Traditional Uses and Rights

In summary, the Hawaiian *k puna* and other members of the Hawaiian community who participated in the interviews and meetings believe the area in which the proposed experiment would be conducted is highly significant as a traditional and current fishing ground for native Hawaiians. The most significant cultural/traditional features are the *ko‘a* – fishing grounds/stations at sea, which lie within the boundaries of the project area. Although the frequency of their use may differ between generations and fishing objectives, knowledge about them and their significance has carried into the present times. The most significant cultural practice is fishing – through time this has ranged from being subsistence-based to a highly valued sport. It is also a common commercial activity in the project area. The most significant aspect of the cultural lore, as it pertains to the physical uniqueness

ask questions, invitations were not widely distributed. At the same time, the team followed a policy of leaving attendance open (i.e., of excluding no one). Mr. Curtis Tyler III, the county council member representing North Kona, also attended.

of the project area, is knowledge about the currents. Lastly, the *k puna* themselves are a highly valued cultural resource.

While this may not be the only grounds for highly valued fish such as *aku*, *ahi* and ‘ *pelu*, on the island of Hawai‘i, it has continued to be the preferred fishing grounds from traditional to modern times for these and other fish. The *k puna* also believe that it is connected, largely by association, to a larger repertoire of traditions and practices associated with the lands of the area. The interviews indicate that, overall, there is strong sentiment against the proposed project.

More specifically, the organizations and individuals who were contacted stated that the area is a highly valued fishing ground, and there is great concern about the impact that the proposed experiment might have on this fishery. These concerns are related to the entire food chain, not simply the species that are commercially exploited or used for subsistence. The worry stems in part from the “unknowns” associated with the experiment. In the absence of knowledge about the proposed project, the idea of an “experiment” increases doubts and questions about its possible effects. Native Hawaiians speaking about the experiment express the belief that it does not need to be conducted off Ke hole Point in particular or in Hawaiian waters in general. Some of the misgivings appear to be related to perceived adverse effects of past activities within the NELHA research corridor.

Generally, all waters extending seaward for 5-6 miles from the coastline were identified as traditional fishing areas. This encompasses an area that is routinely exploited by native and non-native Hawaiians and visitors for commercial fishing and other marine recreational activities. No specific features were identified in the area where the experiment would be conducted. The ocean activities required for implementation of the proposed experiment would not restrict continued exercise of traditional fishing by native Hawaiians. The vessels required for the experiment would be typical of vessels that pass through the waters within the large traditional fishing area and would be stationed at the site proposed for the experiment for a maximum period of two weeks.

The concerns expressed by native Hawaiians regarding potential effects on the fisheries in their traditional fishing areas are elements of the overall concern for potential effects on marine life, which are described in Section 5.3.2. An analysis of the relationship between ocean currents in the proposed test area and the releases of carbon dioxide is presented in Section 5.1.1.1.3.

5.4.2 GENERIC OCEAN SITE

In general, traditional uses of the deep sea are confined to fishing. The *Field Experiment* would constrain fishing operations in the immediate vicinity of the release while the tests would be performed, due simply to the presence of the research vessels. Information from any seafloor surveys at an alternate generic ocean site would be reviewed to determine the likelihood of any potential effects on historic resources. Shipwrecks and other officially designated unique and special historic or cultural sites would be avoided in the design of a *Field Experiment*.

5.4.3 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE’s withdrawal from the international agreement under which the *Field Experiment* would be conducted, no effects on historic and cultural resources or traditional uses would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on historic and cultural resources or traditional uses would be similar to those presented for the Ocean Research Corridor.

5.5 EFFECT ON AIR QUALITY & CLIMATE

5.5.1 PROJECT ELEMENTS WITH POTENTIAL TO IMPACT CLIMATE OR AIR QUALITY

5.5.1.1 Vessel Operations

The vessels used in the *Field Experiment* would produce air emissions from their power plants. These vessels would comply with appropriate U.S. regulations, as well as the Diesel Engine Requirements contained in Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).

5.5.1.2 Planned Emissions and Releases

None of the liquid CO_2 discharged on the seabed would be expected to escape into the atmosphere. Hence, the *Field Experiment* would not have the potential to affect air quality.

The more important aspect of the *Field Experiment*'s potential effect on air quality is associated with the contribution that the experiment would make to an understanding of the ability of the oceans to assimilate anthropogenic CO_2. As previously discussed in Sections 3.1 through 3.3, the fundamental purpose of the *Field Experiment* would be to investigate at a small-scale one potential method for mitigating the potential climatic effects of atmospheric emissions of CO_2.

5.5.1.3 Accidental Releases & Discharges

If the discharge tubing ruptures near the sea surface, a maximum of about one metric ton (1.1 short ton) of CO_2 could potentially be released to the atmosphere over a short period. Possible effects of this release are discussed below (Section 5.5.2.3). If the rupture occurs deeper, the CO_2 would not reach the surface and would not, therefore, affect air quality.

5.5.2 AIR QUALITY & CLIMATE EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.5.2.1 Effect of Vessel Operations

The air emissions from the research vessels would be a very small percentage of the emissions expected from the normal vessel traffic in the area. At least eleven large (>50 feet) charter boats operate out of Honok hau Harbor alone (the closest harbor to the Ocean Research Corridor), and at least one fishing tournament is held each month (Kona Sportfishing Promotional Group 2000). Substantial numbers of smaller boats operate from Honok hau Harbor and from other locations along the Kona Coast. The U.S. Army Corps of Engineers (COE 1996) reported 734 vessel arrivals (not including domestic fishing boats) in 1996 (the latest available report) at Kawaihae Harbor, just to the north of the Ocean Research Corridor. The emissions from the research vessels would have no substantial effect on air quality.

5.5.2.2 Anticipated Effects of the *Field Experiment*

As noted above, none of the CO_2 released during the planned *Field Experiment* would reach the surface. Instead, the CO_2 would be expected to dissolve completely into the deep seawater and not affect air quality.

5.5.2.3 Potential Effects of Accidental Releases & Discharges

As discussed in Section 5.5.1.3, an accidental rupture of the discharge tubing could release about 1.6 cubic yards (1.25 m^3, approximately 1 metric ton) of CO_2 at the surface. If this release would occur on the ship, CO_2 would vent under high pressure. This quantity would be too small to have an adverse effect on general air quality.[34] Hence, the only real concern would be for a slow leak that

[34] To place this in perspective, the largest possible amount that the experiment could release into the atmosphere represents approximately 0.02% of the present average daily man-made CO_2 emissions on the Big Island (DBEDT and DOH

would allow CO_2 to build up without awareness by the ship's crew. Standard precautions taken in maintaining and monitoring high-pressure tanks aboard a ship would be sufficient to reduce this threat to a minor level.

5.5.3 GENERIC OCEAN SITE

The air-quality effects of vessel operations during the *Field Experiment* and accidental releases for a generic ocean site would be expected to be the same as those predicted for the Ocean Research Corridor site.

5.5.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, then no effects on air quality would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on air quality would be similar to those presented for the Ocean Research Corridor.

5.6 NOISE AND VIBRATION EFFECTS

5.6.1 PROJECT ELEMENTS WITH POTENTIAL TO CAUSE NOISE AND VIBRATION

5.6.1.1 Vessel Operation and Oceanographic Data Acquisition

Noise would be generated from research vessels used during the *Field Experiment*. Diesel generators and ships' engines, winches and other handling gear, ROV or submersible servos and electric motors, and acoustic telemetry devices would all create noise during conduct of the *Field Experiment*.

Open ocean ambient noise levels range from 74-100 dB (broadband power levels in 20-1000 Hz, reference 1 µPa @ 1 m; Federation of American Scientists, 1998). Sound energy measured from a purse seiner fishing boat, a vessel likely to be of similar size to the research ships to be used in the *Field Experiment*, was 120 dB while underway, concentrated below 2 kHz with a strong peak at 360 Hz. Noises from other equipment associated with the *Field Experiment* would be emitted at lower decibel levels. Normal noise levels from speedboats reach 120 to 125 dB with the strongest peak at about 2 kHz. Propeller boats at chase speeds cause the sound to pulsate and to reach a maximum of 130 dB (Awbrey *et al*. 1977). The speedboat sound levels are likely to be similar to many of the recreational and fishing boats to be expected in the NELHA Research Corridor. A tug pulling a fully loaded barge into Kawaihae Harbor might have a source level of about 170 dB (Richardson *et al*. 1995).

5.6.1.2 Experimental Discharge

The CO_2 discharge would not be expected to produce high levels of noise, either on the sea-surface site or at the seafloor discharge site, since the release would consist of a liquid being discharged into another liquid medium. The acoustical energy produced by these activities would consist principally of noise from vibrations of the nozzle, extension and recovery of the tubing, and operation of surface valves and pumps associated with the delivery of liquid CO_2 to the seafloor.

1997). Because of the large amount of CO_2 emitted by the Island's volcanoes, it is only 0.002% of all average daily CO_2 emissions from Big Island sources (USGS 2000).

5.6.2 NOISE & VIBRATION EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.6.2.1 Vessel and Oceanographic Data Acquisition

The activities carried out by the research vessels while acquiring oceanographic data would consist of standard practices that are carried out commonly by research ships worldwide. The engine and equipment noises and the acoustic telemetry systems would all produce relatively low-level sounds that would not carry far through seawater or air. These sounds would be comparable to the noises made by fishing vessels, cargo vessels, and other ships that commonly pass through the area. The noise levels would not be audible on land, and they would not be of the magnitude that has been observed to disturb marine organisms.

5.6.2.2 Experimental Discharge

The high frequency, low-level sounds expected from the discharge system would only be audible within a few hundred yards of the discharge site. Marine life within the immediate vicinity of the discharge would not be expected to be adversely affected by the temporary presence of this noise.

5.6.3 NOISE & VIBRATION EFFECTS AT A GENERIC OCEAN SITE

The equipment and procedures to be used at an alternate site would produce very similar levels and frequencies of sound as those anticipated at the Ocean Research Corridor site. Marine life within the immediate vicinity of the discharge would not be expected to be adversely affected by the temporary presence of this noise.

5.6.4 NOISE & VIBRATION EFFECTS: NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no noise or vibration effects would occur. If the *Field Experiment* was conducted without DOE participation, then the noise and vibration effects would be similar to those presented for the Ocean Research Corridor.

5.7 EFFECTS ON TRANSPORTATION FACILITIES

5.7.1 PROJECT ELEMENTS WITH POTENTIAL TO AFFECT TRANSPORTATION FACILITIES

5.7.1.1 Mobilization and Construction

Fabrication of the tubing, discharge platform and associated deployment machinery would take place at suitably equipped manufacturing facilities. Custom pieces of equipment, such as the discharge platform and other necessary hardware, would be shipped to a staging port for assembly and checkout before being loaded onto the vessels. All shipping would be via commercial carriers. The staging port would be selected to minimize transportation, storage, and vessel transit and lease costs. It would be equipped with lifting equipment adequate to stage the materials dockside. Loading onto the ships would be accomplished using either dockside cranes or the handling gear aboard the vessels.

5.7.1.2 Experimental Activities

Vessels deploying the discharge platform, tubing, and ROV or submersible would have restricted mobility for periods as long as a few days while the platform would be deployed, checked out, and operated. These ships would observe the standard practice of showing the proper signal flags and lights to communicate their situations during these periods. While on site, the vessels would be serviced as necessary only by small craft running in and out from Honok hau or Kawaihae Harbors. These service calls would be expected to be limited to necessary transfers of personnel and delivery of emergency replacements.

5.7.2 TRANSPORTATION AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.7.2.1 Mobilization and Construction

Mobilization and construction activities would be expected to take place at a remote site properly equipped and established to carry out the necessary fabrication, handling, and checkout activities. Because the needed facilities would already exist and the needed activities would be part of the normal course of business at those facilities, only minor effects would be expected to result.

5.7.2.2 Experimental Activities

The *Field Experiment* would be carried out over two weeks or less. The Ocean Research Corridor site would not be in a constricted navigation channel or a major shipping route. Fishing boats frequent the area where the experiment would be conducted. The movement of fishing boats and other vessels operating in the area would be constrained slightly by the need to provide suitable clearance around the research vessels during deployment of the platform. This would not prevent fishing boats and other vessels from carrying out most of their normal activities.

5.7.3 TRANSPORTATION AT GENERIC OCEAN SITE

Mobilization and construction activities would be very similar regardless of the location of the *Field Experiment*. The specific locations of transportation activities at a generic ocean site would be dictated by the particular constraints of schedule, budget, and facility availability posed by the selected site. The effects on transportation corridors at a generic ocean site for the *Field Experiment* would be similar to those expected at the Ocean Research Corridor site.

5.7.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no transportation effects would occur. If the *Field Experiment* was conducted without DOE participation, then the transportation effects would be similar to those presented for the Ocean Research Corridor.

5.8 EFFECTS ON LAND USE

5.8.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND OTHER GENERIC OCEAN SITES

The *Field Experiment* would be conducted using vessels operating well offshore. The limited shore side activities (e.g., project administration) would be conducted using existing facilities. Consequently, no measurable effects on land use would occur from conducting the *Field Experiment* within the Ocean Research Corridor or at a generic ocean site.

The relationship between the project team and NELHA has been established with the full knowledge that sensitive mariculture activities are taking place there. NELH tenants were the first group with which the project held a formal presentation, in August 1999. This took place before an application to host the project was submitted to NELHA. The approval was granted from NELHA in October 1999. The project staff for the *Field Experiment*, in collaboration with NELHA and its tenants, is formulating a specific monitoring plan for the NELH deep-water intake, which would be carried out during the *Field Experiment* CO_2 release activities to ensure that the *Field Experiment* poses no risk to the NELH activities.

5.8.2 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no land use impacts would occur. If the *Field Experiment* was conducted without DOE participation, then the land use impacts would be similar to those for the Ocean Research Corridor.

5.9 AESTHETIC EFFECTS

The *Field Experiment* would not alter landscape or other visual amenities on the land. The vessels conducting the *Field Experiment* would operate well offshore. Consequently, the *Field Experiment* would not have the potential to cause aesthetic impacts.

5.10 SOCIOECONOMIC IMPACTS

5.10.1 PROJECT-RELATED EMPLOYMENT AND BUSINESS ACTIVITY

About $2.4 million U.S. dollars would be directly expended in the State of Hawai‘i for conduct of the *Field Experiment* within the Ocean Research Corridor. About $2 million from this total would be devoted to labor salaries, services, local researchers’ activities, and administrative expenses. In addition, out-of-state expenditures would be made for purchasing some materials (e.g., the tubing).

5.10.2 ADEQUACY OF EXISTING LABOR SUPPLY AND SUPPORT BUSINESSES

Scientific and ship personnel staffing the *Field Experiment* would be employed at existing institutions and organizations. Local businesses would possess more than sufficient capacity to provide the support services that would be needed for any of the alternatives under consideration.

5.10.3 OTHER SOCIOECONOMIC EFFECTS

Since 1970, the catch rate for the Hawaiian International Billfish Tournament (HIBT) has varied significantly from year to year, but there has been no significant drop during that period either in total catch rate or catch per unit effort (Pacific Ocean Research Foundation, 2000). From 1959 to 1994, over 30% of the blue marlin caught in the HIBT were caught in the general vicinity of Ke hole Point (Davie 1995). In 1995, only 7.5% of the HIBT landings were caught in that area (Seki in preparation). Nonetheless, the area remains important to the sport-fishing industry.

As discussed elsewhere in this chapter (for example, Section 5.3.2.2), the *Field Experiment* would not have the potential to affect the fish on which the industry depends and would not constrain fishing activities, except for a short time in the immediate vicinity of the research vessels. Consequently, the *Field Experiment* would not be expected to affect the industry adversely.

Because the *Field Experiment* would not affect the shoreline or nearshore waters, it would not impact shoreline fishing, SCUBA diving, snorkeling, or swimming. The *Field Experiment* would be only of a short duration in a very limited area, and it would not have a substantial effect on sailing or charter boat operations.

Currently, there are no other active ocean-based research programs with the potential for conflict with the *Field Experiment* in the Research Corridor, and the *Field Experiment* would not be expected to have any effect on other research uses of the Corridor. The DUMAND (Deep Underwater Muon and Neutrino Detector) program, which did undertake a number of oceanographic deployments in the area between 1981 and 1995, currently has no field expeditions planned. The *Field Experiment* has no direct relationship with other research programs that have been undertaken in the area in recent years, including the acoustic studies carried out by the U.S. Navy. A new cold-water intake pipe is scheduled for installation in the Research Corridor sometime during 2001. The *Field Experiment* would be scheduled such that there would be no conflict between the two activities.

5.11 EFFECTS ON PUBLIC FACILITIES AND SERVICES

5.11.1 PROJECT-RELATED NEED FOR PUBLIC FACILITIES & SERVICES

In general, the *Field Experiment* would not require the use of any public facilities or services. The only possible exception could occur in the event of a shipboard accident that would require medical treatment. In the unlikely event that such an accident would occur, the type of physical injury that would be expected would almost certainly be similar to injuries that occasionally occur during ship operations. Examples include fractures, contusions, and sprains.

5.11.2 PUBLIC FACILITIES AND SERVICES EFFECTS: NELHA OCEAN RESEARCH CORRIDOR SITE

Existing West Hawai‘i medical facilities are equipped to stabilize patients with injuries of the kinds that could occur during the *Field Experiment* and to provide the care needed until patients could be released or transferred to a larger medical facility for specialized care. Air transport that might be needed to carry patients with severe injuries to the large metropolitan hospitals on O‘ahu would be available.

5.11.3 PUBLIC FACILITIES & SERVICES EFFECTS: GENERIC OCEAN SITE

Access to emergency medical care would vary at alternate sites. At some locations (e.g., Gulf of Mexico), the ready availability of emergency helicopter service would make air transport for emergency medical treatment equivalent to that available in West Hawai‘i. At other locations, the distances to emergency medical facilities, and thus the time delays before treatments, would be greater.

5.11.4 PUBLIC FACILITIES AND SERVICES EFFECTS: NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE’s withdrawal from the international agreement under which the *Field Experiment* would be conducted, no effects on public facilities and services would occur. If the *Field Experiment* was conducted without DOE participation, then the impacts on public facilities and services would be similar to those for the Ocean Research Corridor.

5.12 PUBLIC AND WORKER SAFETY & HEALTH

5.12.1 OVERALL WORKER HEALTH AND SAFETY ISSUES

None of the activities that would be conducted during the *Field Experiment* would have the potential to affect the general safety of the public.

With respect to worker safety, fabrication of the platform, CO_2 storage tank, and tubing that would be used to deliver the CO_2 to the seafloor, and other experimental equipment would involve medium-to-heavy industrial activities. These activities would be carried out in facilities with the proper equipment and procedures, and the contractors would be required to comply with applicable Occupational Safety and Health Administration (OSHA) regulations and other workplace requirements. None of the required manufacturing or assembly activities would be unusually dangerous or hazardous. The CO_2 required for the experiment would be the same type used in many industries and hospitals, would be purchased from existing suppliers, and would not require unusual activities or delivery procedures. Hence, little potential for adverse effects on worker safety and health would result.

Because of the motions imparted by ocean waves, limited on-deck space, and other factors, activities carried out at sea would be inherently more dangerous from the viewpoint of worker safety than the same activities carried out on land. The operators of the research vessels would be accustomed to these risks, however, and would typically require stringent training and safety procedures designed to minimize the additional risk.

5.12.2 SAFETY ISSUES RELATED TO *FIELD EXPERIMENT*-SPECIFIC ACCIDENT AND RELEASE

5.12.2.1 CO_2 Storage Tank

While the liquid CO_2 would be stored under relatively high pressure, the pressure level would be well within the range for tanks commonly used for regular industrial and recreational activities. A SCUBA tank, for example, stores air at approximately 2,300 pounds per square inch, or about seven times the pressure of the CO_2. Thus, the potential for a catastrophic failure would be remote.

If a slow leak was to develop, the transformation of CO_2 from a liquid to a gas would cool the area around the leak, possibly even causing ice to form, which would draw immediate attention to the leak. Hence, there would be little likelihood that CO_2 could escape unnoticed. Even if a leak was to go unnoticed, the fact that the tank would be stored on deck in the open air means that the CO_2 would not collect in occupied spaces. Instead, the CO_2 (which is heavier than air) would spill over the deck and eventually disperse into the atmosphere. Consequently, a storage tank leak would not constitute a hazard to shipboard personnel.

5.12.2.2 Tubing Failure

If the tubing was to fail, the escaping CO_2 could act as a jet, moving the tubing about violently. If a break would occur well below the surface of the ocean, the drag of the water would attenuate the motion of the tubing to the point where it would not be a concern. Consequently, the greatest safety hazard would arise from a possible break several tens of feet from the ship. In this case, gas escaping from the tubing could whip the tubing about, possibly causing an impact to equipment or people on the deck of the ship.

This type of hazard would be similar to the movement that would occur if a cable breaks under tension (as would occur if a line used by a tug to pull a barge breaks). Crews routinely take precautions to keep deck space clear of unnecessary activity under such circumstances, which would reduce the potential for injury. The system used for the *Field Experiment* would minimize the possibility of injury from such an accident by having an automatic cutoff valve that would immediately terminate the flow of CO_2 into the pipe if a rapid depressurization occurs.

5.13 BIODIVERSITY AND ENVIRONMENTALLY SENSITIVE RESOURCES

While ocean waters are considered sensitive environments, as discussed in previous sections of this chapter, the *Field Experiment* would be conducted in (and would affect) a subsurface area that does not contain especially sensitive resources. The activities required for conducting the *Field Experiment* would also not have an adverse effect on biodiversity.

The *Field Experiment* would be conducted well offshore and at a depth of approximately 2,600 feet (800 meters). The changes in water quality that would result from the experiment would be undetectable above a depth of approximately 500 meters and then only close to the *Field Experiment*. Reef-building corals are limited to water depths far above this; hence, no adverse effect on reef-building corals would be possible. Most deep-sea precious corals also occur only at depths above 500 meters. Some, such as the pink coral (*Corallium secundum*), are found at this depth and below. The closest known deep-sea precious coral beds on the west side of Hawaiʻi are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (~300 to 500 meters). No precious corals have been seen during the submersible and ROV inspections of the site. Consequently, the *Field Experiment* would have no potential to affect deep-sea precious corals and would be consistent with the provisions of Executive Order 13089: Coral Reef Protection (see Section 7.1.8).

The *Field Experiment* would take place outside the 100-fathom isobath and beyond the southernmost limit of the Hawaiian Islands Humpback Whale National Marine Sanctuary. As discussed in Section 5.2.1.4, the CO_2 that would be released during the *Field Experiment* would only affect water quality at substantial depths, and the plume would not travel sufficiently far from the point of release to enter the Sanctuary. This means that there would be no potential for substantial adverse effect on the Sanctuary habitat or Humpback whales themselves (see Section 7.1.6).

Over the long term, the information that the *Field Experiment* would be designed to collect would assist in providing a better understanding of the ability of the oceans to assimilate anthropogenic CO_2. This information could be critically important in identifying and developing measures that could slow or prevent anthropogenic climate change. Unchecked, such changes would have far greater potential to reduce biodiversity and disrupt environmentally sensitive resources than would the *Field Experiment.*

5.14 ENVIRONMENTAL JUSTICE

5.14.1 APPLICABLE REQUIREMENTS (EXECUTIVE ORDER 12898)

Executive Order 12898 is intended to make achieving environmental justice part of the mission of Federal agencies by requiring agencies to identify and address, as appropriate, the potential for disproportionately high or adverse human health or environmental effects on minority or low-income populations.

5.14.2 COMPLIANCE SUMMARY

The *Field Experiment* would be conducted well offshore in deep ocean waters. No minority populations reside in the area. Members of minority groups do fish within the Ocean Research Corridor and might fish at another ocean site. The *Field Experiment* would not involve activities that would have an adverse effect on persons in the area. In view of the foregoing, the *Field Experiment* would be consistent with Executive Order 12898. No disproportionately high or adverse effects on minority or low-income populations would result from the proposed action.

5.15 SUMMARY OF POLLUTION PREVENTION MEASURES

5.15.1 FEATURES INCORPORATED IN THE FUNDAMENTAL EXPERIMENTAL DESIGN

Efforts to minimize the potential for pollution began at the outset of defining the concepts for a *Field Experiment* and have continued throughout the evaluation and definition of those concepts. The goal of these efforts was to identify pollution-limiting approaches and to integrate these approaches into plans for the *Field Experiment*. To achieve this goal, the following tenets were established:

- The experiment would be designed to use the smallest possible amount of CO_2 consistent with achievement of the scientific objectives. Thus, the 44-66 short tons (40-60 metric tons) included in the preliminary plan for the experiment is considerably less than the amount (100 to 300 metric tons) initially considered as being required to achieve scientific objectives.
- The duration of the experiment has been shortened from the month-long series of tests that was originally envisioned to 10 to 14 days.
- Individual test releases of CO_2 would be limited to the smallest rates (1.6 to 16 gallons per minute) and the shortest durations (2 hours) possible while still providing some assurance that the required scientific measurements could be made.

- The experimental concept would include consideration of an advanced, vessel-based deployment system that would eliminate the need to construct and operate a pipeline through a nearshore environment.
- Test facilities used for the experiment would be completely removable at the conclusion of the testing.

5.15.2 ADDITIONAL POLLUTION PREVENTION MEASURES

The computer modeling that has been done by scientists from around the world using a variety of computer models and data sources provides reasonable assurance that the water quality effects of the experiment would fall within the predicted envelope. As with any enterprise designed to expand scientific understanding of natural processes, some uncertainty remains.

Because of this uncertainty, the experimental plan (see Appendix C) would require real-time monitoring of the releases. While complete details of this monitoring program are still being developed, the program would include items such as: (1) pH monitors to determine if a release reduces pH to a greater or lesser extent than anticipated; and (2) visual observations of the release platform and surrounding waters to indicate if megafauna are being acutely affected by the release.

The experiment would involve the use of a high-pressure system for the CO_2. Pressure sensors connected to automatic shut-off valves would constantly monitor the system. If an unexpected loss of pressure would be detected, the sensors would send a signal that would immediately close the valves. This would limit the amount of CO_2 that could be released to only slightly more than the amount present in the pipeline.

The State Department of Health (DOH) has determined that the release would be subject to Hawai‘i Administrative Rules Section 11-54 (Water Quality Standards) and Section 11-55 (Water Pollution Control). DOH has indicated that due to the research nature of the *Field Experiment* and the fact that the release would be intermittent and of short duration, the requirement for an NPDES permit may be waived under certain conditions. One of those conditions would be the submission to, and approval by, DOH of a satisfactory monitoring program for the *Field Experiment*. The DOH-approved program would be expected to identify specific control measures and to make them legally enforceable.

As previously noted, shipboard personnel would be briefed on the characteristics and risks associated with the high pressure CO_2 system. At the first indication of an unintentional release, the CO_2 holding tank would be secured.

The research ships and the vessel that would deploy the discharge system would notify the U.S. Coast Guard immediately should any spills of petroleum products occur.

Public notices concerning the planned experiment would be published before the beginning of the experiment. Information concerning the timing and nature of project-related ship movements would be included in these notices. If possible, the notices would be posted at the Honok hau small boat harbor and at other locations from which boat operators might begin operations requiring use of waters within the NELHA Ocean Research Corridor.

6.0 CONSISTENCY WITH FEDERAL, REGIONAL, STATE, & LOCAL LAND USE PLANS, POLICIES, & CONTROLS

6.1 NELHA OCEAN RESEARCH CORRIDOR SITE

6.1.1 CONSISTENCY WITH LOCAL LAND USE PLANS, POLICIES, & CONTROLS

The NELHA Ocean Research Corridor site is outside the jurisdiction of the County of Hawai‘i. Hence, there are no applicable local land use plans, policies, or controls.

6.1.2 CONSISTENCY WITH STATE LAND USE PLANS, POLICIES, & CONTROLS

The NELHA Ocean Research Corridor site is located within the Conservation District (Figure 4-1). The State of Hawai‘i Department of Land and Natural Resources (DLNR) has determined that a Conservation District Use Permit would not be needed for the *Field Experiment* because of its temporary nature of less than fourteen days on the seafloor. The use of this area for the *Field Experiment* would be consistent with the overall purpose of the approved Ocean Research Corridor, which is intended for activities that include temporary ocean research.[35]

6.1.3 CONSISTENCY WITH FEDERAL LAND USE PLANS, POLICIES, & CONTROLS

There are no Federal land use policies covering the proposed NELHA Ocean Research Corridor site.

6.2 OTHER GENERIC OCEAN SITES

6.2.1 CONSISTENCY WITH LOCAL LAND USE PLANS, POLICIES, & CONTROLS

Local jurisdiction typically ceases at the shoreline. Consequently, all of the other locations at which the *Field Experiment* could be conducted would also be outside local jurisdiction.

6.2.2 CONSISTENCY WITH LAND USE PLANS, POLICIES, & CONTROLS OF STATES OR FOREIGN NATIONS

Generic ocean sites at which the *Field Experiment* could be conducted may be subject to controls by other State or National jurisdictions. Should the research be conducted at one of these locations, DOE and other project sponsors would work with the entities having jurisdiction to insure that the project would be consistent with applicable plans, policies, and controls.

6.3 NO ACTION ALTERNATIVE

If the *Field Experiment* is not carried out, no concerns about consistency would exist. If the *Field Experiment* would occur without DOE participation, the same consistency criteria for the project site would apply. That is, acceptability of any site would depend on the *Field Experiment* being consistent with the existing land use plans, policies, and controls that apply to that site.

[35] The existence of the Ocean Research Corridor and the oceanographic and environmental data that have been collected within the Corridor are among the factors that influenced interest in this location.

7.0 COMPLIANCE WITH OTHER REGULATIONS

7.1 FEDERAL REQUIREMENTS

The *Field Experiment* would be planned and conducted in compliance with the National Environmental Policy Act (NEPA). The *Field Experiment* would also be subject to review under several other Federal regulations. These include:

- Section 401 of the Federal Clean Water Act;
- Section 402 of the National Pollutant Discharge Elimination System;
- Department of the Army Permit, for activities subject to regulation under Section 404 of the Federal Clean Water Act and Section 103 of the Marine Protection, Research, and Sanctuaries Act;
- Section 106 of the National Historic Preservation Act of 1966;
- Section 7 of the Endangered Species Act of 1973, as amended;
- Provisions of the Fish & Wildlife Coordination Act; and
- National Invasive Species Act of 1996.

7.1.1 NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

This Environmental Assessment (EA) has been prepared in conformance with NEPA. The EA was developed through a process of internal and public scoping and consultation with cognizant Federal, State, and local officials. DOE and other project participants also coordinated with resource management agencies and members of the public following publication of a draft EA to determine their concerns. In accordance with the tenets of NEPA, development of concepts for the *Field Experiment* has been substantially modified in response to suggestions that have been received. These changes included suspending consideration of shore-based alternatives that would have required a pipeline through nearshore waters, reducing the anticipated number of pipeline deployments and increasing the ecological monitoring component of the planned tests.

7.1.2 SECTION 401 OF THE FEDERAL CLEAN WATER ACT AND SECTION 402 OF THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

The Federal government has delegated responsibility for enforcing the Clean Water Act and handling National Pollutant Discharge Elimination System (NPDES) permits to the State Department of Health. Compliance with these regulations is discussed in Section 5.2.1.6 and Section 7.2.1.

7.1.3 DEPARTMENT OF THE ARMY PERMIT

The U.S. Army Corps of Engineers has determined that the *Field Experiment* would not require a Department of the Army permit (see letter in Appendix G).

7.1.4 NATIONAL HISTORIC PRESERVATION ACT OF 1966; NATIVE AMERICAN GRAVES PROTECTION AND REPATRIATION ACT OF 1990

A Federal review process, administered by the National Advisory Council on Historic Preservation and the State Historic Preservation Officer, has been established to ensure significant historic properties are considered during Federal project planning and execution. In accordance with guidance issued for that process, the State Historic Preservation Division of the Department of Land and Natural Resources, the Office of Hawaiian Affairs (OHA), and Hui M lama I Na K puna O Hawai'i Nei ("Hui M lama") were contacted about conducting the vessel-based *Field Experiment* at the NELHA Ocean Research Corridor site. The purpose of these consultations was to identify potential effects of the *Field Experiment* on significant historic, cultural, or religious properties.

The Office of Hawaiian Affairs is a semi-autonomous, "self-governing body" authorized by Chapter 10 of Hawai‘i Revised Statutes. OHA was established as a public trust, mandated to better the conditions of native Hawaiians and the Hawaiian community. OHA is funded with a *pro rata* share of revenues from state lands designated as "ceded" – such as NELHA's Ocean Research Corridor. Hui M lama is a private, not-for-profit native Hawaiian organization dedicated to the proper treatment of ancestral native Hawaiians. In the enabling legislation, the U.S. Congress explicitly cites these two organizations as examples of the kinds of organizations that should be considered as possible consulting parties for both the National Historic Preservation Act (36 CFR §800) and the Native American Graves Protection and Repatriation Act (25 CFR §3001). As mentioned in Section 3.4.3 and Section 3.4.4, and discussed further in Appendix B, the extensive public participation program that has been initiated in conjunction with planning for the *Field Experiment* is a further effort to insure that individuals with special concerns about potential impacts on historic, religious, or cultural resources are able to make their concerns known.

As described in Section 5.4 of this EA, the State Historic Preservation Division has confirmed there is no record, and little likelihood, of historic properties in the offshore area proposed for the *Field Experiment*. Review of other environmental documentation for the area does not indicate the presence of physical remains that might be of cultural or historic concern in areas that could be affected by the proposed activities, so long as activities would be restricted to the offshore site (HURL 1991, 1999).

The *Field Experiment* project team initially contacted the OHA Trustee for the Island of Hawai‘i on July 7, 1999. In OHA's July 13, 1999 response, the agency stated the letter and information had been forwarded to their Land and Natural Resources Division for review. No further correspondence from OHA was received at that time. Once the decision to pursue a vessel-based experiment was made (March 2000), the project team notified OHA regarding the project change and requested further consultation. No formal response was received prior to the publication of the draft EA.

Beginning in late August, project team members held various meetings with OHA and exchanged letters and information (see Appendix G). The results of this correspondence are discussed in the impact analysis for Historical and Cultural Resources (Section 5.4.1) and in a Cultural Impact Assessment Study, presented in Appendix F.

7.1.5 OTHER KEY RULES ADMINISTERED BY THE U.S. FISH & WILDLIFE SERVICE AND THE NATIONAL MARINE FISHERIES SERVICE

In compliance with the Section 7 of the Endangered Species Act and the Fish and Wildlife Coordination Act, DOE consulted with the U.S. Fish & Wildlife Service and with the National Marine Fisheries Service during preparation of the Environmental Assessment. The written correspondence from this consultation is reproduced in Appendix G. DOE has confirmed that, in conducting the *Field Experiment*, it would comply with the Migratory Bird Treaty Act (16 USC, Section 703 *et seq.*) and with the National Invasive Species Act of 1996 (Public Law 104-332). The *Field Experiment* activities would be short-term, localized, and focused primarily on the deep seabed at water depths of about 2,600 feet. These activities would not substantially affect threatened, endangered, or migratory birds or the marine food chains that help support these species. As outlined in Section 5.2.1.5, ships used for the *Field Experiment* would comply with all applicable laws and regulations designed to prevent the introduction of exotic species into coastal marine waters.

DOE has contacted the National Marine Fisheries Service (NMFS) concerning potential effects on sea turtles and other listed species under its jurisdiction. Potential effects on Humpback whales are discussed in Section 7.1.6. DOE submitted an Essential Fish Habitat Assessment to the NMFS in accordance with requirements of the 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (Public Law 94-265).

As discussed in Section 5.3.2.2.2, the threatened or endangered species in the vicinity of the planned *Field Experiment* are all air-breathers (reptiles and mammals) that are not normally found at depths that would experience changes in water quality. Even if these animals were to reach such depths, their need to return to the surface to breathe would severely limit the time during which they would be exposed to reduced pH. In addition, because they are air breathing, CO_2 would not be exchanged across their respiratory membranes (see Section 5.3.2.2.2). The pH levels of the *Field Experiment* would not be expected to be caustic to their body surfaces because of the relatively low expected acidity and persistence. Hence, they would be very unlikely to be affected.

Collisions with ships or the transport pipe would be more likely to harm these organisms. Pipe collision would be relatively unlikely especially for the sonar capable Odontoceti. Ship collision is a known source of mortality for sea turtles and marine mammals, but usually only when the ships are moving. Spotters would be on duty during ship transits to minimize the potential for such collisions.

7.1.6 OCEAN DUMPING ACT

The Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) has two basic aims: to regulate intentional ocean disposal of materials and to authorize related research. Title I of the Act, which is often referred to as the Ocean Dumping Act, contains permit and enforcement provisions for ocean dumping. Passed in 1972, the Act provides a framework for managing ocean dumping activities and for conducting basic oceanic research. The law bans ocean dumping of radiological, chemical, and biological warfare agents and high-level radioactive wastes. Amendments in 1988 extended this ban to sewage sludge, industrial wastes, and medical wastes. The law provides a mechanism for meeting U.S. commitments under the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters, an international ocean dumping treaty signed by 80 countries. The Act authorizes research on the effects of ocean dumping, pollution, over-fishing, and other human-induced stressors, including oil spills.

The experimental release of CO_2 for scientific research that is proposed as part of the *Field Experiment* is not believed to fall within the definition of “dumping” as defined in 40 CFR Part 220.2.[36] If activities proposed under the *Field Experiment* are determined to be regulated by the Ocean Dumping Act, however, a research permit would be pursued.

7.1.7 COAST GUARD REGULATIONS

Research vessels for the *Field Experiment* would be equipped with U.S. Coast Guard-approved marine sanitation devices (33 CFR 159) to preclude unauthorized discharges of sanitary wastes. The research vessels would comply with all applicable U.S. Coast Guard safety procedures and required navigational lighting and day shapes for operating vessels in restricted maneuverability and at night. Research vessels would comply with U.S. Coast Guard regulations (33 CFR 151) and other applicable Federal and State of Hawai‘i laws and regulations for the management of bilge and ballast water to minimize pollution and the introduction of non-indigenous or exotic species into U.S. waters.

7.1.8 EXECUTIVE ORDER 13089: CORAL REEF PROTECTION

In 1998, the President issued Executive Order 13089: Coral Reef Protection.[37] Its purpose is to preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral

[36] …It [ocean dumping] does not mean the … intentional placement of any device in ocean waters or on or in the submerged land beneath such waters, for a purpose other than disposal, when such construction or such placement is otherwise regulated by Federal or State law or occurs pursuant to an authorized Federal or State program.

[37] The Executive Order is intended to support the purposes of various U.S. laws and regulations. These include the Clean Water Act of 1977, as amended (33 USC. 1251, *et seq.*), Coastal Zone Management Act (16 USC. 1451, *et seq.*), Magnuson-Stevens Fishery Conservation and Management Act (16 USC. 1801, *et seq.*), National Environmental Policy Act of 1969, as amended (42 USC. 4321, *et seq.*), and National Marine Sanctuaries Act (16 USC. 1431, *et seq.*).

reef ecosystems and the marine environment. It defines coral reef ecosystems as those species, habitats, and other natural resources associated with coral reefs in all maritime areas and zones subject to the jurisdiction or control of the United States (e.g., Federal, State, Territorial, or commonwealth waters), including reef systems in the south Atlantic, Caribbean, Gulf of Mexico, and Pacific Ocean.

The Executive Order requires Federal agencies whose actions may affect U.S. coral reef ecosystems to:

- Identify actions that may affect U.S. coral reef ecosystems;
- Utilize their programs and authorities to protect and enhance the conditions of such ecosystems; and
- Ensure (to the extent permitted by law) that any actions they authorize, fund, or carry out will not degrade the conditions of such ecosystems.

The *Field Experiment* would be conducted well offshore at a depth of approximately 2,600 feet (800 meters). The changes in water quality that would result from the experiment would be undetectable above a depth of approximately 500 meters and, then, only close to the *Field Experiment*. Reef-building corals are limited to water depths far above this and occur only well beyond distances where dispersion of releases from the experiment could have an effect. No adverse effect on reef-building corals would be possible.

Most deep-sea precious corals also occur only at depths above 500 meters. Some, such as the pink coral (*Corallium secundum*), are found at this depth and below. The closest known deep-sea precious coral beds on the west side of Hawai‘i are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (~300 to 500 meters). The *Field Experiment* would have no potential to affect deep-sea precious corals and would be consistent with the provisions of Executive Order 13089: Coral Reef Protection.

7.1.6 HAWAIIAN ISLANDS HUMPBACK WHALE NATIONAL MARINE SANCTUARY

The waters around the main Hawaiian Islands constitute one of the world’s most important North Pacific Humpback whale (*Megaptera novaeangliae*) habitats. These waters are the only place in the United States where Humpbacks reproduce. Scientists estimate that two-thirds of the entire North Pacific Humpback whale population (approximately 4,000-5,000 whales) migrates into Hawaiian waters to breed, calve, and nurse. While in Hawai‘i, usually between November and May with a peak season in January and February, Humpback whales are most often found in shallow coastal waters, at depths usually less than 300 feet (~100 meters).

The U.S. Congress, in consultation with the State of Hawai‘i, designated the Hawaiian Islands Humpback Whale National Marine Sanctuary on November 4, 1992. This designation was finalized with the formal approval by Hawai‘i Governor Ben Cayetano on June 15, 1997. The Hawaiian Islands National Marine Sanctuary Act is intended to:

- Protect Humpback whales and their habitat within the Sanctuary;
- Educate and interpret for the public the relationship of Humpback whales and the Hawaiian Islands marine environment;
- Manage human uses of the Sanctuary consistent with the Hawaiian Islands National Marine Sanctuary Act and the National Marine Sanctuary Act; and
- Provide for the identification of marine resources and ecosystems of national significance for possible inclusion in the Sanctuary.

The National Marine Sanctuary regulations are found at 15 CFR 922. As defined by Section 922.181, the Hawaiian Islands Humpback Whale National Marine Sanctuary consists of the submerged lands and waters off the coast of the Hawaiian Islands seaward from the shoreline, cutting across the mouths of rivers and streams. In the waters off the Big Island, the Sanctuary extends from ‘Upolu Point southward to Ke hole Point, where it ends to the north of the Ocean Research Corridor site. The Sanctuary extends from the shoreline to the 100-fathom (600 feet or ~183 meters) isobath.

The regulations make it unlawful for any person to conduct or cause to:

- Approach within 100 yards of any Humpback whale except as authorized under the Marine Mammal Protection Act (MMPA);
- Operate any aircraft above the Sanctuary within 1,000 feet of any Humpback whale except as necessary for takeoff or landing from an airport or runway, or as authorized under the MMPA and the Endangered Species Act (ESA);
- Take any Humpback whale in the Sanctuary except as authorized under the MMPA and the ESA;
- Possess within the Sanctuary (regardless of where taken) any living or dead Humpback whale or part thereof taken in violation of the MMPA or the ESA;
- Discharge or deposit any material or other matter in the Sanctuary;
- Alter the seabed of the Sanctuary; or
- Discharge or deposit any material or other matter outside the Sanctuary if the discharge or deposit subsequently enters and injures a Humpback whale or Humpback whale habitat.

The *Field Experiment* would take place well outside the 100-fathom isobath and beyond the limit of the Hawaiian Islands Humpback Whale National Marine Sanctuary. As discussed in Section 5.2.1.4, the CO_2 that would be released during the *Field Experiment* would only affect water quality at substantial depths, and the plume would not travel sufficiently far from the point of release to enter the Sanctuary. This means that there would be no potential for adverse effect on the Sanctuary habitat or Humpback whales themselves.

7.1.7 COASTAL ZONE MANAGEMENT PROGRAM

Hawai‘i’s Coastal Zone Management (CZM) Program is carried out in accordance with the National Coastal Zone Management Act of 1972, as amended, and with Chapter 205A, Hawai‘i Revised Statutes. In Hawai‘i, the coastal zone includes the water seaward from the shoreline to the seaward limit of the State’s jurisdiction. The Ocean Research Corridor site would be located within this coastal zone.

The National Coastal Zone Management Act requires Federal activities and development projects to be consistent with approved State coastal programs to the maximum extent practicable. Also, Federally permitted, licensed, or assisted activities occurring in, or affecting, the State’s coastal zone must be in agreement with Hawai‘i’s CZM Program objectives and policies. Federal agencies cannot act without regard for, or in conflict with, State policies and related resource management programs that have been officially incorporated into the State CZM program.

DOE funding for the experiment is not subject to formal CZM consistency review. Nonetheless, the experiment’s consistency with the program’s ten policy areas has been evaluated. The results are summarized below. Each of the ten objectives is presented in italics. This is followed by a discussion of the project’s consistency with that objective.

<u>Recreational Resources Objective</u>: *To provide coastal recreational opportunities accessible to the public and protect coastal resources uniquely suited for recreational activities that cannot be provided elsewhere.* The *Field Experiment* would not harm coastal recreational resources. It would not have an adverse effect on marine biological communities relevant to recreation. The presence of research vessels within NELHA’s Ocean Research Corridor for a period of 10 to 14 days would not interfere with fishing or other recreational uses of this area.

Historic Resources Objective: *To protect, preserve, and where desirable, restore those natural and manmade historic and prehistoric resources in the coastal zone management area that are significant in Hawaiian and American history and culture.* There are no historic or cultural sites in areas that might be affected by project-related activities. Native Hawaiians have expressed concern about the *Field Experiment*'s effects on traditional and current fishing grounds at the Ocean Research Corridor site.

Scenic and Open Space Resources Objective: *To protect, preserve, and where desirable, restore or improve the quality of coastal scenic and open space resources*. The proposed activities would not have the potential to affect these resources.

Coastal Ecosystems Objective: *To protect valuable coastal ecosystems, including reefs, from disruption and minimize adverse impacts on all coastal ecosystems*. As discussed in detail in Section 5, the proposed activities would not have the potential to alter water quality or otherwise modify the marine environment sufficiently to have an adverse effect on these resources.

Economic Uses Objective: *To provide public or private facilities and improvements important to the State's economy in suitable locations and ensure that coastal dependent development such as harbors and ports, energy facilities, and visitor facilities, are located, designed, and constructed to minimize adverse impacts in the coastal zone area.* The proposed activity is not related to this objective.

Coastal Hazards Objective: *To reduce hazard to life and property from tsunami, storm waves, stream flooding, erosion, subsidence, and pollution.* The proposed activity is not related to this objective.

Managing Development Objective: *To improve the development review process, communication, and public participation in the management of coastal resources and hazards.* The proposed activity is not related to this objective.

Public Participation Objective: *To stimulate public awareness, education, and participation in coastal management; and maintain a public advisory body to identify coastal management problems and provide policy advice and assistance to the CZM program.* The proposed activity is not related to this objective.

Beach Protection Objective: *To protect beaches for public use and recreation; locate new structures inland from the shoreline setback to conserve open space and to minimize loss of improvements due to erosion.* The proposed project would not have the potential to adversely affect beaches or other shoreline areas that are used for recreational purposes.

Marine Resources Objective: *To implement the State's ocean resources management plan.* The proposed activity is not related to this objective.

7.1.8 OCEANS ACT

The Oceans Act of 2000 (Public Law 106-256; effective date January 20, 2001) was enacted on August 7, 2000, for the purpose of developing a coordinated and comprehensive national ocean policy. Included among the policy objectives that will be pursued under the Act are actions to promote the following:

- Protection of the marine environment and prevention of marine pollution;
- Expansion of human knowledge of the marine environment, including the role of the oceans in climate and global environmental change; and
- Preservation of the role of the United States as a leader in ocean and coastal activities and, when in the national interest, cooperation by the Unites States with other nations and international organizations in ocean and coastal activities.

Policy development activities will be based on equal consideration of environmental, technical feasibility, economic, and scientific factors. Under the Act, a 12-member Commission on Ocean

Policy that will be appointed by the President in 2001 will develop policy recommendations. This Commission, in developing ocean policy recommendations, could potentially benefit from technical and environmental information resulting from the proposed *Field Experiment*.

7.2 STATE REQUIREMENTS

Conducting the *Field Experiment* at the NELHA Ocean Research Corridor site would make it subject to certain State regulations. These include Chapters 11-54 (Water Quality Standards) and 11-55 (Water Pollution Control) of the Hawai‘i Administrative Rules and the Historic Preservation requirements established by Chapter 6E, Hawai‘i Revised Statutes.

7.2.1 STATE WATER QUALITY REGULATIONS

Project personnel have met with the State Department of Health (DOH) to discuss issues relating to water quality should the *Field Experiment* be conducted at the location off Ke hole Point. DOH determined that the release of CO_2 would constitute an activity subject to Chapter 342D of Hawai‘i Revised Statutes and Hawai‘i Administrative Rules (HAR), Section 11-54 (titled Water Quality Standards) and Section 11-55 (titled Water Pollution Control). The Department concluded that the requirements for an NPDES permit might be waived if certain conditions are met. This tentative determination took into consideration that the proposed action would constitute a research project, would be located within the Ocean Research Corridor, would involve a discharge that would be both intermittent and of short duration, and would be conducted under proper control. The conditions noted in DOH’s letter include:

- Being consistent with the purposes of the NELHA Ocean Research Corridor.
- Compliance with the State’s Anti-Degradation Policy as specified in HAR Section 11-54-01.1, properly addressing this issue through the processing of environmental impact documentation.
- Consulting with and complying with applicable rules administered by the U.S. Fish & Wildlife Service, National Marine Fisheries Service, and Division of Aquatic Resources of the State Department of Land and Natural Resources.
- Submitting results of preliminary sampling of biota and bacteria populations in the immediate vicinity of the discharge nozzle to the Clean Water Branch.
- Obtaining DOH approval of final plans for the *Field Experiment*.
- Obtaining DOH approval of a monitoring and assessment plan.
- Submitting a final research and study report to DOH upon completion of the *Field Experiment*.

Should the *Field Experiment* be conducted at a Generic Ocean site within areas under State jurisdiction, then a similar review for compliance at that location would be needed before undertaking the project. Other regulations could apply if the *Field Experiment* were conducted elsewhere.

7.2.2 STATE HISTORIC PRESERVATION LAW

Chapter 6E-1, Hawai‘i Revised Statutes (HRS), establishes State regulations for historic and cultural properties, consistent with the National Historic Preservation Act of 1966**,** as amended. Properties of traditional religious or cultural importance are among those that can be determined to be eligible for recognition as historic properties. Such properties include districts, sites, buildings, structures, and objects of significance in American history, architecture, archaeology, engineering, and culture. Chapter 6E-1 notes that the Constitution of the State of Hawai‘i recognizes the value of conserving and developing the historic and cultural property within the State for the public good and makes it public policy to promote the use and conservation of such property for the education, inspiration, pleasure, and enrichment of its citizens.

HRS 6E-5 provides for the Governor to appoint a State Historic Preservation Officer (SHPO). It makes the SHPO responsible for the comprehensive historic preservation program and for being the liaison officer for the conduct of relations with the Federal government and the respective states with regard to matters of historic preservation.

As discussed in Section 7.1.4, DOE and other project participants have consulted with the SHPO. The SHPO has no record of historic sites at the Ocean Research Corridor site and believes that the probability of any kind of historic property at this depth and location seems remote (see consultation letter in Appendix G). DOE and the SHPO agree that the proposed project would most likely have no effect on significant historic sites.

7.3 HAWAI‘I COUNTY REQUIREMENTS

No Hawai‘i County ordinances or regulations are directly applicable to the *Field Experiment*.

7.4 INTERNATIONAL AGREEMENTS

Sites that are within the Territorial waters of nation states (typically at least 12 miles) are not directly subject to the provisions of international agreements. Most of the locations under consideration for the *Field Experiment* fall into this category.

8.0 SECONDARY & CUMULATIVE EFFECTS AND LONG-TERM ENVIRONMENTAL CONSEQUENCES

8.1 SECONDARY (INDIRECT) EFFECTS

Secondary, or indirect, effects are effects caused by actions that occur later in time or farther removed in distance, but which are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

As described in Section 5 of this report, the effects of the *Field Experiment* would be limited to direct short-term perturbations in seawater chemistry and localized impacts on marine biota. The *Field Experiment* would not represent a commitment to larger-scale tests or to actual use of ocean sequestration as a disposal technology. Consequently, no substantial secondary effects are anticipated.

8.2 CUMULATIVE EFFECTS

The Council on Environmental Quality's (CEQ) regulations for implementing the National Environmental Policy Act (NEPA) define cumulative effects as the impact on the environment which results from the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such other actions (40 CFR, Section 1508.7).

No similar activities have taken place at the NELHA Ocean Research Corridor site, no additional similar experiments are planned for that area, and no activities with effects that, when added to the consequences of the proposed action could lead to adverse impacts, are known to be planned by others. Because of this and the fact that the *Field Experiment*'s effects would be localized, there would be no potential for cumulative effects at this location. Due to the unique aspects of the proposed experiment, cumulative effects would also not be expected at a generic ocean site.

8.3 LONG-TERM ENVIRONMENTAL CONSEQUENCES

The *Field Experiment* would be designed to provide needed technical information related to potential mitigation of atmospheric emissions of CO_2. By itself, the *Field Experiment* would have no long-term environmental consequences. If the *Field Experiment* were completed successfully, it would have the potential of providing policymakers and the public with better capability for judging the feasibility and effectiveness of marine CO_2 sequestration. Such enhanced capability would make it more likely that informed and environmentally beneficial policy decisions could be made than would otherwise be possible without the results from the *Field Experiment*. A discussion of the scientific context for the *Field Experiment* is presented in Appendix D.

9.0 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

9.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND GENERIC OCEAN SITE

The principal natural resources affected by the *Field Experiment* would be the deep-sea marine life near the CO_2 discharge. Some fraction of the benthic life in this area would be stressed to an important degree, and some mortality would be expected. Because of rapid recolonization due to mixing with surrounding waters, the effect on organisms inhabiting the water column would likely be very short. To the extent that the benthos would be affected, recovery to background levels of biomass and diversity would take longer. While substantial effects would not be anticipated, the depressed pH level that would result from the CO_2 plume would be expected to kill zooplankton and possibly other fauna within a small area. Even under the worst assumptions, recovery would occur within a period of years.

Emplacements of the discharge platform would likely crush or bury the fauna living on and in the underlying seafloor. The disturbed patches would be expected to return to pre-experiment conditions in periods ranging from a few weeks to a few years. Disturbance on this scale would not cause any long lasting negative impacts to any of the seafloor fauna at the population or species level.

As discussed in Section 5.3.2.1.3, additional areas would be impacted by the repeated deployments of the platform and tubing. The effects caused by the tubing moving over the seafloor would include the obliteration of small-scale sediment features that result from movement, feeding, and defecation by sediment-dwelling animals. Disruptions of this sort are commonly reported effects of trawling, which affects vast tracts of the seafloor in many regions of the world's oceans. While recovery of hard and soft substrate fauna following disturbances would likely require months to several years, the disturbances would not be permanent.

Resources irreversibly and irretrievably committed to the *Field Experiment* would also include research funds and the time, scientific knowledge, and energy of the individuals involved in carrying out the work. Devoting vessel time to the *Field Experiment* would preclude use elsewhere.

As discussed in Chapter 5, deep-sea biological communities are similar over large parts of the ocean floor. Because a vessel-based *Field Experiment* would be carried out essentially the same way at any ocean site, very similar commitments of natural resources would be expected. However, since calm seas and predictable winds would not be nearly so favorable at other sites as at the NELHA Ocean Research Corridor, increased commitments of research funds would probably be required at other locations.

9.2 NO ACTION ALTERNATIVE

No commitments of resources would be predicted if the *Field Experiment* is not conducted due to the withdrawal of DOE participation. The absence of the scientific knowledge that the planned *Field Experiment* would provide could lead to poor decisions that misuse scarce resources. If the *Field Experiment* were carried out in the absence of DOE participation, then the same commitments of resources as required for conduct of the experiment in the Ocean Research Corridor would be expected.

10.0 RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

10.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND GENERIC OCEAN SITE

The *Field Experiment* would occupy a localized area of the seafloor for a period of two weeks or less. After completion of the *Field Experiment*, the research ships, all instrumentation, and discharge equipment would be removed. If the *Field Experiment* is successful in obtaining the data sought, the results could have important implications for future, long-term policy decisions regarding mitigation of atmospheric emissions of CO_2.

The balance between the short-term use of the sea and seafloor and the potentially long-term benefits of the *Field Experiment* would be essentially the same if the *Field Experiment* were conducted at any ocean site. The probability of success for the *Field Experiment* may be lower at a site outside the Ocean Research Corridor, however, due to the superior wind and wave conditions expected at the Ocean Research Corridor site.

10.2 NO ACTION ALTERNATIVE

If the *Field Experiment* is not conducted due to withdrawal of DOE participation resulting from a No-Action decision, there would be no action to consider. If the *Field Experiment* is carried out in the absence of DOE participation, then the balance between short-term uses and long-term productivity of the environment would be the same as that for the Ocean Research Corridor.

11.0 SIMILAR ACTIONS AND ACTIONS BEING CONSIDERED UNDER OTHER NEPA REVIEWS

The proposed action, which would involve participation by the U.S. Department of Energy (DOE) in the conduct of the *Ocean Sequestration of CO_2 Field Experiment*, is not similar to any other action being considered by (or currently being implemented by) DOE and is not a segment of any other action for which review under NEPA would be required.

Many policy options and technological concepts have been identified as possible approaches to address causes of climate change induced by human activity, including carbon taxes, emission caps and emission trading systems, incentive programs to promote changes to low- or zero-carbon emitting technologies, and a variety of geochemical/engineering concepts for mitigating the warming of the atmosphere. Also, geochemical and engineering concepts for reducing carbon emissions would include options such as use of renewable energy sources or fuel switching, improving the efficiencies of systems for both energy supply and energy utilization, and sequestering carbon.

DOE has historically supported research and development projects that focus on creating less carbon-intensive and more efficient methods for generating energy. Although technologies that could result from these activities may help reduce emissions of greenhouse gases, given the importance of developing adequate strategies for mitigating climate change, other approaches, such as carbon sequestration, if successfully developed, may offer additional potential as an option for future consideration in planning strategies for reducing the buildup of greenhouse gases in the atmosphere. As noted in Section 3.2.1, DOE is conducting research to establish an adequate scientific understanding of candidate approaches for carbon sequestration.

DOE has identified several possible concepts to sequester carbon dioxide. However, to validate the feasibility of these options, a knowledge base on the concepts needs to be developed. To establish that knowledge base, research on a variety of concepts must be performed, and such research has been initiated through a number of separate projects to determine the viability of a variety of options for carbon management. The proposed *Ocean Sequestration of CO_2 Field Experiment* is one of those projects.

The purpose of DOE's research on carbon sequestration is to identify and evaluate concepts that could help meet any future challenges potentially resulting from global climate change. This research has been, and continues to be, exploratory in nature, to study the technical merits and to assess the potential economic and environmental consequences of various options for capturing, storing, and reducing emissions of greenhouse gases, particularly carbon dioxide. Sequestration options dealing directly with carbon dioxide can be separated into the following categories of research:

- <u>separation and capture</u>, to identify approaches that could potentially improve greenhouse gas collection and reduce their costs,
- <u>sequestration in geologic formations</u>, to identify and address the technical and environmental potential for sequestering CO_2 in oil and gas reservoirs, coal seams that cannot be mined, and deep saline formations,
- <u>ocean sequestration</u>, to study approaches for injecting CO_2 into deep areas of the ocean, for stimulating natural carbon absorption from the atmosphere, or for converting CO_2 into ocean-stable minerals,
- <u>terrestrial sequestration</u>, to enhance the natural CO_2 absorbing processes of soils and vegetation,
- <u>other concepts</u>, to examine novel chemical or biological methods for converting CO_2 into commercial products or inert, stable compounds, and
- <u>modeling and assessment</u>, to develop improved methods to assess the costs, risks, and potential of various CO_2 sequestration options. These methods would be used to evaluate sufficiently the

advantages and disadvantages of research options in order to establish whether or not they warrant further development.

In addition to the proposed *Field Experiment*, DOE is providing funds for research on a variety of projects in each of these areas, with each of the separate projects being performed by a university, research institute, DOE laboratory, or industrial organization. Projects are currently being examined in the following areas:

<u>separation and capture</u>

- membrane approach for separating CO_2 from gas streams
- capture of CO_2 from gas streams using chemicals

<u>sequestration in geologic formations</u>

- studies and tests of CO_2 storage in coal seams
- study of saline reservoirs to assess CO_2 storage capabilities and environmental risks
- development of subterranean imaging technology

<u>ocean sequestration</u>

- analysis of natural ocean deposits of CO_2 hydrates on the seafloor
- investigation of analytical techniques to determine long-term fate, biological responses, and sediment effects of CO_2 hydrate in the deep sea

<u>terrestrial sequestration</u>

- evaluation of reclamation and re-forestation approaches that would sequester CO_2 in trees or abandoned mines

<u>other concepts</u>

- evaluation of photosynthetic organisms in specially designed bioreactors for enhancing the rate of CO_2 conversion
- evaluation of species of micro-algae for photosynthesis of CO_2 from power plant exhaust gases

<u>modeling and assessments</u>

- development of a computer model to assess sequestration options and costs
- development of a data base to catalog CO_2 source-to-sequestration information

These research projects are independent elements of DOE's effort to identify potential approaches that could assist in future efforts to control buildup of greenhouse gases in the atmosphere. A variety of approaches are being investigated to assess their technical, economic, and environmental viability. None of these separate research projects, including the proposed *Field Experiment*, is an integral element of an established commercialization plan for the large-scale sequestration of carbon dioxide.

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13.0 APPENDICES

APPENDIX A: **PROJECT AGREEMENT FOR INTERNATIONAL COLLABORATION ON CO_2 OCEAN SEQUESTRATION**

APPENDIX B: **PUBLIC OUTREACH PROGRAM**

APPENDIX C: **DRAFT EXPERIMENTAL PLAN FOR THE OCEAN SEQUESTRATION OF CO_2 *FIELD EXPERIMENT***

APPENDIX D: **CONCEPTS AND MODELS RELEVANT TO THE *FIELD EXPERIMENT***

APPENDIX E: **OBSERVATIONS OF SEAFLOOR LIFE AT THE OCEAN RESEARCH CORRIDOR SITE**

APPENDIX F: **CULTURAL IMPACT ASSESSMENT STUDY**

APPENDIX G: **CONSULTATION AND PUBLIC PARTICIPATION**

APPENDIX A: PROJECT AGREEMENT FOR INTERNATIONAL COLLABORATION ON CO_2 OCEAN SEQUESTRATION

This Project Agreement is entered into among the Federal Energy Technology Center (FETC) of the Department of Energy of the United States of America, the New Energy and Industrial Technology Development Corporation (NEDO) of Japan, and the Research Council of Norway (NRC) (collectively the "Parties").

WHEREAS, in 1995 member countries of the International Energy Agency and the Organization for Economic Cooperation and Development created the Climate Technology Initiative (CTI);

WHEREAS, the CTI seeks to support the objectives of the United Nations Framework Convention on Climate Change by increasing the use of existing climate-friendly technologies and developing new and improved climate-friendly technologies through the promotion of international cooperation in research, development, deployment and information dissemination;

WHEREAS, an objective of CTI's Task Force 7 is to enhance international collaboration in research and development in greenhouse gas capture and disposal, including research on ocean sequestration of CO_2; and

WHEREAS, the CTI's Task Force 7 invites the Parties to explore on an international collaborative basis the technical feasibility and environmental impact of CO_2 ocean sequestration, in order to advance current knowledge of the behavior of discharged CO_2 in the ocean;

NOW THEREFORE, the Parties agree as follows:

Article 1
Objective of the Project

The objective of the international collaboration project on CO_2 ocean sequestration (the "Project") is to determine the technical feasibility of, and improve understanding of the environmental impacts of, CO_2 ocean sequestration in order to minimize the impacts associated with the eventual use of this technique to reduce greenhouse gas concentrations in the atmosphere.

Article 2
Scope of Work

To advance current knowledge of the behavior of discharged CO2 in the ocean, joint research shall be undertaken which mainly focuses on dissolution-type CO_2 discharge experiments conducted at an ocean site. In this joint research, a CO_2 injection system will be constructed and operated to observe near-field phenomena such as droplet plume dynamics and subsequent peeling and intrusion of enriched water. This joint research shall be conducted within the estimated cost of the Project as described in Article 9.

Article 3
Work Program

The program of work for the Project (hereinafter the "Work Program") shall be as follows:

1. Selection of the most suitable site for ocean field experiments.
2. Determination of the discharge depth, rate, timing and duration of experiments.
3. Design of facilities for CO_2 storage, transport and discharge.
4. Selection of the items to be measured and monitored in experiments.
5. Preparation and testing of equipment for measurement and monitoring.
6. Construction of CO_2 storage, transport and discharge facilities.
7. Carrying out of ocean field experiments.
8. Analysis of data acquired during experiments.
9. Collation of overall results obtained in the field experiments.
10. Formulation of a proposal for the next phase of the Project.
11. Other activities as may be mutually agreed by the Parties in writing.

All Parties shall cooperate with one another to promote the Work Program.

Article 4
Addition and Withdrawal of Project Participants

(1) Upon approval of the Steering Committee (described in Article 6), participation in the Project shall be open to other organizations which sign or accede to this Project Agreement, accept the rights and obligations of a Party, and make an appropriate contribution to defray the cost of the Project.

(2) In the event a Party wishes to withdraw from the Project for budgetary or other reasons, it may do so at the end of a fiscal year (as defined in Article 8) upon sixty (60) days' written notice to the other Parties.

Article 5
Implementing Research Organizations

(1) Each Party may implement Project activities through an appropriate domestic research organization (hereinafter "Implementing Research Organization"). Alternatively, a Party may undertake Project activities itself.

(2) The Parties' designated Implementing Research Organizations are as follows:

For FETC:
Massachusetts Institute of Technology (United States of America)

For NEDO:
Research Institute of Innovative Technology for the Earth (Japan)

For NRC:
Norwegian Institute for Water Research (Norway)

(3) The Parties shall support their respective Implementing Research Organizations by providing annual funding to be used for implementing the Project, subject to Article 9.

(4) In order to establish work responsibility, details regarding treatment of intellectual property, and necessary policy and procedure for the Project, the Implementing Research Organizations shall conclude an annual joint research agreement for each fiscal year of the Project.

Article 6
Steering Committee

(1) A committee consisting of one representative of each Party (hereinafter "Steering Committee") shall be established to manage the overall direction and scope of the Project and to consider and approve the participation of other organizations in the Project.

(2) The Steering Committee shall be responsible for resolving any misunderstandings or problems related to this Project Agreement or the Project based on the principles of mutual benefit, equality, cooperation and trust.

(3) The Steering Committee shall hold its first meeting within one (1) month of the execution of this Project Agreement to establish duties, policies and procedures for implementing the Project. Following its first meeting, the Steering Committee shall meet approximately once a year at a place mutually agreed by all members.

Article 7
Technical Committee

(1) The Parties shall establish a Technical Committee consisting of up to three (3) representatives appointed by each Implementing Research Organization, to formulate the annual Work Program for each year of the Project, to supervise its technical aspects and execution, and to consult about treatment of intellectual property.

(2) The Technical Committee shall also be responsible for managing the budget for implementing the Work Program and coordinating any optional research studies which may be undertaken during the Project.

(3) The Technical Committee shall report to the Steering Committee at least twice a year regarding implementation of the annual Work Program for the Project.

(4) The specific functions of the Technical Committee shall be set forth in the annual joint research agreements among the Implementing Research Organizations.

Article 8
Project Fiscal Year

The Parties agree that the fiscal year of the Project shall extend from April 1st to March 31st of the following year.

Article 9
Cost Contributions

The total estimated cost of the Project is Three Million Eight Hundred Thousand U.S. Dollars (U.S.$3,800,000). Subject to the availability of appropriated funds and appropriate authorizations by their respective governments, the Parties agree to share the cost of the Project as follows:

Agency	Funding Level (U.S.$)	Percentage of Funding
FETC	$850,000	22.4%
NEDO	$2,600,000	68.4%
NRC	$350,000	9.2%

Article 10
Treatment of Project Results

Basic policy regarding the use and protection of research data and intellectual property resulting from Project activities shall be determined through mutual discussion and agreement of the Parties. Specific details concerning the treatment of project results shall be included in the annual joint research agreements provided for under Article 5.

Article 11
Waiver of Claims for Damages

In the event of any material damage or loss of life due to an accident or any reason other than willful misconduct or gross negligence during the implementation of the Project, no compensation shall be claimed by any Party against any other Party or against the Implementing Research Organizations.

Article 12
Amendment of this Agreement

In the event the Steering Committee determines that it is necessary to amend this Project Agreement, it may be amended by written agreement of the Parties.

Article 13
Mutual Trust and Cooperation

(1) Each Party shall endeavor, in the spirit of mutual trust, to resolve any difficulties or misunderstandings which might arise concerning the Project or this Project Agreement.

(2) Each Party shall conduct the collaboration under this Project Agreement in accordance with the applicable laws and regulations under which each Party operates.

(3) Any questions arising in connection with the interpretation or implementation of this Project Agreement or anything not specified herein shall be promptly discussed through mutual consultation among the Parties.

Article 14
Responsibility for and Use of Information

(1) The Parties support the widest possible dissemination of information generated by Project activities. Such information may be made available for public dissemination at the discretion of the Parties, subject to the need to protect proprietary information in accordance with Article 14(2).

(2) The Parties shall take all necessary measures as they may consider appropriate to protect proprietary information. For the purposes of this Article, proprietary information shall include information of a confidential nature such as trade secrets and know-how (for example, computer programs, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes or treatments) which:

> (i) is not generally known or publicly available from other sources;
>
> (ii) has not previously be made available by the owner to others without obligation concerning its confidentiality; and
>
> (iii) is not already in the possession of the recipient without obligation concerning its confidentiality.

It shall be the responsibility of each Party supplying proprietary information to identify the information as such and to ensure that it is marked "Proprietary Information".

(3) Information transmitted by one Party to another Party shall be accurate to the best knowledge and belief of the transmitting Party, but the transmitting Party does not warrant the suitability of the information transmitted for any particular use or application.

Article 15
Effective Date, Extension, and Termination

(1) This Project Agreement shall be effective from the date of its signing by all Parties through March 31, 2002, unless extended or terminated.

(2) By mutual written agreement, the Parties may extend this Project Agreement for additional periods.

(3) The Parties may by mutual written agreement terminate this Project Agreement at any time.

IN WITNESS WHEREOF, each Party has executed this Project Agreement on the date indicated, with each Party to retain one (1) fully executed copy.

Federal Energy Technology Center
Department of Energy
United States of America

Signature:
Name: Harvey M. Ness
Title: Director, Power and Environmental Systems
Date: December 4, 1997

New Energy and Industrial Technology
Development Organization
Japan

Signature:
Name: Hiroshi Mitsukawa
Title: Executive Director
Date: December 4, 1997

Research Council of Norway
Norway

Signature:
Name: Eirik Normann
Title: Assistant Director
Date: December 4, 1997

APPENDIX B: PUBLIC OUTREACH PROGRAM

As the implementing organization, the Pacific International Center for High Technology Research (PICHTR) developed and initiated an extensive public outreach program for the *Ocean Sequestration of Carbon Dioxide Field Experiment*. The outreach program has had several key purposes:

- Expand pre-consultation process to include environmental and community organizations, as well as other local stakeholders in order to provide an opportunity to give input into the experimental design.
- Work with stakeholders to keep them well informed and to listen to their concerns.
- Instill a sense the *Field Experiment* would be conducted with full public knowledge.
- Secure an understanding of the *Field Experiment*'s importance to informed public policy decision-making.

The public outreach program consists of several phases. Those phases, and the objectives of each, are outlined below.

Phase I: Gather Information and Prepare Outreach. Develop a public outreach program for the *Ocean Sequestration of Carbon Dioxide Field Experiment*. Identify key contacts, including: NELHA tenants; citizen and native Hawaiian marine advocates; scientists and extension agents; West Hawai‘i Fishery Council; private sector representatives; and elected officials.

Phase II: Prepare NELHA Site Proposal. Build understanding of the rationale for conducting the *Field Experiment* at the Natural Energy Laboratory of Hawai‘i Authority's Ocean Research Corridor. Listen to and address concerns through mailing information packages to key contacts, telephone calls and one-on-one (or small group) meetings with decision-makers, media contacts, and project-related articles and opinions published in local newspapers and magazines. On August 6, 1999, a project presentation was made at a NELHA Tenants Association Meeting. A web site containing descriptive information concerning the *Field Experiment* and links to other relevant web sites was established (www.co2experiment.org). This web site has been updated several times in subsequent phases. The project web site includes an Email address for the public to submit comments. The project team has made great efforts to try and respond to all public inquiries. Email correspondence with the public has continued in subsequent phases.

Phase III: NELHA Site Proposal and Review. Continue building community involvement and initiate formal environmental scoping. Activities included presenting at a University of Hawai‘i Sea Grant Extension Service's REEFTALK (September 14, 1999), showing a video of this presentation several times in November 1999 on a West Hawai‘i public access cable channel. The project team also briefed the NELHA Board, held a public scoping meeting for the Environmental Assessment (Section 3.4.4), and informed project leadership about concerns so that appropriate adjustments could be made in the *Field Experiment*'s design.

Phase IV: Prepare EA and (if necessary) apply for permits. Foster public understanding and ensure plans for the *Field Experiment* are adjusted as needed. On March 1, 2000, a presentation was given to the Hawaiian Islands Humpback Whale National Marine Sanctuary Advisory Council. Email correspondence between the project team and local stakeholders continued throughout this and other phases.

Phase V: Final activities prior to conducting *Field Experiment*. The next phase in the extensive public outreach effort is in the time leading up to the actual conducting of the *Field Experiment*. Planned activities include: (i) preparing and circulating a press release prior to initiation of the *Field Experiment* and (ii) continuing background briefings with media contacts at West Hawaii Today, Hawaii Tribune-Herald, Honolulu Star-Bulletin, and the Honolulu Advertiser.

Phase VI: Experiment Phase and Post-Experiment Activity. Provide the public with current and accurate information on the final preparation for and conducting of the *Field Experiment*. Results of the *Field Experiment* would be published in the technical literature available to the public. In addition, if the project web site remains activated for a sufficient time after the completion of the *Field Experiment*, data and results may be posted and thus become available online. It must be realized, however, that for technical reasons there usually is a substantial delay between the collection of raw field data and their availability as calibrated or processed information. An even longer delay should be anticipated in the case of peer-reviewed technical literature. The presence of observers during the execution of the *Field Experiment* would pose logistical and safety problems. While observers that are not directly affiliated with the project could be admitted onboard the research vessels, a strict protocol would have to be enforced to ensure everyone's safety and to avoid interference with ongoing experimental and monitoring activities. Such a protocol would naturally restrict the number of people who could serve as observers.

APPENDIX C: DRAFT EXPERIMENTAL PLAN FOR THE OCEAN SEQUESTRATION OF CO_2 FIELD EXPERIMENT

APPENDIX D: CONCEPTS AND MODELS RELEVANT TO THE FIELD EXPERIMENT

An understanding of the potential utility and environmental effects of ocean sequestration of CO_2 requires knowledge of natural processes that take place within widely different scales of time and space. One of the ways that scientists investigate such processes and their implications for ocean sequestration is through development of computer models. The models are developed using known physical principles to predict measurable consequences. Such models are supported, modified, and validated by oceanographic investigations that measure the actual causes and results in the real world.

The proposed *Field Experiment* is one example of this kind of investigation, and it is focused on the small scale. The following passages consider three different scales, global, mesoscale, and the small scale proposed for the experiment, and describe the relevance of the proposed *Field Experiment* to each. This is followed by a short description of the specific models that the *Field Experiment* is designed to support.

Global Scale

A basic understanding of the relationship between CO_2 in the ocean and CO_2 in the atmosphere is necessary for appreciating the rationale for ocean sequestration of CO_2. In general, regions of upwelling correspond to a transfer of CO_2 from the ocean into the atmosphere, while the highly alkaline waters of subtropical gyres, cold waters in high latitudes and biologically productive surface waters all absorb CO_2 from the atmosphere (Wong and Hirai 1997, p. 23-24).

The difficulties associated with the measurement of seasonally and locally varying carbon fluxes on the vast expanses of the entire oceanic surface are substantial. At a given time and location, these fluxes are proportional to the difference between p_a, the partial pressure of CO_2 in the atmosphere, and p_m, the partial pressure of free CO_2 in the mixed layer of the ocean. The coefficient of proportionality itself depends on various factors such as wind speed, local CO_2 solubility, etc. The net sink associated with the North Pacific Subtropical Gyre (NPSG), for example, was recently estimated to be 0.2 GtC/yr, over an area of 26.3 x 10^6 km^2 (Winn *et al.* 1994). This value corresponds to a small partial pressure imbalance $p_a - p_m$ of the order of 10 µatm (or ppmv).

While our improved ability to measure detailed carbon fluxes is very important, especially for three-dimensional predictive tools such as Ocean Global Climate Models (OGCMs), some global knowledge already is available (Siegenthaler and Sarmiento 1993). On one hand, it is acknowledged that prior to the middle of the 19^{th} Century, the pre-industrial atmosphere and ocean had been in global equilibrium for many centuries, with large fluxes across the ocean surface (of the order of 74 GtC/yr) balancing each other out. Today, not only have global carbon fluxes across the ocean surface increased (to about 90 GtC/yr), but more importantly, the mixed layer has become a net global carbon sink, of about 2 GtC/yr across an oceanic surface of about 3.7 x 10^8 km^2. The NPSG appears to be an average region, with local values aligned with global estimates.

Notwithstanding uncertainties that remain to be clarified, the net global carbon sink across the ocean surface can be attributed to current anthropogenic CO_2 emissions in the atmosphere (about 6 GtC/yr). In other words, the mixed layer of the ocean already has been absorbing the equivalent of one third of all atmospheric emissions from the burning of fossil fuels.

As CO_2 atmospheric emissions have been projected to rise sharply on a worldwide basis through the 21^{st} Century, certain physical and chemical phenomena that play a crucial role in the carbon budget of the oceanic mixed layer should be succinctly discussed. It will be seen that, as a result of these mechanisms, the oceanic mixed layer represents a veritable bottleneck to the eventual transfer of excess atmospheric carbon to the deep ocean.

The mixed layer of the ocean is typically 60 to 75 m thick and lies between the atmosphere and the deep ocean. The upper reaches of the deep ocean, down to approximate depths of 1,000 m, constitute the main (or permanent) thermocline. Because of the density stratification of the upper deep ocean, transport phenomena such as turbulent eddy diffusion (dispersion) are greatly inhibited. Vertical stability through the thermocline can be 'visualized' by imagining a tiny water blob moving up (down) into less (more) dense ambient water; it would immediately tend to sink (rise) back into its original position because of an imbalance between its weight and buoyancy.

Thus, a first limiting transfer mechanism affecting the mixed layer is the slow downward vertical migration of any excess carbon through the thermocline. Recent estimates of the vertical eddy diffusivity are actually one order of magnitude lower than previously thought (Wong and Matear 1996). As a result, the influence of the deep ocean in limiting the rise of atmospheric and mixed-layer carbon concentrations might not be felt over time scales of decades, when it would be most critical. It is noteworthy to add that this limitation also applies to the downward dispersion of heat. In other words, slow vertical dispersion through the main thermocline might also prevent a timely reduction of any temperature buildup (Global Warming) in the upper layers.

Going back to the flux of CO_2 across the ocean surface, another fundamental mechanism must now be described that limits the transfer of excess atmospheric CO_2 into the mixed layer. It was mentioned in previous sections that in seawater, several carbon species exist and that their relative amounts are controlled by the requirements of chemical equilibrium. Thus, when CO_2 is added to seawater, the amount of dissolved inorganic carbon (DIC) increases accordingly. In spite of the buffering (neutralizing) effect of carbonate ions (CO_3^{2-}) on CO_2, [CO_2] increases sharply with [DIC] and the pH is reduced.

A fundamental result from the chemistry of carbon species in seawater is that with the addition of carbon, the <u>relative</u> increase in [CO_2] greatly exceeds the <u>relative</u> increase in [DIC]. Since [CO_2] is proportional to the free CO_2 partial pressure p_m, one can define the Revelle factor ξ as:

$$\xi = \{(p_m - p_{m0})/p_{m0})\}/\{([DIC]-[DIC]_0)/[DIC]_0)\},$$

where the subscript 0 indicates a state of reference.

Currently, ξ is of the order of 10, and is an increasing function of [DIC]. High values of ξ indicate that the transfer of excess atmospheric carbon into the ocean's mixed layer is rather difficult. Increasing values of ξ with [DIC] mean that this transfer will get even more difficult as more carbon is released into the system. An intuitive explanation of this point can be stated as follows. A small relative increase in [DIC], which measures the storage capacity of the mixed layer, corresponds to a ξ -fold relative increase in p_m. In turn, high values of p_m choke the flux of carbon into the mixed layer, which is controlled by $p_a - p_m$. In general, most CO_2 emitted into the atmosphere stays in the atmosphere, with only a small fraction being transferred into the ocean mixed layer.

The above discussion provides the fundamental tenet underlying the general concept of CO_2 Ocean Sequestration. The ocean mixed layer is a very narrow bottleneck inhibiting the transfer of the excess CO_2 from the atmosphere into the deep ocean. This bottleneck has two components: the import of carbon from the atmosphere into the mixed layer (the Revelle factor effect) is difficult, and the export of carbon to the deep ocean from the mixed layer (from the stratification of the main thermocline) is difficult. CO_2 Ocean Sequestration essentially calls for bypassing the ocean mixed layer. Moreover, the stratification of the upper deep ocean – an impediment to vertical dispersion - would now help confining CO_2 disposed directly into the deep ocean.

If one considers the potential for future large-scale implementation of CO_2 ocean sequestration, the feasibility of the concept and its environmental effects should be evaluated by OGCMs, preferably coupled with a climate model including the atmosphere, biosphere, surface ice, etc.

A dozen or so of these models are being developed and tested by various groups throughout the World. Currently, the prediction time scale for these models is from years to decades and centuries. The space scale is of the order of 100 km at the very least (the smallest grid size ever run on very powerful supercomputers is one degree, or 60 nautical miles). In addition to computer run time limitations, a better understanding of many complex mechanisms needs to be developed, and what occurs at sub-grid scales needs to be integrated as 'input' (in a generalized sense).

For an OGCM evaluation of the CO_2 ocean sequestration concept, the marine macro-scale biogeochemical cycle would be considered. A more commonly used term is "the biological pump" (Wong and Hirai 1997, p. 24-26). The detritus flux of organic matter sinking below the pycnocline accelerates the transfer of carbon to the deep ocean. The primary components of this 'pump' include the silicate and calcium carbonate exoskeletons from phytoplankton as well as the fecal matter from zooplankton that graze upon them.

Nitrogen, phosphorus, oxygen, and other elements all have their own global cycles as well. In the ocean, a fundamental coupling between these elements and carbon occurs via biological activity. The photosynthesis reaction itself is a striking illustration of such coupling. Some very interesting one-dimensional models have been published that show the role of marine biota on the overall compositional structure of the world oceans (Kheshgi and Flannery 1991).

Currently, ongoing OGCM evaluations of the CO_2 ocean sequestration concept try to include the cycling of as many elements as possible. However, the interaction of carbon that would be disposed in the ocean, with elements such as nitrogen for example, would take place indirectly, inasmuch as changes in the concentrations of inorganic carbon species, pH and alkalinity (if the dissolution of calcareous sediments occurs) would affect biological processes. The small scale and short duration of the *Field Experiment* do not lend themselves to a critical evaluation of the interplay between carbon and nitrogen cycles under CO_2 disposal scenarios.

A primary goal of OGCMs is to describe accurately the large-scale ocean currents in all their complexity. In this sense, they should be able to simulate the thermohaline "conveyor," whereby deep water is formed in polar latitudes, and resurfaces elsewhere. Our understanding of this circulation has greatly evolved over the past decade (Wong and Hirai 1997, p. 46; Wong and Matear 1996).

Results from the proposed *Field Experiment* would not contribute directly to the understanding of these processes or to the validation or modification of OGCMs.

Mesoscale

Phenomena that are just too small or perhaps too short-term to be yet modeled by OGCMs, but that develop in a matter of weeks or months and span dimensions of orders 10 to 100 km, are also important for the understanding of ocean sequestration. The Kona coast of the Big Island is an interesting example where mesoscale eddies often develop in the lee of the island. These eddies can even be generated in pairs: along the North Kona coast a cyclonic (counterclockwise) eddy, and along the South Kona coast, an anticyclonic (or clockwise) eddy (Flament, *et al.* 1997). Ke hole Point lies at the boundary of the formation zones of these eddies, and therefore may be subjected to the action of a cyclonic eddy, or of an anticyclonic eddy. In the former case, coastal waters experience a North running (Kohala) current, with the core area of upwelled water well offshore (order of tens of kilometers).

Wyrtki *et al.* (1967) identified and characterized a cold-core cyclonic eddy off the North Kona coast well before the advent of satellite imagery. They performed oceanographic measurements down to 300 m in the course of two successive research cruises, in May and July of 1965. The eddy seemed to have formed within two months before the first cruise, and intensified between the May and July observations (inasmuch as the same eddy did persist for two months!). Its size was about 100 km. Data on the deformation of isotherms showed that the eddy was concentrated in the upper 300 m in the earlier, less intense stage (May observations), but affected deeper water in July. Observations were not available for water deeper than 300 m, however.

Current measurements collected at Ke hole Point in August 1999 showed the presence of shear (horizontal current reversal) about 500 m below the surface while satellite data showed a strong mesoscale cyclonic eddy offshore (Sundfjord and Golmen 2000). These results suggest that the dynamic effects of mesoscale eddies along the Kona coast are mostly confined in waters shallower than 300 to 500 m.

The proposed *Field Experiment* is not designed to evaluate such oceanographic processes or the behavior of CO_2 releases at these temporal and spatial scales. Though the currents to be expected on the seabed at the *Field Experiment* site may be influenced indirectly by such eddies and other mesoscale processes, the proposed releases of CO_2 will not be large or persistent enough to be tracked long enough or far enough away from the release point to permit a credible study of the interactions between the released CO_2 and these natural processes.

The *Field Experiment*

The size and duration of the controlled CO_2 releases planned during the *Ocean Sequestration of CO_2 Field Experiment* place the project at the low end of small-scale (local) dynamics. Time scales of hours to days, and spatial scales of tens of meters to a few kilometers characterize the regime of interest for the *Field Experiment*. The scientists involved with the project hope to investigate the near-field behavior of a CO_2 release to get a better understanding of the complex interactions between dissolving liquid CO_2 droplets and deep seawater. The natural processes that would control the behavior of the released CO_2 include tides, internal waves, localized solid boundary effects, and other processes.

The models developed to study the small-scale evolution of CO_2 that would be released in deep waters (buoyant rise, dissolution, dispersion, etc.) use computers just as powerful as the OGCMs, but deal with small-scale physics and grid sizes of the order of meters. Incidentally, more powerful computers would only increase the simulation times that can be calculated, or permit smaller grid sizes – great benefits *per se*, but would offer no insight on basic input sub-models (hydrate effects, droplet dissolution rates, droplet terminal velocities, etc.). In turn, it is not possible to replicate the complex stratified seawater column in a laboratory at the necessary sizes, especially because of high-pressure requirements.

Several groups have been developing specific models of the behavior of CO_2 when it would be released into deep seawater. There currently are two methods of approach: one based on laboratory experiments conducted on the basis of similarity laws, and another that involves the numerical solution of complex equations with powerful computers. In all cases, the *Field Experiment* would provide valuable data that would help dispel modeling uncertainties.

A group led by Dr. Adams at the Massachusetts Institute of Technology has spearheaded plume studies based on similarity analysis. Laboratory experiments conducted on fluids other than CO_2 that do not necessitate very high pressures and unrealistic tank sizes have provided results on plume behavior that have been interpreted in terms of non-dimensional numbers (these numbers combine different physical properties of the fluids). This establishes a basis for extrapolation to the case of liquid CO_2. This type of analysis has the potential to identify very subtle qualitative phenomena, such as the existence of multiple intrusion layers resulting from the peeling of dense seawater out of the core of a rising plume, or the possible separation of the cloud of droplets from the dense carbon-rich seawater in a cross flow (current). It is not obvious whether existing computer-based models have sufficiently high spatial resolutions to predict such qualitative features. The inherent weakness of these laboratory experiments, however, is that CO_2 and high-pressure seawater cannot directly be used.

One computer-based model that has been available and developed for more than three years is the three-dimensional (3-D) code of Dr. Alendal's group, at the Nansen Environmental and Remote Sensing Center (NERSC) in Norway. Seawater and CO_2 droplets are treated as two separate phases in a two-phase Computational Fluid Dynamics (CFD) solver of the basic momentum and continuity equations. Transport equations allow the mapping of temperature, salinity, carbon, and droplet density. The fact that CO_2 exists in the form of droplets (dispersed phase) is accounted for by the introduction of the "droplet density" parameter. The CO_2 and seawater phases interact through drag (as the buoyant droplets rise through the water column) and mass transfer (as carbon dissolves into seawater). From the results calculated by the CFD model's transport equations, pH can be determined from another set of equations describing carbon chemistry in seawater. The CO_2 injection nozzle is modeled in one numerical cell as a source term.

Other computer-based models developed to describe the behavior of liquid CO_2 injected in deep seawater share the same basic approach. One such 3-D model was conceived by Dr. Sato of the University of Tokyo. Typical reasons for differences between computer-based model results are the size and resolution of numerical grids (i.e., how closely spaced "calculation points" are) and the choice of the relationships describing the interaction between CO_2 and seawater (dissolution rates and droplet slip velocity), including hydrate formation and droplet shape.

Dr. Chen of Japan's Research Institute of Innovative Technology for the Earth (RITE) also developed a two-dimensional (2-D) computer model. The loss of one dimension (width) in the constitutive equations of the CFD code can be seen as a weakness of this approach, although the other two dimensions (height and length) are in a sense more fundamental. This means that "flat" maps of the physical quantities of interest (e.g., pH) are obtained instead of fully three-dimensional results that would be visually more representative of reality. In a 2-D approach, the much smaller numerical grid leads to shorter computer run times, which facilitates the inclusion of additional (and complicating) features such as current shear, or allows a finer numerical-grid spacing. All things being equal, a two-dimensional algorithm could be viewed as globally conservative since it does not allow any spreading of the injected matter along the missing third dimension (in other words, concentrations should be higher).

Recent work by these scientists and others indicates that the input relationships describing CO_2 droplet dissolution and droplet slip velocity are mostly responsible for differences between different predictions.

APPENDIX E: OBSERVATIONS OF SEAFLOOR LIFE AT THE OCEAN RESEARCH CORRIDOR SITE

The following table describes the observations made from the video tapes collected by the Hawai‘i Undersea Research Laboratory (HURL) submersible *Pisces IV* when examining the seafloor at the Ocean Research Corridor site in October 2000.

Hawai'i Undersea Research Laboratory
Video Log Records for Dives P4-006, P4-007, P4-008, P4-009, and P4-010
Collected October 2000

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-006-d1-1	0	v	None		none	0	0		
P4-006-d1-2	0	v	None		none	0	625	19 42.193	156 03.895
P4-006-d1-3	5	v	crab;pagurid?		pagurid?	1	625	19 42.193	156 03.895
P4-006-d1-4	10	v	crab;pagurid?		pagurid?	1	625-645		
P4-006-d1-5	10	v	fish;macrourid?		macrourid?	1	625-645		
P4-006-d1-6+	10	v	fish;myctophid		myctophid	2	645		
P4-006-d1-7+	15	v	fish;myctophid		myctophid	2	680		
P4-006-d1-8	15	a	Fish		eel	1	680-770		
P4-006-d1-9	20	v	None		none	0	680-770		
P4-006-d1-10	25	v	None		none	0	770		
P4-006-d1-11	30	v	fish;macrourid?		macrourid?	1	800	19 42.170	156 04.171
P4-006-d1-12	35	v	Fish		fish	1	800-815		
P4-006-d1-13	35	a/v	Squid		squid	1	800-815		
P4-006-d1-14	35	v	fish;macrourid?		macrourid?	1	800-815		
P4-006-d1-15	35	v	fish;eel		eel	1	800-815		
P4-006-d1-16	35	v	Shrimp		shrimp	1	800-815		
P4-006-d1-17	40	v	Shrimp		shrimp	1	815		
P4-006-d1-18	40	v	holothurian;synallactid		Paelopatides retifer?	1	805-815		
P4-006-d1-19	40	v	crab;pagurid		pagurid	1	805-815		
P4-006-d1-20+	40	v	shrimp;nematocarcinid?		Nematocarcinus tenuirostris	1	805-815		
P4-006-d1-21+	40	v	fish;congrid?		congrid?	1	805-815		
P4-006-d1-22	40	v	Fish		fish	1	805-815		
P4-006-d1-23+	45	v	fish;eel		eel	1	805		
P4-006-d1-24	45	v	fish;congrid?		congrid?	1	800		
P4-006-d1-25	50	v	None		none		800	19 42.298	156 04.216
P4-006-d1-26	55	v	None		none		800	19 42.298	156 04.216
P4-006-d1-27	100	v	None		none		800	19 42.298	156 04.216

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-006-d2-1	0	v	None		none		800	19 42.298	156 04.216
P4-006-d2-2	5	v	None		none		800	19 42.298	156 04.216
P4-006-d2-3	10	v	None		none		800	19 42.298	156 04.216
P4-006-d2-4	15	v	None		none		800	19 42.298	156 04.216
P4-007-d7-8	35	v	none		none	0	800		
P4-007-d7-9	40	v	none		none	0	800		
P4-007-d7-10	45	v	none		none	0	800		
P4-007-d7-11	50	v	none		none	0	800		
P4-007-d7-12	55	v	none		none	0	800		
P4-007-d7-13	100	v	none		none	0	800		
P4-007-d8-1	0	v	fish		fish small	1	780-800		
P4-007-d8-2	0	v	cnidarian;anemone		anemone large orange	1	780-800		
P4-007-d8-3	5	v	cnidarian;anemone		anemone large orange	1	780		
P4-007-d8-4	10	a	holothurian		holothurian	1	740-750		
P4-007-d8-5	15	v	cnidarian;anemone		anemone large orange	1	700-740		
P4-007-d8-6	20	v	fish;macrourid		macrourid	1	680-700		
P4-007-d8-7	20	v	cnidarian;anemone		anemone large orange	1	680-700		
P4-007-d8-8	25	v	none		none	0	680	19 43.095	156 04.468
P4-007-d8-9	30	v	cnidarian;anemone		anemone large orange	1	680	19 43.095	156 04.468
P4-007-d8-10	35	v	none		none	0	680	19 43.095	156 04.468
P4-007-d8-11	40	v	none		none	0	680	19 43.095	156 04.468
P4-008-d1-1	0	v	none		none	0	505	19 42.998	156 04.241
P4-008-d1-2	5	v	none		none	0	505-695		
P4-008-d1-3	10	v	none		none	0	505-695		
P4-008-d1-4	15	v	none		none	0	505-695		
P4-008-d1-5	20	v	none		none	0	505-695		
P4-008-d1-6	25	v	none		none	0	695-740		
P4-008-d1-7	25	v	fish		fish	1	740		
P4-008-d1-8	30	a	fish		fish	1	740-800		
P4-008-d1-9	35	v	shrimp		shrimp	1	800	19 42.987	156 04.588
P4-008-d1-10+++	35	v	seastar;goniasterid		Ceramaster bowersi?	1	800	19 42.987	156 04.588

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-008-d1-11	40	a	shrimp;pandalid?		Heterocarpus laevigatus?	1	800	19 42.987	156 04.588
P4-008-d1-12	40	v	fish;eel		eel	1	800	19 42.987	156 04.588
P4-008-d1-13	45	v	none		none	0	800	19 42.987	156 04.588
P4-008-d1-14	50	v	fish;eel		eel	1	800		
P4-008-d1-15	55	v	none		none	0	800		
P4-008-d1-16	100	v	none		none	0	800		
P4-008-d2-1	0	v	none		none	0	800		
P4-008-d2-2+++	5	v	cnidarian;scyphozoan		scyphozoan	1	800		
P4-008-d2-3	10	v	none		none	0	800		
P4-008-d2-4	15	v	none		none	0	800		
P4-008-d2-5	20	v	none		none	0	800		
P4-008-d2-6	25	v	none		none	0	800		
P4-008-d2-7	30	v	none		none	0	800		
P4-008-d2-8	35	v	none		none	0	800		
P4-008-d2-9	40	v	none		none	0	800		
P4-008-d2-10	45	v	none		none	0	800		
P4-008-d2-11	50	v	none		none	0	800		
P4-008-d2-12	55	a	fish;scorpaenid?		Ectroposebastes imus?	1	800		
P4-008-d2-13	100	v	none		none	0	800		
P4-008-d3-1	0	v	none		none	0	800		
P4-008-d3-2	5	v	fish		fish small	1	800		
P4-008-d3-3	5	v	shrimp		shrimp	1	800		
P4-008-d3-4	10	v	none		none	0	800		
P4-008-d3-5++++	15	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800		
P4-008-d3-6	15	a	fish		fish	1	800		
P4-008-d3-7	15	a	holothurian;synallactid		Paelopatides retifer	1	800		
P4-008-d3-8	20	v	shrimp		shrimp	1	800		
P4-008-d3-9	25	v	none		none	0	800		
P4-008-d3-10	30	v	none		none	0	800	19 42.955	156 04.559
P4-008-d3-11	35	v	none		none	0	800		
P4-008-d3-12	40	v	fish;eel		eel	1	800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-008-d3-13	40	v	fish		fish small	1	800		
P4-008-d3-14	45	a	cnidarian;anemone		anemone large orange	1	800-840		
P4-008-d3-15++	45	v	fish;macrourid		Hymenocephalus sp	1	850	19 43.016	156 04.647
P4-008-d3-16	45	v	shrimp		shrimp	1	850	19 43.016	156 04.647
P4-008-d3-17	50	v	fish		fish small	1	850		
P4-008-d3-18+	55	v	fish;squalid?		squalid?	1	850		
P4-008-d3-19	55	v	cnidarian;ceriantharian?		cerianthid black?	1	850		
P4-008-d3-20	55	v	fish;macrourid		Nezumia propinqua?	1	850		
P4-008-d3-21	55	v	cnidarian;anemone		large orange anemone	1	850		
P4-008-d3-22	55	v	shrimp		shrimp	1	850		
P4-008-d3-23	100	v	cnidarian;ceriantharian?		cerianthid black?	1	850		
P4-008-d3-24	100	v	cnidarian;anemone		anemone large orange	1	850		
P4-008-d3-25	100	v	shrimp		shrimp	1	850		
P4-008-d4-1	0	v	fish;eel		eel white-tailed	1	850		
P4-008-d4-2	0	v	fish		fish small	2	850		
P4-008-d4-3	0	v	shrimp		shrimp	1	850		
P4-008-d4-4	0	v	cnidarian		cnidarian long-stalked	1	850		
P4-008-d4-5	0	v	fish;myctophid?		myctophid?	1	850	19 42.738	156 04.539
P4-008-d4-6	5	v	none		none	1	850	19 42.738	156 04.539
P4-008-d4-7+	10	v	holothurian?		holothurian?	1	815-850		
P4-008-d4-8	10	v	shrimp		shrimp	1	815-850		
P4-008-d4-9	10	v	fish		fish small	1	815-850		
P4-008-d4-10	10	v	fish;eel		eel	1	815-850		
P4-008-d4-11	10	v	fish;myctophid?		myctophid?	1	815-850		
P4-008-d4-12+	15	v	cnidarian;anemone		hormathiid sp 2?	1	815		
P4-008-d4-13+	15	v	cnidarian;ceriantharian?		cerianthid black?	1	805-815		
P4-008-d4-14+	15	v	cnidarian;anemone		anemone large orange	1	800	19 42.774	156 04.484
P4-009-d1-1	0	v	fish	eel	eel	1	610	19 42.859	156 04.309
P4-009-d1-2	0	v	cnidarian	anemone	anemone large orange	1	610	19 42.859	156 04.309
P4-009-d1-3	5	v	fish	eel	eel	1	610-750		
P4-009-d1-4	10	a	holothurian	synallactid	Paelopatides retifer	1	610-750		

APPENDIX E

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d1-5	10	a	cnidarian	anemone	hormathiid sp 2?	1	610-750		
P4-009-d1-6	10	v	fish	eel	eel	1	610-750		
P4-009-d1-7	10	v	fish	myctophid?	myctophid?	1	610-750		
P4-009-d1-8	15	v	fish	fish	fish	1	610-750		
P4-009-d1-9	15	v	cnidarian	anemone	anemone large orange	1	610-750		
P4-009-d1-10	15	v	fish	fish	fish small	1	610-750		
P4-009-d1-11	15	v	fish	nettastomid	nettastomid	1	750		
P4-009-d1-12	15	v	fish	myctophid?	myctophid?	1	750-765		
P4-009-d1-13	15	v	fish	macrourid	macrourid	1	750-765		
P4-009-d1-14	15	a	shrimp	shrimp	shrimp	1	750-765		
P4-009-d1-15	20	v	fish	eel	eel	1	750-765		
P4-009-d1-16	20	v	fish	squalid?	squalid?	1	765		
P4-009-d1-17	20	v	cnidarian	ceriantharian?	cerianthid black?	1	765		
P4-009-d1-18	20	v	fish	fish	fish small	1	765		
P4-009-d1-19	20	v	fish	macrourid	macrourid	1	765		
P4-009-d1-20++	25	v	fish	macrourid	macrourid	1	795	19 43.160	156 04.617
P4-009-d1-21	25	v	fish	myctophid?	myctophid?	1	795-805		
P4-009-d1-22	25	v	seastar	goniasterid	Ceramasters bowersi?	1	795-805		
P4-009-d1-23	25	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-24	30	v	fish	eel	eel	1	795-805		
P4-009-d1-25	30	v	shrimp	shrimp	shrimp	2	795-805		
P4-009-d1-26	30	v	cnidarian	ceriantharian?	cerianthid black?	1	795-805		
P4-009-d1-27	30	v	cnidarian	anemone	hormathiid sp 2?	1	795-805		
P4-009-d1-28	30	v	fish	fish	fish small	2	795-805		
P4-009-d1-29	35	v	cnidarian	anemone	hormathiid sp 2?	1	795-805		
P4-009-d1-30	35	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-31	35	v	seastar	goniasterid	Ceramasters bowersi?	1	795-805		
P4-009-d1-32	35	v	fish	fish	fish large red	1	795-805		
P4-009-d1-33	35	v	fish	plesiobatid	Plesiobatis daviesi	1	795-805		
P4-009-d1-34	35	v	fish	fish	fish small	1	795-805		
P4-009-d1-35	35	v	cnidarian	anemone	anemone large	1	795-805		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d1-36	40	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-37	40	v	fish	macrourid	macrourid	1	795-805		
P4-009-d1-38	40	v	fish	eel	eel	1	795-805		
P4-009-d1-39	40	v	fish	fish	fish small	1	795-805		
P4-009-d1-40++	45	v	fish	macrourid	macrourid	1	795-805		
P4-009-d1-41	45	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-42	45	v	cnidarian	anemone	anemone large orange	1	795-805		
P4-009-d1-43	45	v	fish	squalid?	squalid?	1	805		
P4-009-d1-44	50	v	shrimp	shrimp	shrimp	1	800	19 42.896	156 04.547
P4-009-d1-45	50	v	fish	eel	eel	1	795-800		
P4-009-d1-46	50	v	fish	macrourid	Hymenocephalus sp	1	795-800		
P4-009-d1-47	50	v	cnidarian	anemone	anemone large orange	1	795-800		
P4-009-d1-48	55	v	shrimp	shrimp	shrimp	1	795		
P4-009-d1-49	55	a	fish	plesiobatid	Plesiobatis daviesi	1	800	19 42.979	156 04.578
P4-009-d1-50+++	55	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d1-51+++	55	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d1-52	55	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d1-53	55	v	fish	shark	shark large	1	800	19 42.979	156 04.578
P4-009-d1-54+++	100	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d1-55+++	100	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-1	0	v	amphipod?	amphipod?	amphipod?	3	800	19 42.979	156 04.578
P4-009-d2-2	0	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d2-3	0	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-4	0	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d2-5	0	v	fish	macrourid	macrourid	1	800	19 42.979	156 04.578
P4-009-d2-6	0	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d2-7	5	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d2-8	5	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d2-9	5	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-10	10	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-11++	10	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d2-12	10	v	fish	myctophid?	myctophid?	1	800		
P4-009-d2-13	15	v	fish	macrourid	Hymenocephalus sp	1	802		
P4-009-d2-14	15	v	fish	macrourid	macrourid	1	800		
P4-009-d2-15	15	a	shrimp	pandalid	Heterocarpus laevigatus	1	800		
P4-009-d2-16++++	20	v	holothurian	synallactid	Paelopatides retifer	1	800		
P4-009-d2-17	25	v	fish	myctophid?	myctophid?	1	800-805		
P4-009-d2-18++++	25	v	fish	scorpaenid	Ectreposebastes imus	1	805		
P4-009-d2-19	25	v	crab	crab	crab	1	805		
P4-009-d2-20+++	30	v	crab	crab	crab	1	805		
P4-009-d2-21	30	a	shrimp	nematocarcinid	Nematocarcinus tenuirostris	1	805		
P4-009-d2-22	35	v	none	none	none	0	805		
P4-009-d2-23	40	v	none	none	none	0	805		
P4-009-d2-24	45	v	fish	macrourid	Hymenocephalus sp	1	805		
P4-009-d2-25	45	v	fish	fish	fish small	1	805		
P4-009-d2-26	45	a	fish	plesiobatid	Plesiobatis daviesi	1	793-805		
P4-009-d2-27	45	v	cnidarian	anemone	anemone large orange	1	793-805		
P4-009-d2-28	50	v	fish	eel	eel	1	793		
P4-009-d2-29	55	v	none	none	none	0	793-800		
P4-009-d3-1	0	v/a	mollusk	cephalopod	squid unknown	1	800		
P4-009-d3-2	0	v	shrimp	shrimp	shrimp	1	800		
P4-009-d3-3	5	v	none	none	none	0	800	19 42.979	156 04.578
P4-009-d3-4	10	v	none	none	none	0	795-800		
P4-009-d3-5	15	v	none	none	none	0	795		
P4-009-d3-6	15	v/a	fish	plesiobatid	Plesiobatis daviesi	1	795		
P4-009-d3-7++	20	v	fish	fish	fish small	1	795		
P4-009-d3-8	25	v	none	none	none	0	795		
P4-009-d3-9	30	v	none	none	none	0	795		
P4-009-d3-10	35	v	none	none	none	0	785-795		
P4-009-d3-11	40	v	none	none	none	0	785		
P4-009-d3-12	45	v	none	none	none	0	785		
P4-009-d3-13	50	v	shrimp	shrimp	shrimp	1	785-800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d3-14+++	50	v	fish	plesiobatid	Plesiobatis daviesi	1	800		
P4-009-d3-15	55	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d3-16	55	v	fish	plesiobatid	Plesiobatis daviesi	1	800	19 42.979	156 04.578
P4-009-d3-17	100	v	none	none	none	0	800	19 42.979	156 04.578
P4-009-d4-1	0	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-2	5	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-3	10	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-4	10	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d4-5	10	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d4-6	10	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-7	15	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-8	20	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-9	25	v	fish	fish	fish small	1	795-800		
P4-009-d4-10	25	v	fish	macrourid	macrourid	1	795-800		
P4-009-d4-11	25	v	cnidarian	anemone	hormathiid sp 2?	1	795		
P4-009-d4-12	25	v	shrimp	shrimp	shrimp	1	795		
P4-009-d4-13	30	v	fish	eel	eel	1	795-800		
P4-009-d4-14	30	v	cnidarian	anemone	hormathiid sp 2?	1	800		
P4-009-d4-15	30	v	fish	macrourid	Hymenocephalus sp	1	800		
P4-009-d4-16	30	v	cnidarian	ceriantharian?	cerianthid black?	1	800		
P4-009-d4-17	30	v	fish	myctophid?	myctophid?	1	800	19 43.106	156 04.632
P4-009-d4-18	35	v	fish	myctophid?	myctophid?	1	795		
P4-009-d4-19	40	v	fish	eel	eel	1	795-798		
P4-009-d4-20	40	v	cnidarian	ceriantharian?	cerianthid black?	1	795-798		
P4-009-d4-21	40	v	shrimp	shrimp	shrimp	1	795-798		
P4-009-d4-22	40	v	fish	fish	fish small	1	795-798		
P4-009-d4-23	45	v	shrimp	shrimp	shrimp	1	798		
P4-009-d4-24	50	v	seastar	seastar	seastar	1	760-798		
P4-009-d4-25	50	v	fish	fish	fish small	1	760-798		
P4-009-d4-26	50	v	fish	eel	eel	2	760-798		
P4-009-d4-27	50	v	shrimp	shrimp	shrimp	1	760		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d4-28	50	a	holothurian	synallactid	Paelopatides retifer	1	740-760		
P4-009-d4-29+	50	v	cnidarian	anemone	hormathiid sp 2?	1	740		
P4-009-d4-30++	55	v	cnidarian	ceriantharian?	cerianthid black?	1	730-740		
P4-009-d4-31	55	v	cnidarian	anemone	anemone red	1	730-740		
P4-009-d4-32+	55	v	cnidarian	anemone	anemone large orange	2	730-740		
P4-009-d4-33++	55	v	fish	eel	eel small	1	730		
P4-009-d4-34	55	v	fish	fish	fish small black	1	720	19 43.026	156 04.483
P4-009-d4-35	100	v	none	none	none	1	720	19 43.026	156 04.483
P4-009-d5-1	0	v	cnidarian	anemone	anemone large orange	1	690-720		
P4-009-d5-2	0	v	cnidarian	ceriantharian?	cerianthid black?	1	690-720		
P4-009-d5-3	0	v	cnidarian	anemone	hormathiid sp 2?	1	690-720		
P4-009-d5-4	0	v	fish	eel	eel	1	690		
P4-009-d5-5	0	v	shrimp	shrimp	shrimp	1	680-690		
P4-009-d5-6	5	v	cnidarian	ceriantharian?	cerianthid black?	1	680		
P4-009-d5-7+	5	v	cnidarian	anemone	anemone large orange	1	680		
P4-009-d5-8+++	5	v	fish	squalid	Etmopterus sp?	1	680	19 43.060	156 04.456
P4-009-d5-9	10	v	cnidarian	anemone	anemone large orange	1	660-680		
P4-009-d5-10	10	v	fish	eel	eel	1	660-680		
P4-009-d5-11	10	v	fish	fish	fish small	1	660-680		
P4-009-d5-12+	10	v/a	crinoid	crinoid	stalked crinoid	1	660		
P4-009-d5-13	10	v	shrimp	shrimp	shrimp	1	660		
P4-009-d5-14	15	v	shrimp	shrimp	shrimp	1	660	19 43.058	156 04.419
P4-009-d5-15	20	v	none	none	none	0	660	19 43.058	156 04.419
P4-009-d5-16	25	v	seastar	goniasterid	Ceramasters bowersi?	1	660		
P4-009-d5-17	25	v	cnidarian	anemone	anemone large orange	1	660		
P4-009-d5-18	25	v	fish	myctophid?	myctophid?	1	660		
P4-009-d5-19	25	a	shrimp	shrimp	shrimp	1	660		
P4-009-d5-20	25	a	fish	eel	eel	1	660		
P4-009-d5-21+++	25	v	fish	ophidiid	Pycnocraspedum armatum	1	660		
P4-009-d5-22+++	25	v	cnidarian	anemone	hormathiid sp 2?	1	660		
P4-009-d5-23	25	v	cnidarian	ceriantharian?	cerianthid black?	1	660		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d5-24	30	v	fish	scorpaenid	Ectreposebastes imus	1	650		
P4-009-d5-25	30	v	shrimp	shrimp	shrimp	1	660		
P4-009-d5-26	30	v	fish	fish	small fish	1	660	19 43.020	156 04.412
P4-009-d5-27	35	v	fish	ophidiid	Pycnocraspedum armatum	1	660	19 43.020	156 04.412
P4-009-d5-28	35	v	fish	plesiobatid	Plesiobatis daviesi	1	660	19 43.020	156 04.412
P4-009-d5-29++	40	v	fish	myctophid?	myctophid?	1	690		
P4-009-d5-30	45	v	fish	macrourid	Hymenocephalus sp	1	700	19 42.984	156 04.456
P4-009-d5-31	50	v	none	none	none	0	700	19 42.984	156 04.456
P4-009-d5-32	55	v	none	none	none	0	700		
P4-009-d5-33	100	v	none	none	none	0	700		
P4-009-d6-1+	0	a	fish	scombrid?	scombrid big?	1	700-755		
P4-009-d6-2	0	a	fish	plesiobatid	Plesiobatis daviesi	1	755		
P4-009-d6-3	5	v	none	none	none	0	755		
P4-009-d6-4	10	v	fish	fish	fish small	1	735-755		
P4-009-d6-5+++	10	v	fish	plesiobatid	Plesiobatis daviesi	1	735		
P4-009-d6-6	10	v	cnidarian	cnidarian	cnidarian brown	1	740		
P4-009-d6-7	15	v	fish	eel	eel	1	750		
P4-009-d6-8	15	v	fish	macrourid	Hymenocephalus sp	1	750-755		
P4-009-d6-9	15	v	shrimp	shrimp	shrimp	2	750-755		
P4-009-d6-10	15	v	cnidarian	ceriantharian?	cerianthid black?	1	750-755		
P4-009-d6-11	15	v	cnidarian	anemone	hormathiid sp 2?	1	750-755		
P4-009-d6-12	15	v	fish	macrourid	macrourid	1	750-755		
P4-009-d6-13	20	v	fish	macrourid	Hymenocephalus sp	1	760	19 42.860	156 04.485
P4-009-d6-14	25	v	none	none	none	0	780	19 42.858	156 04.484
P4-009-d6-15	30	v	fish	macrourid	Hymenocephalus sp	1	780		
P4-009-d6-16	30	v	shrimp	shrimp	shrimp	1	780		
P4-009-d6-17	30	v	cnidarian	anemone	anemone large orange	1	780		
P4-009-d6-18	30	v	fish	eel	eel	1	780		
P4-009-d6-19	35	v	fish	macrourid	macrourid	1	780-785		
P4-009-d6-20	35	v	shrimp	shrimp	shrimp	2	785		
P4-009-d6-21	35	v	fish	eel	eel	1	785		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d6-22	35	v	cnidarian	anemone	hormathiid sp 2?	1	785		
P4-009-d6-23	35	v	fish	macrourid	Hymenocephalus sp	1	785		
P4-009-d6-24	40	v	fish	eel	eel	1	780		
P4-009-d6-25	40	v	cnidarian	anemone	hormathiid sp 2?	1	780		
P4-009-d6-26	45	v	none	none	none	0	780	19 43.008	156 04.548
P4-009-d6-27	50	v	shrimp	shrimp	shrimp	1	780		
P4-009-d6-28	55	v	shrimp	shrimp	shrimp	1	775		
P4-009-d6-29	55	v	fish	macrourid	macrourid	1	777		
P4-009-d6-30	100	v	none	none	none	0	780	19 42.954	156 04.553
P4-009-d7-1	0	v	cnidarian	anemone	anemone large orange	1	740-780		
P4-009-d7-2	0	v	fish	eel	eel	1	740-780		
P4-009-d7-3	0	v	fish	myctophid?	myctophid?	1	740-780		
P4-009-d7-4	5	v	cnidarian	ceriantharian?	cerianthid black?	1	740		
P4-009-d7-5	5	v	fish	eel	eel	1	700-740		
P4-009-d7-6++	5	v	fish	fish	fish unknown black	1	700-740		
P4-009-d7-7	5	v	cnidarian	anemone	hormathiid sp 2?	1	700-740		
P4-009-d7-8	5	v	seastar	goniasterid	Sphaeriodiscus ammophilis?	1	700		
P4-009-d7-9	5	v	cnidarian	anemone	anemone large orange	1	700		
P4-009-d7-10	10	v	cnidarian	ceriantharian?	cerianthid black?	1	680		
P4-009-d7-11	10	v	tunicate	thaliacean	thaliacean	1	680	19 42.945	156 04.410
P4-009-d7-12++++	15	v	cnidarian	anemone	corallimorpharian	1	680	19 42.934	156 04.409
P4-009-d7-13	15	v	cnidarian	hydrozoan	tubularid	1	680	19 42.934	156 04.409
P4-009-d7-14++++	20	v	cnidarian	hydrozoan	tubularid	1	680	19 42.934	156 04.409
P4-010-d1-1	0	v	cnidarian;anemone		anemone large orange	1	660	19 42.930	156 04.382
P4-010-d1-2	5	v	none		none	0	660-750		
P4-010-d1-3	10	v	fish		fish small	1	660-750		
P4-010-d1-4	15	v	fish;eel		eel	1	660-750		
P4-010-d1-5	15	v	fish		fish small	1	750		
P4-010-d1-6	20	v	fish;eel		eel	1	750-800		
P4-010-d1-7	20	v	fish		fish small	1	800	19 42.992	156 04.582
P4-010-d1-8	25	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800	19 42.992	156 04.582

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d1-9	30	v	fish		fish small	1	800		
P4-010-d1-10	30	v	fish;eel		eel	1	800		
P4-010-d1-11+	30	v	fish		fish unkown	1	800		
P4-010-d1-12+++	35	v	none		none	0	800		
P4-010-d1-13	40	v	none		none	0	800		
P4-010-d1-14	45	v	none		none	0	810		
P4-010-d1-15	50	v	none		none	0	810		
P4-010-d1-16	55	v	none		none	0	810		
P4-010-d1-17	100	v	none		none	0	810		
P4-010-d2-1+	0	v	fish;macrourid		Hymenocephalus sp	1	810-818		
P4-010-d2-2	0	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	818		
P4-010-d2-3	0	v	fish		fish small	1	818		
P4-010-d2-4	5	v	fish;macrourid		Hymenocephalus sp	1	818		
P4-010-d2-5	10	v	none		none	0	818-825		
P4-010-d2-6	15	v	none		none	0	825	19 43.008	156 04.612
P4-010-d2-7	20	v	none		none	0	825	19 43.008	156 04.612
P4-010-d2-8	25	v	fish;macrourid		Hymenocephalus sp	1	825	19 43.008	156 04.612
P4-010-d2-9+++	30	v	cnidarian;scyphozoan		scyphozoan	1	825	19 43.008	156 04.612
P4-010-d2-10	30	v	fish;eel		eel	1	800-825		
P4-010-d2-11	30	v	fish		fish small	1	800-825		
P4-010-d2-12	30	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800-825		
P4-010-d2-13++	30	v	fish		fish unkown	1	800		
P4-010-d2-14	35	v	fish		fish small	1	800		
P4-010-d2-15	35	v	fish;macrourid		macrourid	1	800		
P4-010-d2-16	40	v	fish;gempylid?		gempylid?	1	800		
P4-010-d2-17	40	v	cnidarian;anemone		hormathiid sp 2?	1	800	19 43.071	156 04.608
P4-010-d2-18	40	v	fish		fish small	1	800	19 43.071	156 04.608
P4-010-d2-19+	45	v	holothurian;synallactid		Paelopatides retifer	1	800	19 43.071	156 04.608
P4-010-d2-20	45	v	cnidarian;ceriantharian?		cerianthid black?	1	785-800		
P4-010-d2-21	45	v	fish		fish small	1	785-800		
P4-010-d2-22	45	v	cnidarian;anemone		hormathiid sp 2?	1	785-800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d2-23	50	v	fish;ophidiid		ophidiid	1	785	19 43.115	156 04.627
P4-010-d2-24	50	v	fish;macrourid		macrourid	1	785	19 43.115	156 04.627
P4-010-d2-25	50	v	cnidarian;anemone		hormathiid sp 2?	1	785	19 43.115	156 04.627
P4-010-d2-26	55	v	fish		fish small	1	800		
P4-010-d2-27	55	v	shrimp		shrimp	1	800-810		
P4-010-d2-28+	55	v	fish;myctophid?		myctophid?	1	800-810		
P4-010-d2-29	100	v	none		none	0	800-810		
P4-010-d3-1	0	v	cnidarian;anemone		anemone	1	800-810		
P4-010-d3-2	0	v	shrimp		shrimp	1	800-810		
P4-010-d3-3+++	0	v	mollusk;cephalopod		squid unknown	1	810		
P4-010-d3-4	0	v	fish;eel		eel	1	805-810		
P4-010-d3-5	0	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	805-810		
P4-010-d3-6	0	a	fish;scombrid?		scombrid?	1	805-810		
P4-010-d3-7	0	v	cnidarian;anemone		hormathiid sp 2?	1	805		
P4-010-d3-8	5	v	none		none	0	800	19 43.189	156 04.688
P4-010-d3-9	10	v	holothurian;synallactid		Paelopatides retifer	1	795-800		
P4-010-d3-10	10	v	cnidarian;anemone		anemone large orange	1	795-800		
P4-010-d3-11	10	v	fish;eel		eel	1	795-800		
P4-010-d3-12	10	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	795-800		
P4-010-d3-13	10	v	fish		fish small	1	795-800		
P4-010-d3-14	15	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-15	20	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-16+++	25	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-17	30	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-18	35	v	none		none	0	795-805		
P4-010-d3-19	40	v	fish		fish small	1	795		
P4-010-d3-20	45	v	fish;macrourid		macrourid	1	795		
P4-010-d3-21	50	v	fish;macrourid		Hymenocephalus sp	1	795		
P4-010-d3-22	55	v	none		none	0	795	19 43.282	156 04.681
P4-010-d3-23	100	v	none		none	0	795	19 43.282	156 04.681
P4-010-d4-1	0	v	none		none	0	795	19 43.282	156 04.681

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d4-2	5	v	none		none	0	795	19 43.282	156 04.681
P4-010-d4-3	10	a	fish;plesiobatid		Plesiobatis daviesi	1	795-820		
P4-010-d4-4	15	a	mollusk;cephalopod		squid unknown	1	795-820		
P4-010-d4-5	15	v	cnidarian;anemone		anemone large orange	1	820		
P4-010-d4-6	15	v	fish;macrourid		Nezumia propinqua?	1	820-850		
P4-010-d4-7	20	v	shrimp		shrimp	1	850	19 43.306	156 04.779
P4-010-d4-8	25	v	shrimp		shrimp	1	850	19 43.306	156 04.779
P4-010-d4-9	25	v	cnidarian;anemone		anemone large orange	1	850		
P4-010-d4-10	25	v	fish;macrourid		macrourid	1	825-850		
P4-010-d4-11	25	v	cnidarian;anemone		hormathiid sp 2?	1	825-850		
P4-010-d4-12	25	v	fish;gempylid		gempylid	1	825-850		
P4-010-d4-13	25	v	cnidarian;anemone		hormathiid sp 2?	1	825-850		
P4-010-d4-14	25	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	825	19 43.292	156 04.738
P4-010-d4-15	30	v	fish		fish small	1	800-825		
P4-010-d4-16	30	v	fish;macrourid		macrourid	1	800-825		
P4-010-d4-17	35	v	fish;eel		eel	1	800		
P4-010-d4-18	35	v	cnidarian;scyphozoan		scyphozoan	1	775		
P4-010-d4-19	35	v	cnidarian;anemone		hormathiid sp 2?	1	760		
P4-010-d4-20	40	v	fish;neoscopelid?		Neoscopelus macrolepidotus?	1	750-760		
P4-010-d4-21	40	v	cnidarian;anemone		anemone large orange	1	750	19 43.265	156 04.636
P4-010-d4-22	45	v	cnidarian;anemone		anemone large orange	1	750	19 43.265	156 04.636
P4-010-d4-23	45	v	cnidarian;anemone		hormathiid sp 2?	1	750		
P4-010-d4-24	45	v	fish;macrourid		macrourid	1	750		
P4-010-d4-25	45	v	fish;eel		eel	1	750		
P4-010-d4-26	50	v	cnidarian;anemone		anemone large orange	1	750		
P4-010-d4-27	50	v	cnidarian;gorgonian		Bathypathes conferta?	1	750		
P4-010-d4-28	50	v	sponge?;hexactinellid?		hexactinellid?	1	750		
P4-010-d4-29	50	v	cnidarian;hydrozoan		tubularid	1	750		
P4-010-d4-30	50	v	fish;macrourid		macrourid	1	750		
P4-010-d4-31	50	v	shrimp		shrimp	1	750	19 43.194	156 04.606
P4-010-d4-32	55	v	shrimp		shrimp	1	745-750		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d4-33	55	v	fish;eel		eel	1	745-750		
P4-010-d4-34	55	v	cnidarian;anemone		anemone large orange	1	745-750		
P4-010-d4-35	100	v	fish;macrourid		macrourid	1	745-750		
P4-010-d5-1	0	v	cnidarian;anemone		anemone large orange	1	745-750		
P4-010-d5-2	0	v	fish;macrourid		Hymenocephalus sp	1	745-750		
P4-010-d5-3	0	v	fish		fish small	1	745		
P4-010-d5-4	0	v	shrimp		shrimp	2	710-745		
P4-010-d5-5	0	v	cnidarian;anemone		hormathiid sp 2?	1	700-710		
P4-010-d5-6	0	v	fish;eel		eel	1	700-710		
P4-010-d5-7	0	v	fish;gempylid		gempylid	1	700	19 43.183	156 04.549
P4-010-d5-8	5	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.183	156 04.549
P4-010-d5-9	5	v	shrimp		shrimp	1	700	19 43.183	156 04.549
P4-010-d5-10	5	v	cnidarian;anemone		hormathiid sp 2?	1	700		
P4-010-d5-11	5	v	cnidarian;anemone		anemone large orange	1	700		
P4-010-d5-12	5	v	fish		fish small	1	700		
P4-010-d5-13	10	v	cnidarian;anemone		hormathiid sp 2?	1	695-700		
P4-010-d5-14	10	v	fish;eel		eel	1	695-700		
P4-010-d5-15	10	v	cnidarian;scyphozoan		scyphozoan	1	695-700		
P4-010-d5-16	10	v	cnidarian;anemone		anemone large orange	2	695-700		
P4-010-d5-17	15	v	fish		fish unkown	1	695-700		
P4-010-d5-18	15	v	cnidarian;anemone		hormathiid sp 2?	1	695-700		
P4-010-d5-19	15	v	cnidarian;anemone		anemone large orange	1	695-700		
P4-010-d5-20	15	v	fish;eel		eel	1	695		
P4-010-d5-21	15	v	fish		fish small	1	700		
P4-010-d5-22	20	v	cnidarian;anemone		hormathiid sp 2?	1	700	19 43.374	156 04.596
P4-010-d5-23	25	v	fish		fish small	1	700	19 43.374	156 04.596
P4-010-d5-24	25	v	sponge?;hexactinellid?		hexactinellid?	1	700	19 43.374	156 04.596
P4-010-d5-25	25	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.374	156 04.596
P4-010-d5-26++	25	v	fish;macrourid		macrourid	1	700	19 43.374	156 04.596
P4-010-d5-27	30	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.374	156 04.596
P4-010-d5-28	35	v	none		none	0	700	19 43.374	156 04.596

Key:

Record #:	This field can be used as the index field for PIs who wish to export this file into Microsoft Access. Each record # provides the vehicle (i.e. P4 for Pisces IV), dive # (i.e. 008), tape format, tape number (i.e. d1= digital tape 1), and record number for each organism observed or mentioned on the videotapes. In addition, one or more "+" at the end of the record indicate that the image of the organism is better than average or the organism is of particular interest. Videocaptures were only made of images that were rated ++, +++, or ++++. These records will also have the exact video counter for the image in the notes section (see below).
Int:	For the purpose of providing a rough estimate of the number of observations made of each species during the dive, the tape was analyzed in 5-minute intervals. Interval 0 corresponds to the 0-5 minute interval while interval 115 corresponds to the interval between 1 hr and 15 minutes and 1 hr and 20 minutes. If the PI so chooses, he can use the intervals essentially as sampling units to analyze the data.
A/V:	The A/V field identifies the observation as an audio (a) or video (v) record. If v/a is the code, that means that the animal is visible on the video, however, its identification was based on the audio record.
Org Type:	This field is for the two most general descriptions of the observed organism. A semicolon is used in this field and other fields as a delimiter to provide flexibility in searchs.
Org Name:	This field is for the most detailed description of the organism that we could make (to genus and species when possible).
Org #:	This field is for the estimate of the animal's abundance. The values are 0 (none, only used when no organisms of any species are observed in a 5 minute interval), 1 (1-5 organisms observed), 2 (6-10 organisms observed), and 3 (greater than 10 organisms observed). Again, due to time constraints, it was not possible to obtain an exact count for each species.
Depth:	This field is for the depth the observation was made. When the precise depth is not known, the value will be a range between the closest recorded depths before and after the observation. All values are in meters water Depth
Latitude:	The latitude the observation was made, when known.
Longitude:	The longitude the observation was made, when known.

APPENDIX F: CULTURAL IMPACT ASSESSMENT STUDY

Potential Effects of the Proposed CO_2 Ocean Sequestration Field Experiment on Traditional Fishing Sites, Keähole, Kona, Hawai‘i

Prepared for:

Pacific International Center for High Technology Research (PICTHR), Honolulu, Hawai‘i, in collaboration with Planning Solutions, Inc., Honolulu, Hawai‘i

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November 14, 2000

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This report was made possible by the gracious participation of individuals who shared their history of the land and waters of the Keähole area. It is the memories of *küpuna* Robert Ka‘iwa Punihaole Sr., George Kinoulu Kahananui Sr., John Hills Ka‘iliwai, Valentine Ako, and Eddie Ka‘ana‘ana that illustrate the significance of the project area. A special thanks goes to each of them for sharing their histories.

Introduction

The following report presents the results of a study of "Traditional Fishing Sites at Keähole, Kona: an Assessment of Potential Effects of the Proposed CO_2 Ocean Sequestration Field Experiment". The study, based on oral histories, was done by Social Research Pacific, Inc. (SRP), with the assistance of Kumu Pono Associates. It was completed for Pacific International Center for High Technology Research (PICTHR), Honolulu, Hawai‘i, in collaboration with Planning Solutions, Inc., Honolulu, Hawai‘i.

This study was completed to meet Section 106 Consultation requirements of the National Historic Preservation Act (NHPA) (under 36 CFR 800). It directly responds to requests made during the Section 106 review process of the Environmental Assessment (EA)(U.S. Department of Energy, 2000). The interviews, conducted between September 28 and October 24, 2000, were done with Hawaiian *küpuna* primarily on the island of Hawai‘i. The *küpuna* (Hawaiian elders) included those recommended by the State of Hawaiian Office of Hawaiian Affairs (OHA). The study also aimed to satisfy the Hawaii State Historic Preservation Office's (SHPO) request of identifying traditional fishing sites in the vicinity of the project area. This request was met by holding interviews with *küpuna* who have fished in and around the Keähole area, and could identify traditional fishing practices and sites.

This report presents a glimpse of the cultural resources in the area, including the *küpuna* themselves; it is by no means an exhaustive effort looking at native Hawaiian traditions and practices in the Keähole area. Following a brief introduction to the purpose of the study, project area and study approach, the oral histories are presented. The results of the study are presented at the end of this report, and include a review of the six areas identified for assessing cultural impacts.

Purpose of the study

The purpose of this study was to assess the potential effects of the CO_2 Ocean Sequestration Field Experiment on native Hawaiian cultural resources in the area. Cultural resources as pertaining to this project, includes practices, beliefs and traditions associated with an area's significance. The primary objective of the project was to gather information through interviews with individuals knowledgeable about the area and its significance as an ocean resource to native Hawaiians. The project entailed identifying individuals who could provide such information (interviewees), arranging and conducting the oral interviews, and preparation of this report. Interviews completed on the island of Hawai‘i were arranged for by Kepä Maly of Kumu Pono Associates.

Applicable Federal and State Guidelines

Federal and state guidelines for conducting social and cultural impact assessments follow the same principals and similar procedures. At the federal level, Section 106 of NHPA defines the process by which these assessments are to be completed. Given the location and goals of the project, guidelines established under the National Environmental Policy Act of 1969 (NEPA), specifically, section 40 CFR 1508.8, also apply to this study. Hawaii state guidelines help to further define the applicability of these procedures to the local context. A standard approach for evaluating direct and indirect impacts was considered inappropriate for this study since these generally address stationary and/or physical features; the project area is completely water-bound, and information on its significance is based primarily on oral histories. Given the unique nature of this project, as discussed below, state guidelines that also meet the federal criteria are considered acceptable for compliance with Section 106 procedures.

The State of Hawai‘i, under Articles IX and XII of the State Constitution of Hawai‘i (Chapter 343, HRS), requires government agencies to promote and preserve cultural beliefs, practices, and resources of native Hawaiians and other ethnic groups. As such, preparers of environmental impact assessments and statements need to study the impacts of a proposed action on cultural practices and features associated with a project area. The “Guidelines for Assessing Cultural Impacts”, adopted by the Environmental Council of the State of Hawai‘i, on November 19, 1997, identifies the protocol for conducting cultural assessments. The impacts addressed by this study look at the ocean as a cultural resource to the people of the Keähole area. Though the subject matter of the study is neither common nor usual, the project was completed following the protocol established by the Environmental Council.

The Project Area

The project area is located seaward of Kona International Airport and the Natural Energy Laboratory of Hawaii Authority (NELHA), at Keähole, Hawai‘i. Figure 4-1 shows the exact location and boundaries of the project area. The project area proper has no adjoining land boundaries, however, the nearest coastline spans over several *ahupua‘a* boundaries.

The Study Approach

An ethnohistorical approach was taken, with the primary emphasis placed on oral interviews with individuals who could share knowledge about traditional uses of the project area. Since the project area is located in the ocean, and since a major objective of the study was to identify traditional fishing sites (as requested by the SHPO), efforts were made to interview *küpuna* who had been fishermen in these waters. All of the *küpuna*, except for Eddie Ka‘ana‘ana who is from the village of Miloli‘i, have been fishing in the area since they were children. It should be noted that while the project area does not consist of any land area per se, the traditional Hawaiian system of *ahupua‘a* includes the ocean waters which front the landmass. Land resources are discussed only briefly in this report.

Both formal and informal interviews were conducted; these took place between September 28 and October 24, 2000. The goal of the formal interview was to:

1. identify traditional uses of the project area and its surrounding vicinities;
2. identify traditional fishing sites in the vicinity of the project area;
3. identify cultural features (other than ocean-bound) in the area;
4. identify stories, legends and beliefs that may describe traditional uses of the area; and
5. obtain information on if and how the proposed project may impact or effect traditional practices in the area.

While the primary method of obtaining information was through the oral interviews, the study also involved the following tasks:

1. Review of literature to identify known historical areas of significance
2. Identification and location of sources/individuals to interview
3. Conducting interviews on Hawai‘i (and O‘ahu)
4. Translation and transcription of interviews
5. Preparation of draft report

Oral Histories: Interviews with *Küpuna* and others

A total of five *küpuna*, four of whom are current residents of the Kona-Keähole area, were interviewed for this study. In addition, eight other individuals from the island of Hawai‘i shared their knowledge and information about traditional uses of the project area and its surrounding vicinities. Appendix F(1) provides a list of the names of individuals interviewed and/or contacted for this project, and their current residence.

The *küpuna* are all fishermen. All have fished off the waters at Keähole Point, some more regularly than others. They continue to fish in the Keähole area, however, more as a leisure activity than one based on subsistence. Although they differ somewhat in age and the time period during which they became fishermen, their recollections and experiences reveal a great deal of similarities. This is attributed to the consistency in the tradition and practices required for knowing (a) when, (b) where, (c) what and (d) how to fish.

Oral accounts leave little doubt that the cultural practices of native Hawaiians were passed on through the generations, and have continued with each successive generation. Interviews with family members representing more than one generation indicates the degree to which these "traditional ways of doing things" can and does persist. While much of the information shared during the interviews is based on personal accounts, some individuals also shared the lore passed on from their ancestors. Their knowledge of things Hawaiian (a.k.a. traditional) can be assumed to be remnants of how the land and the sea were used during traditional times.

<u>The Interview process</u>

Selection of people to interview was done primarily by locating individuals and families of Hawaiian ancestry, who had lived in the Keähole area and/or had knowledge about the waters off of Keähole Point. OHA was first contacted for recommendations of individuals to interview. As mentioned earlier, interviews with *küpuna* on Hawaii were identified and arranged for by Kepä Maly.

After personal introductions, the interviews proceeded with a summary presentation of the project (including a map of the project area), followed by recollections and narratives of the traditions and uses of the area. The final portion of the interviews entailed questions and answers directed at the interviewer about the project. This allowed the interviewer to elicit responses directed towards whether there would be specific cultural impacts as a result of the project.

In addition to formal interviews, numerous discussions and informal interviews were held with individuals and groups who provided names of Hawaiian *küpuna* and/or knowledgeable community residents. Among these were individuals who have knowledge about the proposed project and shared their views, not necessarily based on personal experience in the area, but on the basis of knowledge and interest in the general cultural traditions and practices of Hawaiians.

Results of the Study

The oral interviews allowed the opportunity to gather information which supplement existing written histories of the project area and its vicinities. The significance of the interviews with the *küpuna* is that these are men who are actively [still] using the waters in and around the project area for their fishing activities. Traditional, and current, fishing sites in the Keähole area are numerous. Many of these sites have been previously documented (see the narratives of J.W.H. Isaac Kihe and John Ka'elemakule, recently translated by Kumu Pono Associates, in Appendix F(2)).

Responses to known or recorded information (e.g., written accounts, historical literature and archaeological findings) and new information resulting from the interviews are grouped into three areas: deep-sea fishing, near shore fishing and Keähole Point. These areas summarize the types of “traditional uses” that can be recalled or verified from the area, and are not meant to be exhaustive of all possible types of traditional activities. The author fully acknowledges that near shore and land-based cultural resources, e.g., Keähole Point, would not be separated in the context of an *ahupua‘a*, in other circumstances. This section is presented by using direct quotes (cited in quotations, with bullets) from the *küpuna*, combined with general descriptions and discussions.

Deep Sea Fishing This is within the immediate vicinity of the proposed project area. All of the *küpuna* recall fishing from Keähole out to the deeper ocean. It is an area where both traditional and modern types of fishing continue to the present day. As some of the narratives tell, traditional methods and knowledge that identified where to fish and what to fish for, hold greater value than modern methods for deep-sea fishing. Using a 1981-82 Loran marker map (provided by Valentine Ako), the fishermen were describing the *‘ahi* grounds that extend from Kïholo to Keähole. Among the observations shared by *küpuna* Robert Punihaole, George Kahananui, Valentine Ako, and John Ka‘iliwai, were the following:

- “The traditional fishing grounds extended well beyond the 1+ mile marker shown. The main current heads north…these are where the *aku* grounds are…north side of the island. This area was once both *aku* and *ahi* grounds. Hawaiians used to go fishing way out…maybe about 5-6 miles, and would judge their whereabouts by the clouds. If you weren’t with an experienced navigator, you’d be dead out there.”

- [For] “Deep Sea Fishing today, you gotta go look where they stay…we used to walk with the fish…today you gotta go look where they stay. I used to be able to tell him [*küpuna* Punihaole pointing to his son, Kalei] to go fish for *äholeahole* anywhere. Today I can drive for two hours, but still see no fish. Where the fish all bite, there’s no more the numbers you used to see. You would be able to see acres of *‘ahi*. There were times outside of Keähole, fish would come in a ‘ball’ and you could scoop them up with a bucket. You’d catch no water, only the fish. Its not there no more.”

The following excerpt from Kona elder, John Ka‘elemakule (1854-1935) tells of the importance of deep-sea fishing in the earlier part of this century:

> Let me tell about the customs of fishing in the deep sea, for these are among the things that were practiced by my foster father Kaaikaula, and that he taught to me. Among the important fishing practices of Kekaha, that I was taught in my youth were *aku* fishing, *ahi* fishing, and fishing for *‘öpelu* with nets. These were the important fishing customs that I was taught… Fishing for these fish was done at the *ko‘a ‘öpelu* (*‘öpelu* fishing station or grounds), that was not too far out. And beyond that, was the *ko‘a* for *aku* and *‘ahi* fishing. The *ko‘a* for these fish (the *‘ahi* and *aku*), was the famous *ko‘a lawai‘a* (fishing ground) of Kekaha, known by the name, “Haleohi‘u…” (in *Ka Hökü o Hawai‘i*, November 13, 1928:3; translated by Maly).

<u>Ko‘a – traditional fishing grounds or stations</u>

Ko‘a are fishing grounds or stations out at sea, and knowledge about them is passed on through generations of fishermen. There were and are several within the boundaries of the project area, that are used currently by fishermen. The following narrative from Kihe (in *Ka Hökü o Hawai‘i* – translated by Maly), describes the *ko‘a* off of Keähole; some of these same *ko‘a* were referenced by the *küpuna* during the oral history interviews:

> It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (*ka wili-au*) that flow with the passing current… And there in front of this point, in deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (*muliwai*), and then flow out. It is on that side, that you will find the *ko‘a* (fishing stations) for *aku*, *‘ahi*, *kähala*, *‘öpakapaka* and such. Among these *ko‘a* are Päo‘o, ‘Öpae, Kahakai, Kapapu, Kanaha-ha, Kaluahine, Kanukuhale, Kaho‘owaha, Honu, Muliwai (from where one peers upon the dirt of Hä‘ena, Kohala), and Kaihuakalä, Maui… There are many other *ko‘a*, but these that I’ve mentioned, are the famous *ko‘a*. There are many deep *ko‘a* all in a line, from the Point of Keähole to the Point of ‘Upolu and the *heiau* of Mo‘okini in Kohala (Kihe, October 11-18, 1923).

The following excerpt from the tradition of Ka-Miki (in *Ka Hökü o Hawai‘i*; 1914-1917 – translated by Maly) tells of the *ko‘a* in the Keähole area:

> …In no time the canoe was filled with more than 400 *aku*. An amazing thing is that though Pili’s fishermen and all the fishermen of Kekaha were fishing at Kaka‘i, Kanähähä (Hale‘ohi‘u), the entire ocean from the *ko‘a* of Kapapu (Keähole vicinity) to Kahawai (at Ka‘üpülehu); none of them caught any fish at all…The *aku* school was at the *ko‘a* of Päo‘o, also known by the names Ka-nuku-hale and Päo‘o-a-Kanukuhale; the bonito lure fishing grounds which extended from Kaulana to Ho‘onä, fronting Keähole, which is the source of the (supernatural) currents Ke-au-kä…(Kihe & Wise *et al*. in *Ka Hökü o Hawai‘i*; October 11, 1917)

The *küpuna* discussed how more than one *ko‘a* could be used…this knowledge is still applied to deep-sea fishing today:

- “We used about 3 or 4 ko‘as to fish in the Keähole area….that whole area was all our fishing grounds and I would not want any desecration in that particular area. We used to fish all the down from Kïholo down to Keähole. This included swordfish, *‘ahi* (*kabachi shimi*)…that type of *‘ahi* didn’t have a yellow fin and would grow up to only 90 lbs… *kü kaula* fishing (about 25 to 70 fathoms). The schools would be along the ledge. If you came in, you’d catch *ulua*. When the *‘ahi* bite, you never let ‘em go down again, other wise burn, the meat…”

- “Depending on what type of fishing you’re doing, you go out farther or not. *‘Öpelu* was closer…you go farther out, you get larger fish like *kawakawa* and *ulua*, still further off, you get much larger fish. The *ko‘a* out there [pointing near the point], is the *ko‘a weke;* way inside from 15 to 35 fathom, you can get *weke la‘o*."

Along with knowledge about when and where to fish, the *küpuna* shared some of their traditional methods of attracting and replenishing fish. First, the bait they used was always fresh. They never used *pilau* (stink bait or rotten bait) for catching fish. The *küpuna* stressed how important it was to show respect of eating fresh food…the same courtesy was extended to the fish also.

- "In the younger days, old stink bait was never used; stale bait brings on the sharks. And if you feed dirty food to your fish, you'll eat the dirt as well… We never use pilau, or what this generation now calls '*make* dog.' We cared for the ko‘a, and would not pollute it…"

Along with using fresh bait, feeding the *ko‘a* on a regular basis was also done traditionally…

- "To keep them at home, we'd go feed the *ko‘a*. These would extend from near shore at Keähole to Honoköhau, on the south, and from Keähole to Makalawena and Küki‘o on the north. The *ko‘a ‘öpelu* at Honoköhau was not too far away from shore. They feed the main *ko‘a*. From the black sand of *Pelekane* (on the boundary of Haleohi‘u and Maka‘ula), all the way down, all the *ko‘a* along there would be fed. We'd go out about 100 yards to up to 2 miles out. The formation of the ground is what determined the path we'd take. We would also *ho‘omaha*, let the grounds rest…[we] were careful about what we took."

Near Shore Fishing. Use of the near shore area for fishing continues to the present day. Both modern and traditional fishing methods are used. [Although the near shore fishing resources would not appear to have direct impacts, deeper currents are known to carry to the shoreline areas.] Among the most popular form of near shore canoe fishing (any where from a few hundred yards to a mile off shore) was for *‘öpelu*. As told in the following text by John Ka‘elemakule (in *Ka Hökü o Hawai‘i*; translated by Maly), the Kona area was noted for *‘öpelu* fishing:

> …*‘Öpelu* fishing was another one of the important practices of these islands in ancient times; it was perhaps the foremost of the practices in the streaked sea (*kai mä‘oki‘oki*) of Kona. It became the type of fishing that contributed to the livelihood of the fishermen and their families… For *‘öpelu* fishing, two men are adequate in going on the canoe to the place of the *ko‘a ‘öpelu* which has been known since the days of the ancient people. It is at a place where one can look below and see the fish, that he prepares to feed the *‘öpelu*. The man at the front of the canoe is the fisherman, the one who is prepared for this manner of fishing, he leads in all things for this kind of fishing.
>
> There in front of the fisherman was set out the bait of the *‘öpelu*, that is the *‘öpae ‘ula* (red shrimp) and sometimes other baits as well. He'd give the man at the back of the canoe the bait, this man would do whatever the fisherman told him to. The man in the back had a stone weight, the black dirt, and the coconut sheath in which the *‘öpae ‘ula* or other bait would be placed and

> folded in. This would be wrapped with cordage and let down into the water about 2 or three fathoms deep, then the man would jerk the cord and the bait would be released… (March 5, 1929:4)

The *küpuna* recall that there were plenty of *'öpelu* fishermen in Kailua. Among them were George Ka'iliwai (John Ka'iliwai's father), Hattie Hart, and Kolomona Ka'elemakule. They recall using *limu* and *'öpae 'ula* for catching *'öpelu*:

- "You could see the *'öpelu* on the surface. Depending on what type of fishing you're doing, you go out farther or not. *'Öpelu* was closer in (about 40 feet)…the *ko'a weke*, is way inside from 15 to 35 fathom; you can get *weke la'o*. I used to fish by myself… At another noted place, just north of Keähole, we caught the *kole nuku heu*. It's light brown color – about 15-30 feet deep. I don't know if these fish are still there."

Eddie Ka'ana'ana, once an avid *'öpelu* fisherman, emphasized the importance of the technique/method used for*'öpelu* fishing. This included not just knowledge about the area, the *ko'a*, but also knowledge that could be applied when fishing for *'öpelu* on any of the islands.

Val Ako remembers Kipi Wa'ahila as the first person to catch Kona crabs.

> "…Kipi had a *koa* canoe that he would go out in all the time. He always took plenty dry coconut with him and guava sticks. He would go out there and prepare the nets and everything. He'd come home loaded with Kona crabs, 'and not the small kind eh'. We had a smart man, Ernest Pua, he asked Kipi how he caught the crabs, and finally Kipi told him. Ernest made the nets and began catching them by larger numbers. Later, there was a Filipino man hanaied by a Hawaiian family in Wai'anae. He knew that Wai'anae coast also had Kona crabs, and began fishing for them there. 'Now they're wiped out in Wai'anae too'. Now in Kaua'i, my fishermen friend, they catch Kona crab, and say that every time they catch Kona crab, they use fish head and smelly things."

Keähole Point According to *kupuna* Kinoulu Kahananui, Keähole translates as — *Ke* (the), *ä-hole* (water banging together, twisting). *Ä-holehole* means "water banging, twisting together", where two currents blend together..."Very seldom is the area there calm, its usually bubbling, boiling." The naming of Keähole is not after the fish *äholehole*, but after these unique currents. *Kupuna* Kahananui had previously provided an extensive description of the naming of Keähole to Kepä Maly; this can found in Appendix F(3).

While discussing the nature of the sea and currents at Keähole, and the divisions of the fisheries, the *küpuna* also commented:

- "…We can go down there right now, to Keähole Point, and look and see right in front of your eyes. Very seldom is it calm; most of the time its boiling, boiling…"

- "…Keähole was also the division for various fish. The people of Makalawena fished to the north of Keähole. These were traditional boundaries observed by all fishermen of the island…."

<u>The Currents off Keähole</u>

The following description of Keähole was written by J.W.H. Isaac Kihe (in *Ka Hökü o Hawai‘i* – translated by Maly):

> That stone which is situated in front of the Point of Keähole, is called by its name Keähole, and it is for this stone that the point is called Keähole to this day…(Kihe in *Ka Hökü o Hawai‘i*; October 11-18, 1923).

The *küpuna* recall that there are special currents off of Keähole Point; where they meet, you can see “boiling”. This place is referred to as *Lelewai*, where the water leaps, “boiling” area. (Ho‘onä is the calm place and it is to the right of this current).

The importance of Keähole’s unique currents is captured in the following excerpt from Kihe (ibid.):

> It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current… (Kihe in *Ka Hökü o Hawai‘i*; October 11-18, 1923).

The story of Ka-Miki also tells of the significance of Keähole’s currents:

> …the bonito lure fishing grounds which extended from Kaulana to Ho‘onä, fronting Keähole, which is the source of the (supernatural) currents *Ke-au-kä*, (The current which strikes), *Ke-au-käna‘i* (The current of smooth waters), and *Ke-au-miki* (The current which pulls out to the deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by Mäkälei… (Kihe and Wise *et al*. in *Ka Hökü o Hawai‘i*, October 11, 1917; Maly translator).

The *küpuna* also spoke of stories they were told about the old fishpond [*Pä‘aiea*], which was buried under the flow of 1801.

- “The canoes actually came into the fishpond, inland from the current, and then went back out. It was easier coming in and going back out then to go around because of the current. They used *Pä‘aiea* fishpond, to get back to land”.

According to the *küpuna*, currents were also very significant in determining which place to fish. The location of *‘öpelu* could be determined by the current/undercurrent. Currents also have tremendous influence on the nutrients for the fish, and on the availability of fish.

- “The current off Keähole Point, the white current (appears to be approximately 100 yards offshore), is where *‘öpakapaka*, *‘ula‘ula*, and *kümü* are found. It’s already very deep out there… There’s also a ‘dead spot’ near Kawaihae…an area they all got to know, and stayed away from (an area where there is no fish).”

- "It's like a good [the nutrient value] *ko'a*, the fish bite all the time. If the current's not right, you can sit there 2 to 3 hours and nothing will happen. When the current starts to move however, you're only given about 1-1/2 hrs. to fish and its plenty good at that time."

- *"Kona kai mäʻokiʻoki* (the streaked sea of Kona) is so named because of the current lines [from Kekaha, the *küpuna* point out to where these black current lines appear off of Keähole]. These black lines reflect the formation of the ground. When you see an upwelling in the current, that's when the nutrients are coming up for feed."

- "Observing of currents could be done both by watching the waves from markers on shore and from out at sea."

Once out at sea, the currents had an influence over how and when the fishermen could come back to shore. The following description of "Hoʻonä indicates that it offered a place of refuge when the waters became too rough:

- "Hoʻonä was the place where the water would stay calm… About ¾ to a mile out in the sea, is where the waters mix and be so rough. We had a song for Kona that we used to sing when fishing out there. When it came too rough, we would go in to Hoʻonä for shelter because we couldn't come back in towards Kailua. We could be stuck there for about 4-5 hours and the captain said that we should get back before dark fall [when the lights go out…during the war period]. Hoʻonä is a quiet area, so it was used as a waiting grounds before trying to go back into the landing."

Along with deep sea and near shore fishing practices, the following types of subsistence activities related to fishing, took place off and near the shores of Keähole in traditional times:

1. Shellfish collecting (Kona crabs, *ʻöpihi*, *wana*)
2. Limu gathering
3. Gathering salt from salt pans

Some of these practices, such as gathering salt and *limu*, continue today. Practices that have been abandoned are due to a variety of reasons, including lesser availability of and/or access to resources. Although *Päʻaiea* fishpond no longer exists, it is referenced as a source for subsistence activities in traditional times.

<u>Archaeological and Historical Features in the Keähole area</u>

Although the project area will not have a visible physical impact on the land, the Keähole area is also known for several archaeological and historical features; these are briefly mentioned here. These include the *Mämalahoa* (the old government road) and the *ala loa* (now referred to as *ala Kahakai)* trails. Val Ako, who was born in 1926, remembers that there were various trails leading from Keähole to Hualälai. He remembers, "there were boulders, stepping stones all the way up Hualälai Mountain…they're all gone…they were all blue rock". Though no remnants appear to exist of the fishpond of *Paaiea*, stories about it have passed down through the generations. An extensive description of *Paaiea* fishpond is found in Appendix F(2) (see *Ka Loko o Paaiea*). As indicated in the following narrative by

Kihe (in *Ka Hökü o Hawai'i* – translated by Maly), among the cultural features in the area were:

> It was at Ho'onä that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one the canoe landings of the place. Today, it is where the light house of America is situated. Pelekäne is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *pähoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today. (J.W.H.I. Kihe in *Ka Hökü o Hawai'i*; compiled from the narratives written February 5-26, 1914 and May 1-15, 1924).

Previous oral interviews with area residents also tell of a possible *Könane* board (ancient Hawaiian checkerboard), located in fairly deep water off the shoreline, and burial sites in the area (see Dye and Prasad 2000). These features have not yet been confirmed by archaeological studies.

<u>Documentary Information</u>

Although a comprehensive review of written accounts of the project area was beyond the scope of this study, among written sources that tell of the traditional significance of this area, are the translations completed by Kumu Pono Associates (1998). These include the writings of J.W.H. Isaac Kihe and John Ka'elemakule, native authors writing in Hawaiian newspapers between 1907 and 1929. Portions of their narratives have been cited in the body of this report; the complete narratives are found in Appendix F(2).

Oral histories, other than those completed by Maly, include "A Social History of Kona: Vol. 1 and II". This report presents the results of an oral history project done with residents from the Kona area, by the Ethnic Studies Program at the University of Hawaii (1981). Its emphasis is on the general experiences of these individuals and includes accounts of non-Hawaiian residents. A review of this report helped gain background information on individual's recollections of the history of this area. While little information was provided on issues relating to shoreline access or historical sites, individuals of Hawaiian ancestry in particular, elaborated on land use in the area in the earlier part of the 20th century. Fishing was a "chief livelihood" at the turn of the century, and "the shores were lined with coconut which the Hawaiians used for food and a variety of other means" (1981:A6). Also, ethnic breakdowns indicate changes that were taking place in the Hawaiian community, who numbered only 20 by 1932. In comparing this figure with informants' [from the current study] recollections about settlement in the area, the numbers do not appear to adequately represent the rather large Hawaiian community in the Kona area. Otherwise, the 1981 interviews do indicate the importance of fishing for Kona-area residents.

In addition to oral histories from individual sources, documentation exists on traditional fishing rights in the area; these were established during Kamehameha III's rule. The *konohiki* fishing rights granted use of the area extending from the beach to the outer edge of the reef, or one geographic mile seaward. Kamehameha III also recognized traditional deep sea fishing grounds (*ko'a*), in waters up to 1,800 feet (MacKenzie 1991 in U.S. Department of Energy, 2000).

Summary: Assessing the Potential Effects to Cultural Resources in the Project Area

Based on information gathered from interviews with Hawaiian *küpuna* and members of the Hawai‘i community, the project area is highly significant as a traditional (and current fishing) site for native Hawaiians. It is also, largely by association, connected to a larger repertoire of traditions and practices associated with the lands of the area. The interviews provided both new information and enhanced information known from previous written accounts.

Potential Effects to Traditional Fishing Sites

Given the experimental nature of the proposed project, the potential effects of CO_2 sequestration on traditional cultural resources (e.g., fishing sites) are difficult to determine at this stage. Even if the project was not experimental in nature, the dynamic conditions of the sea (movement of water, weather conditions, nutrient quality, etc. at any point in time) itself create an unpredictable context in which to make adequate analyses. For the same reasons, it is equally difficult to comment on short or long-term effects of the proposed project on [culturally] valued ocean resources.

However, what is known is the area’s value as a cultural resource. Both traditionally and currently, oral histories tell of the significance of the waters off Keähole Point. Any activity that compromises or changes the nature of this resource, can be seen as having a negative impact. These compromises/changes can include: accessibility to the resource, availability of the resource, and temporary or permanent changes to the quality of the resource.

While an adequate evaluation of potential effects to cultural resources cannot be made in this study, the interviews indicate that overall, there is strong sentiment against the proposed project. These areas concerns/issues raised can be grouped into four major categories:

1) the absence of knowledge or lack of knowledge about the proposed project;
2) the possible negative impacts the experiment may have on the fisheries and waters in the area;
3) a lack of understanding about the area; and
4) the current impacts on the fisheries.

It should be noted that none of the *küpuna* interviewed were aware of the project prior to this study, and that, the information they shared about the traditional practices and beliefs of the area preceded any discussions about the proposed experiment. The latter was done to achieve the goal of identifying native Hawaiian traditions and beliefs associated with the project area without bias; presentation of the proposed experiment was not an objective of this study.

Absence of knowledge or lack of knowledge about the proposed project

With the exception of a few members of the community who have been following the proposed project and are interested in its progress, others interviewed, specifically the *küpuna*, expressed that there has been a complete lack of communication with the community about the project. A recurring question raised by interviewees was what is the material [in reference to CO_2] and from where is it being brought in. They feel that a meeting and presentation of the project should be made by the designers of the project. [Although recommendations are not within the scope of the current study, it is felt that information shared on a first-hand basis would be highly welcomed by the *küpuna*. All of them expressed their willingness to hear and learn more about the proposed experiment.]

Possible negative impacts the experiment may have on the fisheries and waters in the area

Since the area is a highly valued fishing grounds, the implications and possible deleterious effects of the proposed project on the fisheries, are in question. There is fear and doubt, some of it due to past experiences with projects done in the area. Cited was the example of the *taape*, a fish from Tahiti that was apparently introduced to Hawaiian waters in an effort to help replenish local stocks. Since its introduction, the numbers of *taape* has quickly risen, possibly due to its predatory nature on indigenous fishes.

There is great concern about the impact on the fisheries in the area; the "unknowns" associated with the experiment worry these *küpuna* fishermen. In the absence of knowledge about the proposed project, the idea of an "experiment" increases doubts and questions about its possible effects. The two questions most often repeated were:

1. why is the experiment being proposed for this area specifically Kona, and for the island of Hawaii in general?
2. what assurance is there that the experiment won't backfire? (Comparisons were made to the problems resulting from introduction of the *taape*).

A lack of understanding about the area

There is specific information about the project area that better describes sites and features which make the waters off of Keähole Point a special fishing grounds. This information known and described by the *küpuna* (fishermen), is not shown on the map prepared for the Environmental Assessment (U.S. Department of Energy, 2000) of the project area. [If a presentation of the project is made to the *küpuna*, this information on traditional areas and practices, can be collected and illustrated].

Another concern was the lack of application of the concept of *ahupua'a* to the project area. Traditional and cultural customs and practices involve addressing the entire *ahupua'a*. The project area adjoins a landmass which covers several *ahupua'a* (as with Kona International Airport and NELHA). Since these waters are considered within this traditional designation, the broader context of an *ahupua'a* may need to addressed.

Current impacts on the fisheries

An area of major concern to *küpuna*, fishermen and residents in the Kona area is the impacts of existing activities (not related to the proposed project) on the fisheries in this area. This is based on (a) an actual supply [reduction] of resources, and (b) limited or restricted physical access to shoreline areas known previously as prime fishing grounds. The reduction in the supply of fish resources is associated with general competition from other fishermen (both subsistence and commercial), changes in fishing techniques (use of drift nets), change in the quality (nutrients) of the waters, and the activities of NELHA. Although these changes are related to other events, in general, people see NELHA's use of the area has having seriously changed the availability of ocean resources in the Keähole area.

An example of changes attributed directly to the presence of NELHA is cited by *küpuna* Ako. According to him, a black sand beach beyond Keähole lighthouse that was a very good fishing ground, was completely destroyed during NELHA's attempts to raise algae. Also, there was easier and greater access to salt ponds in the area; some of these have completely disappeared or are no longer good areas for collecting salt. While these issues may not be directly related to the proposed project, the events are etched in the minds of these *küpuna* and residents.

In addition to the concerns and issues raised by Hawaiian *küpuna* relating directly to the proposed CO_2 experiment, issues and interests of Hawaii based organizations that address impacts on cultural resources, may also need to be considered. Among these are Public Access Shoreline Hawaii (PASH), and the *Kohanaiki Ohana;* both groups are concerned with traditional and cultural rights of Hawaiians in the Kona area (c.f. Native Hawaiian Bar Association, 1997; Office of Planning, 1998). PASH in particular is concerned with (a) limited access to the shoreline within the vicinity of Kona International Airport, (b) access to prime fishing grounds, and impacts to aquifers and sea beds, and (c) boundaries compromised and/or seen as inseparable from NELHA.

<u>Application of the Environmental Council Guidelines for Cultural Impact Assessments:</u>

Efforts were taken to meet the Environmental Council's guidelines for conducting cultural impact assessments. An evaluation of the council's six-point protocol is offered below. As noted in the introduction and preceding section of this report, a standard approach for identifying direct and indirect (potential) impacts was not considered appropriate for this study since the project area is completely water-bound, and information that tell of the area's significance are connected almost exclusively to oral accounts. There are no stationary or physical features per se.

1) Efforts were made to contact individuals and organizations that have expertise concerning the types of cultural resources, practices and beliefs found within the vicinity of Keähole (these include the *ahupua'a* of Makalawena, Mahai'ula, Haleohi'u, Kalaoa, 'O'oma and Kohanaiki), and the island of Hawai'i.

2) Efforts were made to select individuals who specifically had knowledge of the proposed project area; this included contacts made with six *küpuna* from the island of Hawai'i. (Interviews were completed with five).

3) Formal oral interviews were conducted with seven informants with historical knowledge about the area. In addition, seven informal interviews and discussions were held with individuals who may have had some knowledge about the area, and/or could recommend bearers of cultural information.

4) Documentary research, particularly on the location of cultural and historical uses of the area, was conducted on O'ahu and Hawai'i.

5) Cultural resources (land-based) in the project area are briefly referenced in this report, and are not seen as a major component of the current study's purpose.

6) The summary above is considered an appropriate conclusion since it was not the goal of this study to conduct a comprehensive Cultural Impact Assessment but rather to identify cultural resources (practices, beliefs and traditions) in the project area.

The preceding presentation and discussion have also fulfilled the SHPO's request (in response to the Section 106 review process) of identifying traditional fishing sites in the vicinity of the project area. This includes narratives by the *küpuna,* and references from a limited number of written sources on traditional fishing grounds/stations (*ko'a*) and the currents off of Keähole Point, and the general vicinity of the project area.

Conclusion

The study found that the point of Keähole and the deeper waters surrounding it are prime fishing grounds. It is very likely, that all islands have such "special places". [According to *küpuna* Eddie Ka'ana'ana, rich *'öpelu* grounds are found on nearly all of the Hawaiian Islands]. And while this may not be the only grounds for highly valued fish such as *aku, 'ahi* and *'öpelu,* on the island of Hawai'i, it has continued to be the preferred fishing grounds from traditional to modern times for these and other fish.

The most significant cultural/traditional feature is the *ko'a* – fishing grounds/stations at sea, that lie within the boundaries of the project area. Although the frequency of their use may differ between generations and fishing objectives, knowledge about them and their significance has carried into the present times. The most significant cultural practice is fishing – through time this has ranged from being subsistence-based to a highly valued sport. It is also a common commercial activity in the project area. The most significant aspect of the cultural lore, as it pertains to the physical uniqueness of the project area, is knowledge about the currents. Lastly, the *küpuna* themselves are a highly valued cultural resource.

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Appendix F(1)

Individuals Contacted and Interviewed

Name	Position/Title	Residence
Valentine K. Ako	*Kupuna* (born and raised in Kona)	Kaua‘i
Robert Ka‘iwa Punihaole Sr.	*Kupuna*	Kekaha
George Kinoulu Kahananui Sr.	*Kupuna*	Kekaha
John Hills Ka‘iliwai	*Kupuna*	Kona
Frances Keanaaina	*Kupuna*	Kona
Kepä Maly	Oral Historian	Hilo
Eddie Ka‘ana‘ana	*Kupuna* (born in Miloli‘i)	Oahu
Mauna Roy*	*Kupuna*	Kona
Mikihala Roy	Director, Kulana Huli Honua	Kona
Hanohano Punihaole	Educator	Kekaha
Kalei Punihaole	Commercial fisherman	Kekaha
Isaac Harp	Hawaiian Fisherman and Cultural practitioner	Maui
Elizabeth Ako	family member	Kaua‘i
Edna Punihaole	family member	Kekaha
Annie Coelho	family member	Kekaha
Hannah Springer**	Native resident of Kekaha Kukui‘ohiwai	
Angel Pilago**	Hawaiian advocate/practitioner	

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* An in-person interview was not possible during the study period.

** Attempts to contact and interview these individuals were not successful.

Appendix F(2)

THE FISHERIES AND LANDS OF KEKAHA: AN OVERVIEW OF TRADITIONS RECORDED BY NATIVE RESIDENTS

(compiled by Kepä Maly[38])

The following narratives are excerpted from several native traditions and historical description of the lands, fisheries and practices of native residents of the Kekaha region, North Kona, Hawaiʻi (with emphasis on the lands and fisheries of Kalaoa and vicinity). The original texts were written by native writers (residents of Kekaha), and published in the Hawaiian language newspaper, *Ka Hökü o Hawaiʻi*. The translations were prepared by Kepä Maly as a part of ethnographic studies and oral history interviews which he has conducted since 1991.

About the Native Authors

In the period from ca. 1907 to 1929, J.W.H. Isaac Kihe (who also wrote under the penname "Ka-ʻohu-haʻaheo-i-nä-kuahiwi-ʻekolu") and John Kaʻelemakule, who independently and in partnership with Reverend Steven Desha Sr. and John Wise[39], wrote detailed historical accounts in Hawaiian language newspapers. Their rich narratives provide readers with important documentation regarding the importance of the Kekaha fisheries, and provide important site-specific documentation pertaining to *koʻa* (fishing stations – both in the sea and markers on land), as well as documentation regarding traditional beliefs, customs, and practices associated with these features and resources.

While providing important documentation, the following narratives are in no way complete, and additional documentation has been, and may still be recorded in oral history interviews with elder native Hawaiian residents of Kekaha.

"Kaʻao Hoʻoniua Puʻuwai no Ka-Miki"
(The Heart Stirring Story of Ka-Miki)

…Ka-Miki had his companions Uhalalë and Uhalalï board the canoe, and told them not to sit on the seat lest they fall from the canoe (October 4, 1917). With one push, Ka-Miki had the canoe beyond the shoreward waves, with two dips of the paddle, they passed Kaiwi Point (at Keahuolu). Upon reaching Ahuloa Ka-Miki opened the *hökeo pä hï aku* (bonito lure container) in which the supernatural lure Kaiakeakua was kept. Ka-Miki then commanded that Uhalalë and Uhalalï paddle the canoe. Though these two paddled with all their might, the canoe only moved a little. Ka-Miki then chanted out to his shark *ʻaumakua Nihoʻeleki — mele ʻaumakua, mele lawaiʻa*:

I Tahiti ka pö e Nihoʻeleki	Nihoʻeleki is from ancient Kahiki,
I hana ka pö e Nihoʻeleki	Nihoʻeleki is founded in antiquity
Lawalawa ka pö e Nihoʻeleki	Nihoʻeleki is bound in antiquity
Mäkaukau ka waʻa la e Nihoʻeleki	Nihoʻeleki has made the canoe ready
O ke kä o ka waʻa ʻia e Nihoʻeleki	The canoe bailer is Nihoʻeleki's
O nä hoe a Ka-Miki	The paddlers are Ka-Miki's

[38] *Kumu Pono Associates* – 554 Keonaona St. – Hilo, Hawaiʻi 96720 – (808) 981-0196 – kepa@interpac.net

[39] Kihe and Wise were highly regarded for the knowledge of native traditions, and were primary translators of the "Fornander Collection of Hawaiian Antiquities and Folklore" (1916-1919).

O Uhalalï a me Uhalalë	They are Uhalalï and Uhalalë
O ka pä hi aku o Kaiakeakua	The *aku* lure is Kaiakeakua
Akua nä hana a ke Aku i këia lä	It is a gods work of securing the *aku* on this day
He ‘ïlio nahumaka ‘ai kepakepa	[Fish] Like a fattened dog to be chewed to pieces
‘Ai humuhumu, ‘ai kukukü	Consumed voraciously – noisily
Ku‘i ka pihe, he pihe aku	The din of voices spread, carried about
O ke aku mua kau	It is the first caught *aku*
‘Ö‘ili kähi, pälua, päkolu	Which appears once, twice, three times greater than the rest
O ke aku ho‘olili la	The *aku* which ripples across the ocean surface
O ke aku ka‘awili	The aku which twists in the water
O ke kumu o ke aku la	It is the lead *aku*
o Kumukea-Kähuli-Kalani	Kumukea-Kähuli-Kalani…[40]

When Ka-Miki finished his chant, the *aku* began to strike at the canoe, and Ka-Miki told Uhalalë *mä* to take the first caught and place it in a gourd container. After this the *aku* rose like biting dogs, tearing at the water, and Ka-Miki moved like a swift wind. In no time the canoe was filled with more than 400 *aku*. An amazing thing is that though Pili's fishermen and all the fishermen of Kekaha were fishing at Kaka‘i, Kanähähä (Hale‘ohi‘u), the entire ocean from the *ko‘a* of Kapapu (Keähole vicinity) to Kahawai (at Ka‘üpülehu); none of them caught any fish at all.

The *aku* school was at the *ko‘a* of Päo‘o, also known by the names Ka-nuku-hale and Päo‘o-a-Kanukuhale; the bonito lure fishing grounds which extended from Kaulana to Ho‘onä, fronting Keähole, which is the source of the (supernatural) currents *Ke-au-kä*, (The current which strikes), *Ke-au-käna‘i* (The current of smooth waters), and *Ke-au-miki* (The current which pulls out to the deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by Mäkälei. Ka-Miki then turned the canoe and landed at *Nä Hono ‘Elua* (the two bays) also called *Nä Honoköhau* (Honoköhau), Ka-Miki divided the fish between the family of the chiefess Paehala and people of those lands (October 11, 1917).

Ka-ala-pü‘ali and Kanähähä, the twins of Mä‘ihi challenged the rule of Pili in Kona. Having proven himself before Pili and his court, Ka-Miki was allowed to answer the challenge. Ka-Miki first fought Ke-ala-pü‘ali and defeated him. Kanähähä then challenged Ka-Miki to a battle in the sea. The two contestants departed in Pili's canoes from Niumalu and when they reached the deep sea, they leapt into the ocean. Ka-Miki commanded that the canoes return to Niumalu once the fight began. Kanähähä then leapt to grab Ka-Miki, but Ka-Miki told Kanähähä, “You will not catch Ka-Miki, descendant of Ka-uluhe and Niho‘eleki the shark god from Kahiki-kü. Instead Kanähähä, you will be bound on the coral below and become food for the crabs.”

Calling upon the shark-god form, *Niho‘eleki*, Ka-Miki grabbed Kanähähä and pulled him under, twisting and pushing him into the coral. When Kanähähä stopped moving, Ka-Miki rose to the surface and the two were carried by the current *Ke-au-miki*. Ka-Miki watched the

[40] When the Priest P ‘ao came to Hawai‘i, brought with him the schools of *aku* and ‘ *pelu* fish (cf. Kamakau; *K ‘ ko‘a* –December 29, 1866). In this account, Kumukea-K huli-Kalani was the name of lead *aku* that came to Hawai‘i with P ‘ao.

shore of Kekaha-wai-ʻole, they passed Hoʻonä, Awalua, Kaʻelehuluhulu, and the sands of Kapuʻualiʻi… Ka-Miki then turned around and secured Kanähähä in the ocean, where he became a *koʻa* (deep sea fishing station) at Haleʻohiʻu for *ʻahi* and *aku* lure fishermen of Kekaha-wai-ʻole. Ka-Miki then swam to the shore of Awalua which served as a *mäkähä* (sluice gate) for the fish pond of Paʻaiea (November 29, 1917).

Ka Loko o-Paaiea (The fishpond of Paʻaiea)

…Paʻaiea was a great fishpond, something like the ponds of Wainänäliʻi and Kïholo, in ancient times. At that time the high chiefs lived on the land, and these ponds were filled with fat *awa, ʻanae, ähole*, and all kinds of fish that swam inside. It is this pond that was filled by the lava flows and turned into *pähoehoe*, that is written of here. At that time, at Hoʻonä. There was a *Konohiki* (overseer), Kepaʻalani, who was in charge of the houses (*hale papaʻa*) in which the valuables of the King [Kamehameha I] were kept. He was in charge of the King's food supplies, the fish, the *hälau* (long houses) in which the fishing canoes were kept, the fishing nets and all things. It was from there that the King's fishermen and the retainers were provisioned. The houses of the pond guardians and *Konohiki* were situated at Kaʻelehuluhulu and Hoʻonä.

In the correct and true story of this pond, we see that its boundaries extended from Kaʻelehuluhulu on the north, and on the south, to the place called Wawaloli[41] (in the vicinity of ʻOʻoma). The pond was more than three miles long and one and a half miles wide, and today, within these boundaries, one can still see many water holes.

While traveling in the form of an old woman, Pele visited the Kekaha region of Kona, bedecked in garlands of the *koʻokoʻolau* (*Bidens* spp.). Upon reaching Paʻaiea at Hoʻonä, Pele inquired if she might perhaps have an *ʻamaʻama*, young *äholehole*, or a few *ʻöpae* (shrimp) to take home with her. Kepaʻalani, refused, "they are *kapu*, for the King." Pele then stood and walked along the *kuapä* (ocean side wall) of Paʻaiea till she reached Kaʻelehuluhulu.

There, some fishermen had returned from aku fishing, and were carrying their canoes up onto the shore.

Pele had now taken the form of a beautiful young woman, and she approached one of the houses at Kaʻelehuluhulu, where she was greeted. Because it was seen that she was a stranger to the place, one of the natives commented on this, and asked "Where is this journey that has brought you here, taking you?" Pele confirmed that she was indeed a visitor, and that she had come down to the place of the chief, to fetch some *paʻakai* (salt) with which to season their fish. Pele told them, "When I came down here, I went before the *Konohiki*, and was told that the fish, the *palu* (fish relish), the young mullet, the *ähole*, and the *ʻöpae* were all *kapu* (restricted). They were only for the King. Thus, I have arrived here before you."

When the natives of the village heard Pele's story, the woman who dwelt in the house that Pele was at, told her "Here, the fish is cooked, it has been steamed (*häkuʻi*), let's eat. Then

[41] Maguire's account of Paʻaiea (1929:14-17), indicates that the pond extended as far as Ke hole. This description fits in with the extent of the 1801 lava flows of Hual lai. It will be noted that the pond would have extended beyond Ke hole if canoes traveling on it were to pass inland of the point (see also Kamakau 1961:184-186).

when you've finished eating, you may continue your journey." Pele joined the *kama'äina* of the place, and when she dipped her finger in the bowl, she took and ate all the fish to see if the people would deny her the food. But when she did this, the *kama'äina* set another bowl before her, not refusing her.

Pele then stood up, ready to leave and she told the people, "This evening set up *lepa* (flags, boundary markers) at the corners of your land. One doesn't know if perhaps tonight, something good or bad might occur." Then Pele departed from the place, and she disappeared from sight. Startled, it was then that the people said among themselves, "This woman that visited our home must have been Pele-Honuamea (Pele of the red earth)..."

…That night, a white flash was seen to travel from Mauna Loa to Hualälai, and in a short time a red glow was seen at Ka-iwi-o-Pele. The people along the coast thought that it was the fire of the bird catchers at Hono-(manu)-'ua'u. The light dimmed and then appeared at (*pu'u*) Kïleo where the shiny hills of black *pähoehoe* may be seen. Pele then went underground and appeared at Keone'eli where she caused deep fissures to open, and the *kahe-ä-wai* (fire rivers) to flow… …Now because Kepa'alani was stingy with the fishes of the pond Pa'aiea, and refused to give any fish to Pele, the fishpond Pa'aiea and the houses of the King were all destroyed by the lava flow. In ancient times, the canoe fleets would enter the pond and travel from Ka'elehuluhulu to Ho'onä, at Ua'u'älohi, and then return to the sea and go to Kailua and the other places of Kona. Those who traveled in this manner would sail gently across the pond pushed

forward by the '*Eka* wind, and thus avoid the strong currents which pushed out from the point of Keähole

It was at Ho'onä that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one the canoe landings of the place. Today, it is where the light house of America is situated. Pelekäne (in Pu'ukala) is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *pähoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today. (J.W.H.I. Kihe in *Ka Hökü o Hawai'i*; compiled from the narratives written February 5-26, 1914 and May 1-15, 1924).

Ka Lae o Keähole (The Point of Keähole)

Another of Kihe's short accounts published in this same time period, under the heading "*Na Hoonanea o ka Manawa*," was about the point known as Keähole. Excerpts from this historical piece are included here because Kihe provides readers the names of various *ko'a* (fishing grounds) extending from Keähole to Kohala. Some of these *ko'a* are referenced in various places of this study, but the texts here put them in order of location, south to north.

It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current… And there in front of this point, in deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (muliwai), and then flow out. It is on that side, that you will find the ko'a (fishing stations) for aku, 'ahi, kähala, 'öpakapaka and such. Among these ko'a are Päo'o, 'Öpae, Kahakai, Kapapu, Kanaha-ha, Kaluahine, Kanukuhale, Kahoʻowaha, Honu, Muliwai (from where one peers upon the dirt of Häʻena, Kohala) and Kaihuakalä, Maui… There are many other koʻa, but these that I've mentioned, are the famous koʻa. There are many deep koʻa all in a line, from the Point of Keähole to the Point of Upolu and the heiau of Moʻokini in Kohala.

That stone which is situated in front of the Point of Keähole, is called by its name Keähole, and it is for this stone that the point is called Keähole to this day… (Kihe in *Ka Hökü o Hawaiʻi*; October 11-18, 1923)

"He Moʻolelo no Mäkälei" (*A Tradition of Mäkälei*)

…In the early morning, Mäkälei arrived at the shore, he called is *käohi* into their positions as before, and boarded the canoe himself and they were off to the *koʻa*. The *aku* were swimming all around and Mäkälei had his *käohi* turn the canoe. Then this expert fisherman of Kekaha-wai-ʻole called out in a chant:

E Hina-i-ka-malama-o-Käʻelo	Hail Hina of the season of *Käʻelo*
Kuʻu kupuna wahine kino paʻeʻe	My ancestress of the supernatural body forms
Hoʻoülu mai ka iʻa	Cause the fish to increase
O ke aku aliʻi, aku kahähä,	The chief aku, the astonishing *aku*,
aku oloolo i kaʻelewaʻa	the *aku* which overflow from the canoe hull
O ke aku wiliwiliau i ke kai kähala	The aku which stir up the ocean of the amberjack,
Kai ʻele, kai uli, kai pöpolohua Käne	The dark ocean, the green blue ocean the purplish-blue ocean of Käne
I mae i ke koʻa, huea mai a lana iluna	Let the fish rise off the *koʻa*
Wehe ʻia nä puka o ka hale o ka iʻa	Open the doors of the house [station] of the fish
Mai muli i Kanukuhale	[Which] begins at Kanukuhale
A hoʻe[a] imua o Päoʻo	And reaches before Päoʻo
I ka wiliwilia o Keähole	There at the currents of Keähole
I Hoʻonä i ka hale o ka iʻa i noho ai	At Hoʻonä the house at which the fish dwell

Upon completing his chant, the *aku* began striking from the beginning of Kanukuhale until they reached the front of Päoʻo. The fish rose like smoke from a burning *imu*, they were like gnashing dogs. Mäkälei then had Poʻo and Kapahi turn the canoe around to return to the shore… (March 20, 1928)

Ko Keoni Kaelemakule Moolelo Ponoi — The True Story of John Kaelemakule (Kakau ponoi ia mai no e ia – Actually written by him[42])

…The fishing customs in our land, as handed down from ancient times, is something that was greatly regarded by our beloved chiefs. Cherished customs, taught to the children by their parents. The practices of farming were taught to those of the land, and the practice of fishing were taught to those of the coast. Those were the important skills in the ancient times of our ancestors…Let me tell about the customs of fishing in the deep sea, for these are

[42] This account was published in serial form in the Hawaiian newspaper *Ka H k o Hawaiʻi*, from May 29, 1928 to March 18, 1930. The translated excerpts in this section include narratives that describe Mahaiʻula and nearby lands in Kekaha with references to families, customs, practices, ceremonial observances, and sites identified in text. The larger narratives also include further detailed accounts of Kaʻelemakule's life, and business ventures. A portion of the narratives pertaining to fishing customs (November 13, 1928 to March 12, 1929), and canoeing practices (March 19 to May 21, 1929) were translated by M. Kawena Pukui, and may be viewed in the Bishop Museum-Hawaiian Ethnological Notes (BPBM Archives).

among the things that were practiced by my foster father Kaaikaula, and that he taught to me. Among the important fishing practices of Kekaha, that I was taught in my youth were *aku* fishing, *ahi* fishing, and fishing for *‘öpelu* with nets. These were the important fishing customs that I was taught Fishing for these fish was done at the *ko‘a ‘öpelu* (*‘öpelu* fishing station or grounds), that was not too far out. And beyond that, was the *ko‘a* for *aku* and *‘ahi* fishing. The *ko‘a* for these fish (the *‘ahi* and *aku*), was the famous *ko‘a lawai‘a* (fishing ground) of Kekaha, known by the name, “Haleohiu…” (November 13, 1928:3)

Aku Fishing
Aku fishing was done with a *pä* in ancient times by our fishermen ancestors, at the famous *ko‘a* of Hale‘ohiu, of the land of Kekaha-wai-ole-o-nä-Kona…From this waterless shore of Kona, it is believed that the first *pä aku* fishing was found, made from the shoulder blade (*iwi hoehoe*) of Keuwea. He was the father of that famous fisherman of Kekaha, called Ka‘eha. His story was seen in the “Newspaper, the Star of Hawaii…” [in 1907]. It is said in the legend, that Ka‘eha killed his father, at his father’s command, and that Keuwea’s shoulder and thigh bones were thrown into a *käheka* (tidal pool) of Kekaha. On a following day, Ka‘eha went to look at his father’s bones and he saw growing up from them, some *päpaua* (mother of pearl bivalves). From the *päpaua* on the right side, Kaeha made the “*pä hi aku kuahuhu*” (the *kuahuhu aku* lure). The *päpaua* that was on the left side, was thrown into the sea, and that is the reason that the *päpaua* spread throughout the islands, and how it came to be used for *aku* lures… (December 11, 1928:3)

…It is perhaps appropriate for me to mention some of the famous *aku* fishermen of the days of my youth, those who I fished with at my home of Kekaha-wai-‘ole-o-nä-Kona where I was reared. The fishermen whom I mention, their names are on the list of the foremost *aku* fishermen of those days. Nahale was one of the head fishermen at that time. He dwelt in his home at Makalawena, in the land of Kekaha. He was famous for his distant traveling, finding of the *aku*, and *aku* lure fishing. He was very strong and could lift the *aku* onto the canoe… Hoino was another famous *aku* lure fisherman of those days. He was a resident of Mahai‘ula, and he would fish for *aku* with lures at Hale‘ohiu, the famous *ko‘a* (deep sea fishing station) of Kekaha. When I was young, before I became an *aku* fisherman, I was one of his canoe men… Pahupiula, was a part Caucasian fisherman, and he is the third of the fishermen that I remember here on this page. He was very smart in fishing for *aku* with lures, and very fast at getting the *aku* off of the lure and into the canoe. He was from the village of Makalawena… (January 15, 1929:3)

…When I left Kekaha, Pahupiula and the other head fishermen had died, and new head fishermen arose. Makanani was one of the lead fishermen later. But, not only him, there was also Kamaka, who was among the foremost fishermen of the famous *ko‘a*, Hale‘ohiu. These men held that position later and their fame was made known, because of their strength, alertness, and readiness in lifting the *aku* fish to the canoe, and their quickness in freeing the fish from the *pä*.

The well known head fishermen of Kekaha, those who practiced and became the foremost *aku* fishermen were Nahale, Hoino, Pahupiula, Ka‘elemakule, Makanani, and Kamaka. All of them were fishermen of the first class… (February 5, 1929:2)

Ahi fishing was also an important practice. …The bait that was for *ahi* fishing at the *koa* of

Haleohiu, as well as at other *koa*, was the whole *'öpelu*. Also the sliced *'öpelu* mixed with *aku*. Sometimes, when there was none of this type of bait, the *weke 'ula*, *weke lä'ö*, and even the tail meat of the *'ahi* were used. Some fishermen also used the *po'ou*, *moi*, and *akule* as bait… (February 26, 1929:4)

'Öpelu Fishing

'Öpelu fishing was another one of the important practices of these islands in ancient times; it was perhaps the foremost of the practices in the streaked sea (*kai mä'ok'ioki*) of Kona. It became the type of fishing that contributed to the livelihood of the fishermen and their families… For *'öpelu* fishing, two men are adequate in going on the canoe to the place of the *ko'a 'öpelu* which has been known since the days of the ancient people. It is at a place where one can look below and see the fish, that he prepares to feed the *'öpelu*. The man at the front of the canoe is the fisherman, the one who is prepared for this manner of fishing, he leads in all things for this kind of fishing.

There in front of the fisherman was set out the bait of the *'öpelu*, that is the *'öpae 'ula* (red shrimp) and sometimes other baits as well. He'd give the man at the back of the canoe the bait, this man would do what ever the fisherman told him to. The man in the back had a stone weight, the black dirt, and the coconut sheath in which the *'öpae 'ula* or other bait would be placed and folded in. This would be wrapped with cordage and let down into the water about 2 or three fathoms deep, then the man would jerk the cord and the bait would be released. The water would be blackened by the dirt, and this would help the fisherman see the *'öpelu* eating in the water…When many *'öpelu* were seen, he would have the man feed the fish again and lower the net into the water. While the *'öpelu* were eating, the net was drawn up, and as the fish tried to swim down, they were caught in the net…

While I was a youth living at my beloved land of Mahai'ula, I fished for *'öpelu*. I went with my foster father, Kaaikaula, to fish for *'öpelu* at the *ko'a 'öpelu* (*'öpelu* fishing ground) called "Kaloahale," it was directly seaward of the black sand shore of Awalua… (March 5, 1929:4)

Appendix F(3)

Interview with George Kinoulu "Kino" Kahananui Sr.

(from Excerpts Oral History Kekaha (Honoköhau to Ka'üpülehu) Vicinity, North Kona, Hawai'i, – December 11th 1999, by Kepä Maly, released July 27, 2000)

Describing how Keähole was named, and the ancient fishpond of Pä'aiea:

KM: …*Ua lohe 'oe i këia mau mo'olelo, e like me Keähole. Pehea ka mana'o Keähole*?

…So you heard these kinds of stories, like that of Keähole. What does Keähole mean?

KK: *Ke-ähole no këia au o ke kai*.

Keähole is called that because of the current.

KM: *A, no këlä mau au o ke kai*?

Oh, for the currents of the sea?

KK: *Nä au*. *Mai Kohala a Kona mai a ho'oku'i*.

The currents. From Kohala and from kona, and the strike one another.

KM: *Äholehole*? [Mixing, twisting?]

KK: *Äholehole*. [Mixing, twisting?]

KM: Choppy, *nö ho'i*?

KK: Choppy.

KM: *A 'oia ke kumu. Ua like me au i 'ölelo mua ai, 'o tütü Kihe, ua käkau 'oia i kekähi mo'olelo o Ke-au-kä, Ke-au-miki, Ke-au-käna'i, 'oia nä 'au a wili*.

So that is the reason for the name. It's like the currents spoken of before by tütü Kihe, he wrote a tradition about *Ke-au-kä, Ke-au-miki, Ke-au-käna'i*, the intertwining currents. [see Kihe in this study]

KK: *A wili*. [Twisting.]

KM: *Ma këlä wahi*? [at that place?]

KK: *'Ae pololei. Ho'opüpü no wau i këlä, o pololei*.

Yes, that's correct. By what I draw together (understand), that's right.

KM: *'Ae*. [Yes.]

KK: *Nei 'oe e 'imi i ka mo'olelo o këlä au, këlä ke au pololei. A no laila, ka po'e kahiko, maopopo i ka mo'olelo o Keähole, wehewehe 'ana läkou ma këlä. A'ole ho'i o këia wehewehe, 'he i'a këlä." Pololei he i'a. He inoa i kapa 'ia këia i'a, he äholehole. A'ohe na'e* [chuckles] *no këia. No ke au*!

Like you, you've searched out the old traditions of those currents, those are the proper names. Thus the people of old understood the history of

Keähole, and they've explained it in that way. It is not like it's stated now, 'a fish.' While it's true there is a fish by that name, *äholehole*. It's not because of that. It's for the currents.

KM: *No këia wahi, a'ole no nä i'a*? [So for this place, it's not the fish?]

KK: *A'ale na'e*! [Absolutely not!]

KM: *E pili 'ana ke au*? [So it's about the currents?]

KK: *Ke au*. [The currents.]

KM: *'Oia ke kumu o këlä inoa, hea ia o*…? [So that is the source of that name?]

KK: *Keähole. No ka mea, o Keähole 'oi'oi ia i waho*.

Keähole. Because Keähole, it juts out.

KM: *'Ae*. [Yes.]

KK: *A 'oia ke kumu*. [pointing to location on Register Map 2035] *A këlä wahi ma loko pili…ma ka pili pali, a'ole loa. O këia wahi wale nö*.

That's the reason. (pointing to location on Register Map 2035) That the place in there, close to the cliff, not far out. It's only that place.

KM: *'Ae. Oia ka huina o ke*…? [Yes. So that's the meeting place of the…?]

KK: *Ka huina o këia au. Ka huina o këia mau au, e ho'okui läkou*.

The meeting place of the currents. That's the these currents meet, they strike at one another.

KM: *Ua lohe paha 'oe mamua…? And këia au, he mea ikaika loa. Ua lohe paha 'oe mamua, he loko paha ko këia 'äina, a ua uhi 'ia i ka 'a'ä, i ka pele*?

Did you perhaps hear before…? And these currents are very strong. Did you perhaps hear that there used to be a fishpond on this land, and that it was covered over by the stones, the lava flow?

KK: *Lohe wau i këlä, pololei*. [Right, I heard that.]

KM: *Ua lohe 'oe*. [So you did hear it.]

KK: *Mai Kaloko a ne'e a hö'ea i Ka'üpülehu*.

From Kaloko, all the way to Ka'üpülehu.

KM: *'Ae*. [Yes.]

KK: *He loko nui*! [It was a great fishpond!]

KM: *Ua käkau kekähi po'e küpuna i ka* nineteenth century…

It was written by some elders in the nineteenth century…

KK: *Ka mo'olelo*. [The tradition.]

KM: Yeah. *Mamua nui ka ikaika o ke au o këia wahi o Keähole*.

Yeah. That before, there were very strong currents at this place Keähole.

KK: Uh-hmm.

KM: *A a‘ale hiki iä läkou ke holo pono, holo mua. So ua ho‘okomo ka wa‘a…*

And they could not travel forward in their canoes. So the canoes would enter…

KK: *I loko*. [Inside.]

KM: *‘Ae, i loko o këia loko i‘a. Ua lohe paha ‘oe*?

Yes, in the fishpond. Did you perhaps here about that?

KK: *A‘ole wau i lohe*. [I didn’t hear about it.]

KM: Hmm.

KK: *Ka mea au i lohe mai ku‘u kükü, ‘oia o Kamaka, Palakiko, näna i wehewehe mai këia mo‘olelo.*

What I heard from my elder, that is Kamaka, Palakiko, it was he who shared this story with me.

KM: *‘Ae.* [Yes.]

KK: *I ku‘u nui ‘ana, hele hui launa me kükü Palakiko Kamaka. Näna i wehewehe mai këia mau mo‘olelo a pau. He manawa no hele au e maha‘oi, hele e nänä, pololei paha…*

While I was growing up, I often went with kükü Palakiko Kamaka. He explained all of these stories to me. There were times when I would go, and be inquisitive, I’d go and look, see if what had been said was true.

KM: *‘Ae, hoihoi ‘oe*. [Yes, you were curious.]

KK: *Pololei ka mo‘olelo*. [Well, the story was true.]

KM: *‘Ae*. [yes.]

KK: *Ha‘i mai ‘oia, ka manawa mamua, mai Ka‘üpülehu, këia ‘ao‘ao, a hiki ke ‘ao‘ao pono o he loko nui. He loko nui*.

He said, before times, from Ka‘üpülehu, this side (on the north), to this side right here (pointing to area below his home at Kalaoa), there was a large pond. A great fishpond.

KM: *‘Ae. ‘Oia ka mo‘olelo*? [Yes. So that was the story?]

KK: *‘Oia ka mo‘olelo. Ho‘okähi kuahiwi ai iä Hu‘ehu‘e, ma ka lalo, o Puhi-a-Pele.*

[That is the story. There is a mountain below Hu‘ehu‘e, Puhi-a-Pele.]

KM: *Puhi-a-Pele. ‘Oia ke kumu o këia pele*?

Puhi-a-Pele. And that was the source of the lava flow?

KK: *‘Ae*. [Yes.]…

APPENDIX G: CONSULTATION AND PUBLIC PARTICIPATION

AGENCY CONSULTATION CORRESPONDENCE

The Agencies contacted during development of this Environmental Assessment are outlined in Table G-1, and the correspondence that documented the contacts and the responses is reproduced at the end of this Appendix.

Table G-1 Agencies Contacted

No.	Agency Contacted	Date	Author/ Contact	Date of Agency Response	Author
1	Office of Environmental Quality Control	01/25/00	DOE		
	Office of Environmental Quality Control	04/17/00	PICHTR		
2	DLNR, Land Division	04/17/00	PICHTR	06/07/00	Uchida
3	DLNR, Div. Of Boating & Ocean Recreation	04/19/00	PICHTR	06/06/00	Bearman
4	State Dept. of Health; Env. Management Division	04/19/00	PICHTR	06/13/00	Arizumi
5	U.S. Coast Guard	04/19/00	PICHTR	05/08/00	McClelland
6	U.S. Army Corps of Engineers	04/19/00	NELHA	05/02/00	Young
7	DLNR State Historic Preservation Division	04/28/00	DOE	05/18/00	Johns
	DLNR State Historic Preservation Division	05/24/00	PICHTR	06/01/00	Johns
8	U.S. Fish & Wildlife Service	04/28/00	DOE	06/08/00	Henson
			DOE	09/22/00	Henson
9	National Marine Fisheries Service	04/28/00	DOE		
	National Marine Fisheries Service	08/07/00	DOE	09/13/00	Lent
			DOE	09/15/00	Dupree
	National Marine Fisheries Service	01/12/01	DOE		
10	Office of Hawaiian Affairs (H. Springer)	07/07/99	PICHTR	07/13/99	Springer
	Office of Hawaiian Affairs (C. Kippen)	06/08/00	PICHTR	08/28/00	Kippen
	Office of Hawaiian Affairs (L. Hao)	08/30/00	PSI	10/10/00	Kippen
11	Hui M lama	07/14/00	PICHTR		

Copies of the correspondence with agencies consulted in the formulation of the EA are reproduced at the end of this appendix. As a result of these consultations, actions were taken to respond to the agency concerns and have been incorporated into the Final Environmental Assessment.

PUBLIC REVIEW OF THE DRAFT ENVIRONMENTAL ASSESSMENT

A draft Environmental Assessment (EA) for the *Ocean Sequestration of CO_2 Field Experiment* was released for public participation on August 8, 2000, with a comment period extending through September 8, 2000. The policy and standard practice of the U.S. Department of Energy (DOE) is to consider all comments that are submitted in the comment period during preparation of a final EA, with all comments received following close of the comment period considered to the extent practicable. That standard was used in preparing this final Environmental Assessment.

The draft EA was provided for public review at three libraries in the Hawaiian Islands - at the Kailua-Kona Public Library and at the Hilo Public Library on the Island of Hawai‘i, and at the Hawai‘i State Library in Honolulu on the Island of O‘ahu. The draft EA was also available for review at the DOE – National Energy Technology Laboratory's public reading room in Pittsburgh, PA, and was provided to all individuals who requested a copy. The first page of the draft EA specified the time period for receipt of comments and included contact information for cognizant DOE personnel.

Availability of the draft EA was announced through three newspapers published in the Hawaiian Islands, through two internet web sites, and through an announcement of an agency of the Hawaiian Islands' state government. Newspaper announcements citing availability of the draft EA were published in the West Hawaii Today and Hawaii Tribune-Herald newspapers on the Island of Hawai‘i and in The Honolulu Advertiser on the Island of O‘ahu, beginning August 8, 2000, for a period of three days. Collectively, about 85% of the population of the Hawaiian Islands resides on these two islands. The newspaper announcements specified the closing date of September 8 for submitting responses to DOE and provided the information necessary for interested members of the public to submit telephone (voice-to-voice or toll-free recorded message), mail, fax, or Email comments and feedback to the cognizant DOE individual, the NEPA Compliance Officer for the proposed action.

Availability of the draft EA was also announced by the National Energy Technology Laboratory (NETL), which is the Department of Energy office proposing the action, on its internet site at http://www.netl.doe.gov, and by a proposed participant in the experiment, the Pacific International Center for High Technology Research, on a web site designed for dissemination of information about the proposed project at http://www.co2experiment.org. In addition, availability of the draft EA was announced in the August 8, 2000, issue of the semi-monthly *Environmental Notice*, a publication prepared and distributed by the State of Hawai‘i's Office of Environmental Quality Control for facilitating reviews of the environmental impacts of projects proposed in Hawaii and for inviting public comments on Environmental Assessments and Environmental Impact Statements.

All interested persons were requested to submit comments on the draft EA via telephone, mail, fax, Email, or toll-free number to NETL's NEPA Compliance Officer. Through the close of the comment period on September 8, 2000, a total of 129 responses were received from 120 separate individuals. Responses were submitted by Email, fax, telephone, and letter, with the preponderance of responses submitted by Email. Tables G-2 and G-3 display information on the methods used by respondents to provide comments and on the non-Hawai‘i origins of the 129 replies received in accordance with provided instructions, when such locations could clearly be determined from responses:

Table G-2 Methods of Submitting Responses Received by Closing Date

Type	Number
Email	115
Fax	9
Telephone	3
Letter	2
TOTAL	**129**

Table G-3 Responses Clearly Originating from Outside Hawai‘i

Location	Number
California	10
Texas	2
Georgia	2
New York	1
Washington	1
Florida	1
Ohio	1
New Jersey	1
Oregon	1
Colorado	1
Missouri	1
Canada – Nova Scotia	1
Puerto Rico	1
TOTAL	24

In addition, replies continued to be received following the closing date of September 8, 2000, and some replies were directed to individuals other than the designated NEPA Compliance Officer. Comments continued to be received as late as October 10, 2000; only a request for a copy of the draft EA was received following that date. Comments received from all respondents were considered during the process of preparing this final EA. In most cases, the general themes of comments received after September 8 were similar to those received during the identified comment period.

For the category of late or misdirected responses, a total of 101 additional replies were received from an additional 84 individuals. Thus, through the October 10 date when the most recent comments were received, a total of 230 replies from 204 individuals were submitted in response to the draft EA or to the announcement of its availability. Information from all responses regarding methods used by respondents to provide feedback on the draft EA and the locations of respondents clearly residing outside the Hawaiian Islands are presented in Tables G-4 and G-5 below.

Table G-4 Methods of Submitting Responses Received through October 10, 2000

Type	Number
Email	210
fax	10
Telephone	3
Letter	7
TOTAL	230

Table G-5 Responses Clearly Originating from Outside Hawai‘i (all responses)

Location	Number
California	16
Texas	2
Georgia	2
New York	1
Washington	1
Florida	1
Ohio	1
New Jersey	1
Oregon	1
Colorado	1
Missouri	1
Maine	1
Iowa	1
Alaska	1
Arizona	1
Canada – Nova Scotia	1
Puerto Rico	1
TOTAL	34

Among the 230 responses, a total of 112 individuals forwarded endorsements of comments submitted by other respondents. One individual provided a petition of opposition containing signatures of 60 individuals residing in New York, California, Hawai‘i, Washington, Florida, Oregon, Maryland, Kansas, Ohio, Illinois, Louisiana, Utah, British Columbia, Alberta, Ontario, or Australia.

Responses to the draft EA and to the announcements regarding the proposed action varied widely, but all comments could generally be grouped under one of the following categories:

- requests for additional information,
- brief statements of opposition to (or descriptive characterizations of) the proposed project or project participants,
- concerns about the potential implications of large-scale implementation of the concept proposed for research,
- comments expressing concern about the science underlying the proposed experiment, and
- expressions of concern specific to the potential consequences of (or need for) conducting the proposed experiment at the proposed test site

The types of information requested by respondents included copies of the draft EA, notification of the final DOE decision, copies of the final EA, and other analyses regarding the concept of sequestering CO_2 in the ocean. Where such information was available (e.g., through web sites or the draft EA), the requests were quickly fulfilled. In some cases, requests were submitted for information that was either non-existent (e.g., requests for a specific type of report on the ocean sequestration concept) or that would be available through the final EA. These requests were acknowledged. About 8 of the individuals who provided feedback either provided responses that only requested additional information or expressed no concerns about (or opposition to) the proposed action.

From the 204 individuals who provided responses to the draft EA or to announcements about the proposed action, about 124 provided statements of opposition with no individually identified concerns specific to the proposed action. Statements of opposition to the proposed action were acknowledged if they were received by the closing date for comments, but all statements of opposition were noted and recorded. For preparation of this final EA, no specific changes were made to the text of the Assessment in response to general comments of opposition.

From the approximately 80 respondents who identified individual concerns regarding the proposed action, their concerns focused on (1) the potential problems associated with large-scale implementation of the approach to carbon sequestration that is proposed to be tested under the proposed action, (2) the adequacy of information regarding the scientific foundation for the experiment, or (3) the potential environmental interactions and effects associated with conducting the proposed experiment at the proposed site.

Large-scale implementation of ocean sequestration is neither contemplated under or as part of the proposed action nor an anticipated follow-on activity subsequent to the completing the proposed action. The proposed action is, as explained in Section 3.2.1 (DOE's Purpose) and Section 3.3 (Need for the Action) of the draft EA and this final EA, an action to develop scientific information from which to validate scientific principles and computer models associated with the concept of carbon dioxide sequestration in the deep ocean. To further demonstrate the status of this ocean sequestration experiment as one of a variety of concepts being evaluated by DOE, the final EA includes an expanded discussion of the current scientific investigations on the wide variety of potential approaches to carbon sequestration that are being researched by DOE. This expanded discussion places the proposed action for the ocean sequestration experiment in context, as only one of several concepts being investigated at a relatively small scale, for the purpose of developing information that could be used, if needed, at some unknown future time for decision-making on avenues to be further pursued if sequestration of carbon becomes necessary to alleviate problems of global climate change.

Finally, for those respondents who identified concerns potentially associated with the proposed action, their individually stated concerns could be grouped and categorized under a limited number of topic areas. Those categories of concern are indicated in the Table G-6 below. The number assigned to each topic of concern is provided only for tabulation and reference purposes, and does not ascribe any particular priority to the concerns of the respondents. All concerns have high priority for consideration. Table G-6 lists topics of concern collectively identified from all responses, and it includes concerns that were received following the close of the comment period, through the October 10 date on which the most recent topics were received.

Table G-6 Topics of Concern

Sequence Number	Topic of Concern
1	Potential effects of the experiment on specific fish species
2	Potential effects of the experiment on marine mammals
3	Potential effects of the experiment on marine organisms
4	Potential effects of the experiment on (and its relationship to) coral resources
5	Potential effects of the experiment on (and its relationship to) the Humpback Whale National Marine Sanctuary
6	Potential consequences of ship activity on fish species and pollution
7	Potential consequences of noise generated by ships
8	Potential effects on commercial and individual water activities
9	Potential consequences of released carbon dioxide on mineral deposition, oxygen levels, water clarity, and water chemistry
10	Potential effects and areal extent of the effects of the experiment on seawater acidity and carbon-enriched water

Sequence Number	Topic of Concern
11	Potential long-term effects of the experiment
12	Potential for reasonably foreseeable future carbon dioxide releases and cumulative effects of related activities on the area
13	Potential for accidents or sudden release of injected carbon dioxide to the atmosphere
14	Potential effects and relationship of the experiment to other on-going or completed research or mariculture activities in the area
15	Potential effects of ocean currents and ocean transport of materials from deeper to shallower waters
16	Potential effects of the experiment on ocean transport of nutrients
17	Level of characterization and definition of the existing sea water environment in the project area
18	Incomplete definition of the experimental testing, monitoring, and data analysis and reporting plans; and lack of involvement by marine environment technical expertise in developing experimental plans
19	Potential for disproportionate adverse effects on low-income or minority populations
20	Potential effects of the experiment on Native Hawaiian rights, customs, culture, and interests
21	Degree of consistency of the experimental activities with activities authorized for performance in the project area
22	Degree of compliance of the experimental activities with requirements of existing laws and their implementing regulations, such as the Ocean Dumping Act, Clean Water Act, Endangered Species Act, Coastal Zone Management Act, and Magnuson-Stevens Fishery Conservation and Management Act
23	Need for the proposed action and potential for the experiment to address the need
24	Quality of models used for prediction of potential effects of the experiment
25	Criteria used for site analysis and investigation of potential alternatives
26	Overall consequences of the experiment on the ecosystem of the area

In most cases, the topics of concern are consistent with topics that were identified and analyzed in the draft EA. Respondents who commented on these topic areas, however, generally emphasized either their desire for more detailed experimental or environmental consequence analysis information or their beliefs that significant adverse effects would occur. In some cases, information was provided to support the need for additional analysis of environmental consequences. Many of the concerns, such as a concern regarding the potential for impacts on fish species, were identified by more than one commenter.

The specific concerns identified during the public review process were analyzed and addressed at the appropriate locations in this final EA. In most cases, the stated concerns resulted in incorporation of additional or clarifying information.

AGENCY CONSULTATION LETTERS

DOE/EA-1336

ENVIRONMENTAL ASSESSMENT

OCEAN SEQUESTRATION OF CO_2 FIELD EXPERIMENT

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

March 2001

National Environmental Policy Act (NEPA) Compliance

Environmental Assessment Cover Sheet

Proposed Action: The U.S. Department of Energy (DOE) would participate with a group of international organizations in an experiment to evaluate the dispersion and diffusion of liquid carbon dioxide droplets in ocean waters. The experiment would be conducted in the fall of 2001. If the action is approved, DOE would participate in a series of tests involving the intermittent release of liquid carbon dioxide at a depth of about 2,600 feet (800 meters). The carbon dioxide would be supplied through flexible tubing from a surface vessel to a nozzle attached to a retrievable platform resting on the ocean floor. All testing would be completed within a two-week period. Monitoring of the released carbon dioxide droplets would be accomplished using a combination of remotely operated vehicles controlled from surface vessels, a submersible, and bottom arrays of measurement equipment.

A number of alternative ocean sites were considered for conduct of the proposed experiment. Discharge of liquid carbon dioxide from a surface vessel through tubing to a nozzle attached to a bottom-located platform is preferred. Generally, ocean locations possessing the following characteristics would be appropriate for the experiment: seafloor at about 800 meter depth; weather and surface wave conditions suitable for completing the experiment; proximity to land-based support facilities; and absence of natural resources that would be adversely affected.

Candidate ocean sites within the U.S. territorial waters included several locations offshore from the Hawaiian Islands and in the Gulf of Mexico, off the coasts of Texas or Louisiana. A steering committee comprised of member representatives from participating international organizations would select the final location for the experiment. The currently preferred site is within the Ocean Research Corridor of the Natural Energy Laboratory of Hawai‘i Authority (NELHA) at Ke hole Point, Island of Hawai‘i, approximately 1.2 miles (~1.9 kilometers) from the coast. (See **Note** on continuation page.) This site is described in greatest detail in this Environmental Assessment. However, the characteristics and potential environmental consequences of conducting the experiment within ocean waters outside the Ocean Research Corridor, including locations not within the State of Hawai‘i, are also described.

Type of Statement: Environmental Assessment

Lead Agency: U.S. Department of Energy; National Energy Technology Laboratory (NETL)

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National Environmental Policy Act (NEPA) Compliance

Environmental Assessment Cover Sheet

(continued)

Abstract: DOE's objective in participating in the experiment would be to ensure: (1) that developed information provides improved understanding of the natural processes and of the physical and chemical consequences associated with potential sequestration of carbon dioxide in deep ocean waters; (2) that information is disclosed openly to the public and potential policy makers; and (3) that the U.S. maintains an international leadership role in addressing issues and concerns related to national and global energy and related environmental matters.

The Environmental Assessment (EA) identifies the most notable change from the experiment as a temporary increase in acidity from the dissolution of a cloud of liquid carbon dioxide droplets into seawater. The dissolving plume of carbon dioxide droplets would achieve steady vertical and lateral conditions within one hour (models estimate about 30 minutes) following the start of each release. The resulting carbon-rich seawater could have acidity levels with the potential to affect marine organisms for a maximum of three hours, after which time the action of ocean currents would have reduced the acidity to a level where adverse effects would not be anticipated. Comparative studies indicate that project-related changes in acidity would not persist for sufficient time or at sufficiently reduced levels to substantially affect marine organisms.

Public Comments: DOE encourages public participation in the NEPA process. A draft EA was distributed for public review on August 8, 2000, and comments were solicited through the close of the comment period on September 8, 2000. Due to the preferred site for the experiment off the coast from Ke hole Point, Hawai'i, the EA was made available for public access at the Kailua-Kona Public Library and the Hilo Public Library on the Island of Hawai'i and at the Hawai'i State Library in Honolulu on the Island of O'ahu. Newspaper notices announcing availability of the draft EA were printed in the West Hawaii Today and Hawaii Tribune-Herald newspapers on the Island of Hawai'i and in The Honolulu Advertiser on the Island of O'ahu; collectively, about 85% of the population of the Hawaiian Islands resides on these two islands. In addition, availability of the draft EA was announced on the NETL website and on an internet website established to disseminate information about the proposed experiment. Copies of the draft EA were also distributed to cognizant regulatory agencies and various interested parties. A discussion of feedback received on the draft EA and actions taken to address comments are presented in Appendix G. All comments received from public participation were considered and addressed as appropriate in this final Environmental Assessment for the proposed U.S. Department of Energy action.

Note: On February 26, 2001, subsequent to completing work for preparing a Final Environmental Assessment, the following e-mail communication was received from the Executive Director, NELHA.

> "On February 20th, the Board of Directors of NELHA met in monthly session. During the meeting Peter Young offered a motion for the Board to rescind its 1999 motion to authorize NELHA Staff to work with Pacific International Center for High Technology Research (PICHTR) representatives to negotiate a Facilities Use Agreement. After a second from R. Lim, T. Whittemore called for the question and the motion was carried by the majority."

The communication indicated that the information was from the minutes of that Board meeting and that the minutes are draft only and will not be approved or corrected by the Board until the next meeting. Since the action by the Board of Directors of NELHA does not affect the validity of the analyses of the potential consequences from conducting the proposed experiment at any of the alternative sites, the Environmental Assessment (EA) is being released with this added Note regarding the NELHA action. No additional changes are needed for DOE decision-making.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACM	Acoustic Current Meter
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
C	Centigrade
CDUP	Conservation District Use Permit
CEQ	Council on Environmental Quality
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
cm	centimeters
cm/s	centimeters per second
CO_2	carbon dioxide
COE	U.S. Army Corps of Engineers
CTD	conductivity, temperature, depth probe
CTI	Climate Technology Initiative
CWB	Clean Water Branch (DOH)
CZM	Coastal Zone Management
DAR	Division of Aquatic Resources (DLNR)
dB	decibels
DBEDT	Department of Business, Economic Development & Tourism (State of Hawai‘i)
DIC	Dissolved Inorganic Carbon
DLNR	Department of Land and Natural Resources (State of Hawai‘i)
DOE	U.S. Department of Energy
DOH	Department of Health (State of Hawai‘i)
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
et al.	and others
F	Fahrenheit
FAD	Fish Aggregation Device
FCCC	Framework Convention on Climate Change (United Nations)
FETC	Federal Energy Technology Center (DOE) (now known as the National Energy Technology Laboratory) (NETL)
FY	fiscal year
GHG	greenhouse gas
GtC	billion metric tons (gigatons) of atmospheric carbon
HAR	Hawai‘i Administrative Rules
HDPE	high-density polyethylene

HIBT	Hawaiian International Billfish Tournament
HRS	Hawai‘i Revised Statutes
HURL	Hawai‘i Undersea Research Laboratory
Hz	Hertz (cycles per second)
IEA	International Energy Agency
in situ	In place
IOS	Institute of Ocean Sciences (Canada)
IPCC	Intergovernmental Panel on Climate Change
kg/s	kilograms (2.2 pounds) per second
kHz	kilohertz
km	kilometer(s)
kW	kilowatts
l	liter(s)
m	meters
m^2	square meters
m^3	cubic meters
MARPOL	International Convention for the Prevention of Pollution from Ships
mg/l	milligram(s) per liter
MIT	Massachusetts Institute of Technology
mmol	milli-moles
Pa	micro-Pascals
MMPA	Marine Mammal Protection Act
NASA	National Atmospheric and Space Administration
NEDO	New Energy and Industrial Technology Development Organization
NELH	Natural Energy Laboratory of Hawai‘i
NELHA	Natural Energy Laboratory of Hawai‘i Authority
NEPA	National Environmental Policy Act
NERSC	Nansen Environmental and Remote Sensing Center (Norway)
NETL	National Energy Technology Laboratory (DOE) (formerly known as Federal Energy Technology Center)
NIVA	Norwegian Institute for Water Research
NMFS	National Marine Fisheries Service
NODC	National Oceanographic Data Center
NPDES	National Pollutant Discharge Elimination System
NPSG	North Pacific Subtropical Gyre
NRC	Norwegian Research Council
OGCM	Ocean Global Climate Model
OHA	Office of Hawaiian Affairs (State of Hawai‘i)
OS	U.S. Department of Energy, Office of Science
OSHA	Occupational Safety and Health Administration

p_a	Partial Pressure of CO_2 in the atmosphere
p_m	Partial Pressure of CO_2 in the mixed layer of the ocean
pH[1]	Standard measure of acidity; the negative logarithm (base 10) of the hydronium (H_3O^+) molar activity. The lower the pH (on a scale of 1 to 14), the higher the acidity.
PICHTR	Pacific International Center for High Technology Research
ppm	parts per million
ppmv	parts per million by volume
R&D	Research and Development
RITE	Research Institute of Innovative Technology for the Earth (Japan)
ROV	Remotely operated vehicle
RTV	Remotely operated television
SHPO	State Historic Preservation Office (DLNR)
SMA	Special Management Area
U.S.	United States
USC	United States Code

[1] Pure water has a pH of 7. Normal surface ocean water has a pH of about 8 to 8.5, and deep (800 m) ocean water at the NELHA Ocean Research Corridor site has a pH of about 7.6. Lemon juice has a pH of 2, and most carbonated soft drinks have a pH of about 4.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is proposing to participate, with a group of international organizations, in an experiment to investigate certain scientific and technical aspects of carbon dioxide (CO_2) sequestration in ocean waters (the action proposed by DOE). This Environmental Assessment (EA) describes potential environmental consequences that could result from the experiment, which would consist of releasing small quantities of liquid CO_2 in ocean water at moderate depths in order to test dispersion and dissolution characteristics of carbon dioxide droplets and the evolution of carbon-rich seawater. The experiment would provide information for future use in considering options that might be necessary for effectively managing the build-up of carbon dioxide (a greenhouse gas) in the atmosphere.

If this proposal is approved, DOE would participate as a partner in the *Ocean Sequestration of CO_2 Field Experiment.* The *Field Experiment* would consist of short duration releases of liquid CO_2 during a two-week period in the fall of 2001. It would be conducted by pumping liquid CO_2 from a surface vessel through tubing to a nozzle attached to a platform resting on the seafloor at a depth of about 2,600 feet (800 meters). Ocean sites for the experiment must possess certain characteristics of weather and wave conditions and proximity to land-based logistical support. This EA considers candidate sites for the experiment, including the Natural Energy Laboratory of Hawai‘i Authority's (NELHA's) Ocean Research Corridor, approximately 1.2 miles (~1.9 kilometers) off the western coast of the Island of Hawai‘i, and other generic ocean sites.

During the *Field Experiment*, liquid CO_2 would be injected at low flow rates (i.e., 1.6 to 16 gallons per minute) from a surface vessel to a small discharge platform located on the ocean floor in a series of up to 20 intermittent, controlled-flow tests. Dispersion of the CO_2 into liquid droplets would be achieved using a specially designed discharge nozzle attached to the platform.

The *Field Experiment* would provide information on (1) physical and chemical changes induced in seawater by releasing liquid CO_2 and (2) relationships between release parameters (e.g., flow rate, injection velocity) and the physical dynamics of CO_2 droplets. In addition, sampling of biota and naturally occurring bacteria populations in the vicinity of the discharge nozzle would be conducted to provide insight into potential biological responses resulting from the short-term exposure to CO_2.

This EA identifies and assesses potential environmental and socio-cultural impacts that could result from conducting the *Field Experiment*. A variety of potential sites and concepts for CO_2 injection are discussed; reasonable alternatives for achieving the purpose of the experiment are identified; and alternatives dismissed from further consideration are identified. The potential consequences of a "No Action" alternative are also assessed.

The purpose of the EA is to determine if the action proposed by DOE, which would result in participation in the *Field Experiment*, could cause significant impacts to the environment. If potentially significant environmental impacts are identified, and if they cannot be reduced to insignificance or avoided, then a more detailed Environmental Impact Statement would be prepared and used as the basis for a DOE decision to participate in the *Field Experiment*. If no significant environmental impacts are identified, a Finding of No Significant Impact would be prepared and made available to the public, along with the EA itself, before DOE would proceed with the proposed action.

This study was prepared in accordance with the National Environmental Policy Act (NEPA) of 1969 (42 United States Code 4321 et seq.), the Council on Environmental Quality's Regulations [Title 40, Code of Federal Regulations (CFR), Parts 1500-1508], and the Department of Energy's NEPA Implementing Procedures (Title 10, CFR, Part 1021).

2.0 EXECUTIVE SUMMARY

2.1 INTRODUCTION

2.1.1 PROJECT SUMMARY

This Environmental Assessment (EA) has been prepared by the U.S. Department of Energy (DOE) to provide the results of a study on the potential environmental impacts of an *Ocean Sequestration of CO_2 Field Experiment*. This *Field Experiment* would be conducted from surface vessels in water of about 800 meter depth, either within the Ocean Research Corridor of the Natural Energy Laboratory of Hawai‘i Authority (NELHA), about 1.2 miles (~1.9 kilometers) off the coast of the Island of Hawai‘i (see Figure 2-1), or at a suitable alternate site. If approved, DOE would participate as a team member with a group of international organizations in testing certain scientific and technical aspects of CO_2 sequestration in ocean waters.

Through controlled release of fixed amounts of liquid CO_2 totaling a maximum of 40-60 metric tons (44-66 English, or short, tons), the *Field Experiment* would develop information on (1) physical and chemical changes induced in seawater by the release of liquid CO_2 and (2) effects of release rates and nozzle designs on the physical dynamics of a cloud of CO_2 droplets. In addition, sampling of biota and a study of naturally occurring bacteria populations in the immediate vicinity of the discharge nozzle would be conducted and the results would be compared with background information to determine the effects of CO_2 injection on these organisms. Other observations of the behavior of marine biota while the experiment is underway would be performed.

2.1.2 PURPOSE OF THIS DOCUMENT

This study was prepared in accordance with the National Environmental Policy Act (NEPA) of 1969 [42 United States Code 4321 et seq.], the Council on Environmental Quality’s Regulations [Title 40, Code of Federal Regulations (CFR), Parts 1500-1508], and the Department of Energy’s NEPA Implementing Procedures [Title 10, CFR, Part 1021]. This EA identifies and assesses potential environmental impacts that could result from conducting the *Field Experiment* within NELHA’s Ocean Research Corridor, or at an alternative, generic ocean site. The potential impacts of a “No Action” alternative are also identified.

2.2 PURPOSE AND NEED FOR THE *FIELD EXPERIMENT*

The *Field Experiment* would provide data to confirm scientific predictions and to test and refine theoretical models scientists use to predict the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters).

2.3 SUMMARY DESCRIPTION OF THE *FIELD EXPERIMENT*

The *Field Experiment* would consist of a series of tests. Each test would be conducted with a different set of release parameters or physical ambient conditions to obtain a wide range of data for comparison with and calibration of predictive models. The equipment needed to conduct the tests would be mounted on, and deployed from, vessels chartered for that purpose. One vessel would carry the equipment used to release the liquid CO_2. A discharge platform would be carried on the deck of the ship until it is in position for deployment. A test nozzle would be fitted to the end of an outlet pipe on the platform, and the platform’s inlet pipe would be connected, using a short length of flexible hose, to one end of coiled tubing through which liquid CO_2 would be pumped from the vessel. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet. The vessel used to deploy the discharge platform and flexible tubing would have good positioning capabilities. That is, the vessel would contain the navigational and mechanical equipment needed to

Figure 2-1. Location Map

remain in a fixed position without using an anchor. Other vessel(s) would transport remotely operated vehicles (ROVs) and a submersible that would be used to collect data during the *Field Experiment*. Instrumentation used for data collection would include ocean current meters, pH meters, video cameras, and other oceanographic tools. Moored systems would be deployed to obtain continuous records of oceanographic variables at fixed locations, while the ROV system and submersible would be used to follow the discharge plume down current.

2.4 SUMMARY DESCRIPTION OF SITES AND ALTERNATIVES

This Environmental Assessment considers the potential effects of conducting the *Field Experiment* at the NELHA Ocean Research Corridor site and at a generic ocean site as well as the effects of No Action by DOE.

- The NELHA Ocean Research Corridor Site, within waters having the requisite depth and other desired characteristics. The site would be approximately 1.2 miles (~1.9 kilometers) from the coast.
- The Generic Ocean Site, within ocean waters having the requisite depth and other desired characteristics outside the NELHA Ocean Research Corridor. This alternative includes sites for a *Field Experiment* that would be in international waters, waters at locations away from the Ocean Research Corridor, and waters away from the Hawaiian Islands.
- The No Action Alternative considers the situation of DOE not participating in the *Field Experiment*. Due to the involvement of an international consortium of sovereign entities, the No Action Alternative would not preclude conduct of the *Field Experiment*.

A number of other alternatives were identified, evaluated, and eliminated from consideration during the conceptual planning phase of the project. These are discussed in Section 4 of this report.

2.5 THE *FIELD EXPERIMENT* SCHEDULE

The *Field Experiment* would be conducted during the fall of 2001. The duration of the experiment would be approximately two weeks.

2.6 COMPARISON OF THE EFFECTS OF ALTERNATIVES

Table 2-1 considers the potential environmental effects of the *Field Experiment* conducted at the NELHA Ocean Research Corridor and at another Generic Ocean Site and also the effects of the No Action Alternative.

Table 2-1. Comparison of the Anticipated Impacts of Alternatives

RESOURCE AFFECTED	*FIELD EXPERIMENT* At Ocean Research Corridor Site	*FIELD EXPERIMENT* At Generic Ocean Site	NO ACTION
Marine Water Quality	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	No or similar effects
Seafloor	Local abrasion of surface due to platform and pipe emplacement and movement.	Local abrasion of surface due to platform and pipe emplacement and movement	No or similar effects
Benthic Marine Life	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	No or similar effects
Deep-Water Pelagic Marine Life	Very small loss of plankton and minor effects on mobile organism communities	Very small loss of plankton and minor effects on mobile organism communities	No or similar effects
Midwater Marine Life	Very minor stress on local plankton populations	Very minor stress on local plankton populations	No or similar effects
Surface-Water Marine Life	No adverse effects	No adverse effects	No or similar effects
Historical and Cultural Resources	No effects on archaeological or historic sites. Native Hawaiian groups believe it would adversely affect cultural values and fishing and other traditional uses	No effects on archaeological or historic sites. Depending upon location, native groups could believe it would adversely affect cultural values and fishing and other traditional uses.	No or similar effects
Air Quality and Climate	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	No or similar effects
Noise	No adverse effects	No adverse effects	No or similar effects
Marine Transportation	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	No or similar effects
Land Use	No effects	No effects	No effects
Aesthetic Resources	No effects	No effects	No effects
Socioeconomic Resources	Inputs of goods and services to Hawai‘i communities; expenditures for goods where test equipment would be manufactured.	Inputs of goods and services to communities; expenditures for goods where test equipment would be manufactured.	No or similar effects
Public Facilities and Services	No effects	No effects	No effects
Public Safety & Health	No effects	No effects	No effects

Note: If, under the No Action Alternative the experiment would be performed without DOE support, then the anticipated impacts would be essentially the same as for the NELHA Ocean Research Corridor site.

3.0 PURPOSE AND NEED FOR AGENCY ACTION

3.1 BACKGROUND

In the past 100 years, the amount of anthropogenic carbon dioxide (CO_2) emitted into the atmosphere has greatly increased, primarily due to expanding use of fossil fuels. Scientists estimate that atmospheric CO_2 has risen from pre-industrial levels of 280 parts per million (ppm) to over 365 ppm (Keeling and Whorf 1998). Barring a major change in the way energy is produced and used, predictions of global energy use in the 21st century suggest a continued increase in carbon emissions and rising concentrations of CO_2 in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) estimated that future global emissions of CO_2 will increase from 7.4 billion metric tons of atmospheric carbon (GtC) annually in 1997 to approximately 26 GtC per year by 2100 (IPCC 1996).

Although historical effects of increased CO_2 levels on global climate remain a topic of debate, there is scientific consensus that doubling atmospheric CO_2 concentrations from present levels could have a variety of serious environmental consequences in the 21st century. There is growing evidence, for example, that higher concentrations of CO_2 and other "greenhouse" gases could be contributing to an observed increase in average global temperatures. A global average temperature increase of even a few degrees could lead to an accelerated rise in sea level, changes in weather patterns, and other atmospheric changes that would impact human health, water resources, land use, and other resources (EPA 2000).

While the long-term solution to this problem must include actions associated with use of fossil fuels (e.g., application of more efficient technologies, reductions in fossil fuel use), these actions could not, on their own, be implemented on a schedule that would quickly stabilize CO_2 levels. The sheer magnitude of the present reliance on fossil fuels and the growing energy demands throughout the world make it inevitable that the United States and other nation-states will continue to rely on fossil fuels for energy well beyond the 21st century. Accordingly, some forms of carbon sequestration — carbon capture, separation, and storage or reuse — could be needed to assist in mitigating global climate change.

Carbon sequestration complements two other approaches to carbon management that are being developed by the U.S. Department of Energy (DOE). The first approach increases the efficiency of primary energy conversion and end-use. DOE sponsors a variety of research and development (R&D) programs to investigate more efficient supply-side and demand-side technologies. These technologies include more efficient fossil fuel-fired power plants, buildings, appliances, and transportation vehicles. DOE also fosters research into methods of producing and delivering electricity and fuels more efficiently. More efficient energy conversion and end-use would result in lower CO_2 emissions per unit of energy service.

The second approach is substituting lower-carbon or carbon-free energy sources for current energy sources. Examples include using lower-carbon fossil fuels (e.g., replacing coal or oil with natural gas) and increasing renewable energy use (such as solar or wind). DOE has major R&D programs to develop more efficient fossil energy utilization and renewable energy technologies.

Carbon sequestration, the focus of the *Field Experiment* discussed in this Environmental Assessment (EA), represents a third approach to carbon management. Most effective over the mid-term, carbon sequestration would complement long-term efforts to improve efficiency and transition toward low-carbon fuels. Increased recognition of the urgency in dealing with the CO_2 buildup has focused more interest on the potential of this approach. In response, DOE has established R&D objectives intended to develop a better understanding of the economics and environmental implications of a variety of carbon sequestration technologies. Successful development and implementation of such technologies would allow the world to continue to benefit from the use of fossil fuels without the adverse side effects that result when CO_2 is emitted into the atmosphere. Federal participation in research on carbon sequestration technologies is important at this early stage in their development because technical uncertainties and lack of profit incentive discourage commitment of private resources.

The United Nations' Framework Convention on Climate Change (FCCC), adopted in 1992, called for industrialized nations to reduce their greenhouse gas (GHG) emissions to 1990 levels by the year 2000. This ambitious goal was viewed as an initial step for developed countries under FCCC, but the overarching objective was to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Some 167 countries, including the United States, have ratified FCCC. The International Energy Agency (IEA) established the Climate Technology Initiative (CTI) in 1995, as part of an effort by industrialized nations to fulfill the demands of FCCC. The Kyoto Protocol, negotiated by the nation-states of the world in December 1997, may be viewed in the same way.

CTI (http://www.climatetech.net/home.shtml) seeks to increase the use of existing and new climate-friendly technologies through international cooperation in research, development, deployment, and information dissemination. One objective of CTI is to enhance international collaboration in greenhouse-gas capture and disposal. In December 1997 at Kyoto, Japan, CTI initiated work on a number of practical research and development projects for CO_2 mitigation. Agencies of the governments of the U.S., Japan, and Norway signed an international project agreement in December 1997 (Appendix A) under the Climate Technology Initiative.

The agreement's contents, and the related project scope, resulted from numerous meetings and discussions among international researchers involved in the study of global climate change mitigation technologies for several years. Original signatory agencies were the National Energy Technology Laboratory of the U.S. Department of Energy (formerly, the Federal Energy Technology Center), Japan's New Energy and Industrial Technology Development Organization, and the Norwegian Research Council (NRC). A steering committee, composed of one member per signatory agency, was established to oversee and coordinate projects funded by participating nation-states. One of those projects, now known as the *Ocean Sequestration of CO_2 Field Experiment*, is the subject of the Proposed Action.

Technical stewardship of activities initiated by each signatory under the agreement is the responsibility of a second-tier group of organizations or agencies that receive monies from member nation-states. The implementing organizations originally consisted of the Massachusetts Institute of Technology (MIT), Japan's Research Institute of Innovative Technology for the Earth (RITE), and the Norwegian Institute for Water Research (NIVA). A group of scientists and engineers from each of the implementing organizations (known as the Technical Committee) share ideas, cooperatively establish scientific and engineering objectives for activities, and track progress of initiated activities.

In 1999, Natural Resources Canada and a Swiss private company (Asea Brown Boveri) joined the international project agreement. The Canadian Institute of Ocean Sciences (IOS) is the implementing organization for Natural Resources Canada. In 2000, membership in the project agreement was increased to include participation by Australia's Commonwealth Scientific and Industrial Research Organization and by Japan's Central Research Institute of Electric Power Industry, which is the research organization for the electric power industry in Japan.

The Pacific International Center for High Technology Research (PICHTR), a non-profit R&D organization based in Honolulu, Hawai'i, was selected and funded by RITE (Japan) to serve as the general contractor for the *Field Experiment*. PICHTR is responsible for organizing experimental infrastructure, securing permits and authorizations, and providing technical and support services over the duration of the project. In addition, PICHTR has initiated numerous public outreach activities.

3.2 PURPOSE OF DOE'S CARBON DIOXIDE SEQUESTRATION PROGRAM

3.2.1 DOE'S PURPOSE

The Agreement signed by DOE in December 1997 was established in accordance with DOE's mandate to work in partnership with stakeholders to support development of technologies that could help solve environmental problems related to energy use. The Agreement is part of DOE's ongoing support of research into energy systems.

The main challenges for research on CO_2 sequestration technologies are to reduce the anticipated cost of sequestration, to establish a portfolio of practical sequestration options, and to identify viable options for sequestration that, in the long term, would be effective and would not create new environmental problems. DOE activities related to CO_2 sequestration focus on five research areas (DOE 1997):

- separation and capture at the source;
- sequestration in stable geologic formations;
- sequestration in the ocean;
- sequestration in terrestrial ecosystems; and
- advanced sequestration concepts using chemical, biological, and other innovative approaches.

A sixth area of research addresses systems analysis, which is a critical tool for assessing the effectiveness of alternative strategies. As shown in Table 3-1, ocean sequestration has, by far, the greatest potential of the four research areas related to sequestration (DOE/FETC 1999). As a point of reference, in 1990 global anthropogenic emissions of carbon amounted to 6.0 billion (10^9) metric tons.

Table 3-1. Carbon Sequestration Reservoirs

Carbon sequestration reservoir	**Carbon Capacity (in 10^9 metric tons)**
Oceans	1,400 – 2 x 10^7
Geologic Structures	300 – 3,200
Terrestrial Systems (forestation and soil)	>100
Fixation or Reuse (advanced concepts)	*Unknown*
Source: DOE/FETC 1999	

DOE has identified areas where the understanding of the science and technologies related to ocean sequestration needs improvement (DOE/OS 1999). Questions such as the following remain unanswered:

- To what extent would ocean sequestration be effective?
- What would be the best way to engineer a cost-effective and environmentally benign system?
- How would the carbon cycle function in the deep ocean?

DOE's carbon sequestration research has identified a range of activities needed to close information gaps. These activities include laboratory studies, small-scale field experiments, and near-field computer modeling to increase understanding of the behavior of CO_2 released into the ocean. In addition, knowledge is needed on the effects of changes in pH and CO_2 concentrations on organisms from mid-water and deep-sea habitats.

3.2.2 PROJECT PURPOSE

The *Ocean Sequestration of CO_2 Field Experiment* would be conducted at a depth of approximately 2,600 feet (800 meters) and would be focused on key information gaps, as identified in Section 3.2.1. The *Field Experiment* would provide data needed to test, validate, and refine existing computer and laboratory models concerning the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters).

The specific objectives of the *Field Experiment* would be to:

- Investigate CO_2 droplet cloud dynamics;
- Examine pH in the plume and on its margins;
- Clarify effects that hydrates might have on droplet dissolution;
- Trace the evolution of CO_2-enriched seawater resulting from CO_2 dissolution;
- Assess potential impacts on bacterial biomass, production, and growth efficiency associated with induced changes in seawater pH in the vicinity of the release; and
- Examine the effect of a range of CO_2 injection velocities and injector configurations (e.g., orifice size, number of injectors) on the performance of the system and on physio-chemical effects.

The *Field Experiment* would allow a real-world evaluation of computer model predictions and a refined understanding of the small-scale physics governing the evolution of liquid CO_2 released in the deep ocean. Reliable results obtained from these computer models would represent a very valuable input to the general effort to understand the feasibility and potential consequences of ocean sequestration of CO_2.

3.3 NEED FOR THE ACTION

Global climate change is an issue with many implications for the inhabitants of the planet, and it presents a complex challenge. The potential for climate change, and the response of the nation-states of the world to such change, could dictate fundamental shifts in the methods by which energy is generated and used. In the long-term, options that help to mitigate climate change, such as carbon sequestration, could be essential to preserving or improving the quality of life of the world's inhabitants.

3.3.1 DOE NEED FOR ACTION

The President's Committee of Advisors on Science and Technology recognized the importance of carbon sequestration research and recommended increasing the U.S. Department of Energy's budget for such research (President's Committee 1997). The Committee also recommended that a larger, science-based sequestration program be developed with a focus on providing a science-based assessment of the prospects and costs of CO_2 sequestration. The Committee recognized that this scientific focus would represent long-term research and development that would not be conducted by industry alone.

Among the opportunities for carbon sequestration are the following:

- Cost-effective CO_2 capture and separation processes;
- Geologic storage;
- Enhancement of natural processes in terrestrial and ocean sinks; and
- Chemical or biological fixation or reuse.

Approaches to test technologies in all of the above areas are at an early research stage. As noted in Table 3-1, the world's oceans provide the greatest possible sink for carbon. Additional research is needed to establish answers to critical technical and environmental questions regarding the feasibility, capacity, and long-term viability of enhancing the natural process of CO_2 storage in the ocean. Improved understanding of the basic processes and process chemistries are needed before practical, achievable technology performance and costs can be estimated.

3.3.2 DOE DECISION

The decision to be made by DOE is whether to participate in the *Field Experiment* proposed to be conducted in 2001 at a site that possesses the requisite characteristics of depth, weather and wave regime, proximity to land-based support facilities, and absence of potentially adversely affected sensitive natural resources. Candidate sites exist within the Natural Energy Laboratory of Hawai‘i Authority's Ocean Research Corridor and at other ocean locations. The DOE decision will be based on the potential consequences, identified in this Environmental Assessment, of conducting the proposed experiment within the Ocean Resource Corridor or at another ocean site.

3.4 SCOPING ACTIVITIES

3.4.1 SCIENTIFIC LITERATURE

DOE reviewed the experimental concept for a field test of ocean sequestration of CO_2 at the outset of the program to identify the potential environmental effects that would need to be investigated and discussed. This review included a thorough analysis of the scientific literature.

Some examples of scientific literature reviewed in order to identify potential environmental consequences of the *Field Experiment* include Auerbach *et al.* (1997), Caulfield *et al.* (1997), and Alendal *et al.* (1998). Additional examples are included in Section 12.0 (References).

3.4.2 ENVIRONMENTAL QUESTIONNAIRE

The Department of Energy's National Environmental Policy Act (NEPA) Implementing Procedures (10 CFR 1021) require careful consideration of the potential environmental consequences of all proposed actions during the early planning stages. DOE must determine at the earliest possible time whether such actions require either an Environmental Assessment or an Environmental Impact Statement, or whether they qualify for categorical exclusion. To assist in making this determination, an Environmental Questionnaire must often be completed to provide information that can support determination of the appropriate level of NEPA review.

A NEPA Environmental Questionnaire for land-based implementation of the *Field Experiment* was completed in August 1998. The information supplied on the Questionnaire indicated that an Environmental Assessment would be the appropriate level of review. DOE reconsidered this determination when the focus of the *Field Experiment* changed to a vessel-based alternative. Although the latter would have fewer potential effects than the shore-based alternative, DOE reaffirmed its decision to prepare an Environmental Assessment.

3.4.3 PUBLIC OUTREACH PROGRAM

As the general contractor, the Pacific International Center for High Technology Research (PICHTR) developed and initiated an extensive public outreach program for the *Field Experiment*. The outreach program was developed to inform environmental groups and other local stakeholders about the *Field Experiment* and to provide a mechanism for concerns to be identified and addressed. Activities included contacting the media, hosting one-on-one meetings, holding a public scoping meeting (Section 3.4.4), and establishing a website (www.co2experiment.org). The public outreach effort was divided into several phases, which are specifically defined in Appendix B.

3.4.4 FORMAL SCOPING

PICHTR arranged and conducted a public scoping meeting for a *Field Experiment* within the Ocean Research Corridor. The meeting took place on October 14, 1999, from 6:30 p.m. to 9:00 p.m. at the Kealakehe Intermediate School cafeteria in Kailua-Kona. About 30 members of the public attended. The purpose of the meeting was to explain the project and to gather questions and concerns from the public. Topics discussed at the meeting included the rationale for selecting NELHA's Ocean Research Corridor as a potential site of the *Field Experiment*, impacts that the proposed project might have on marine organisms, sensitivity of the *Field Experiment* to native Hawaiian cultural issues, possible effects on public access to and along the shoreline, and opportunities for public input.

3.5 SCOPE OF THE ENVIRONMENTAL ASSESSMENT

The scope of the Environmental Assessment was determined after reviewing the objective and purpose of the proposed project, the extent of testing that would be performed, activities that would need to be performed to implement the proposed experiment, the proposed setting for the project, and other available technical and environmental information related to the proposed project.

Factors considered in establishing the scope of the Environmental Assessment included the following: air, water, wastewater, noise, health and safety (including accidents), transportation, hazardous and non-hazardous wastes, environmentally sensitive resources, ecology, cultural resources, and land use. The key issues for the proposed action were determined to be: ecological protection, water quality, cultural values, transportation, and seafloor protection.

4.0 ALTERNATIVES, INCLUDING THE PROPOSED ACTION

4.1 INTRODUCTION

As discussed in Chapter 3, DOE is supporting research in many areas that may lead to lower levels of anthropogenic CO_2 emissions to the atmosphere. One of these areas involves ocean sequestration. This Environmental Assessment covers an experiment (the "*Field Experiment*") that has been proposed as a means to expand knowledge of the behavior of CO_2 released into the ocean at moderate depth, which is considered appropriate for testing ocean sequestration.

Theoretical calculations and laboratory experiments have made significant progress in defining chemical and physical limitations that would constrain any future ocean sequestration scheme (e.g., Wadsley 1995, Shindo *et al.* 1995, Aya 1995, Masutani *et al.* 1995). This work has shown that some key uncertainties cannot be resolved without field experimentation. Tests involving the release of extremely small amounts (i.e., a few kilograms) of CO_2 have helped to confirm and extend theoretical and laboratory results (Brewer *et al.* 2000). However, several scientific questions remain that can only be answered through larger *in situ* releases.

Scientists first conceptualized the *Ocean Sequestration of* CO_2 *Field Experiment* in a definitive way in 1996 and 1997. At that time, the concept involved a *Field Experiment* that would most likely use shore-based facilities with a pipeline extending seaward to the required water depth. However, a vessel-based test was recognized as having advantages if technical difficulties could be overcome.

This chapter defines alternatives considered for impact analysis. Section 4.2 discusses concepts that were initially considered but dismissed from detailed consideration as reasonable alternatives. Section 4.3 describes the vessel-based experiment conducted in NELHA's Ocean Research Corridor or in a generic site outside the Ocean Research Corridor. Section 4.4 describes the "No Action" alternative, which would result if the U.S. Department of Energy does not provide funding for the *Field Experiment*.

4.2 CONCEPTS DISMISSED FROM DETAILED CONSIDERATION

4.2.1 PHASE I: INITIAL SCREENING OF EXPERIMENT CONCEPTS

The *Ocean Sequestration of* CO_2 *Field Experiment* would produce information needed to calibrate and refine predictive models describing the behavior of CO_2 released at a moderate ocean depth appropriate for sequestration. Since release parameters represent a fundamental input to the predictive models, the *Field Experiment* would be best conducted under as wide a range of conditions as can be practically achieved. Key aspects of the release conditions that need to be examined include (1) how the nozzle design will affect the size distribution of droplets, (2) the interactions among droplets near the nozzle, (3) the possibility of hydrate formation, and (4) the potential effects of hydrates, if formed. Many of these have been explored in laboratory experiments, but tests in the open ocean would be needed to verify and extend laboratory results. This would require placing instruments near the nozzle to measure physical and chemical changes induced by the release of the CO_2, direct observation of CO_2 droplets, and indirect measurements of the CO_2 plume.

Evaluating the effects of ambient dispersal of the discharged CO_2 would be important to understanding the way in which CO_2 would be assimilated into the ocean environment at a depth of about 2,600 feet (800 meters). Many field experiments have been conducted to measure horizontal and vertical mixing in near-surface waters (e.g., Okubo 1971, Jenkins 1985). Fewer data are available to describe mixing at the depths where CO_2 would have to be released for effective sequestration.

In order to achieve the desired objectives (Section 3.2.2), the scale of the *Field Experiment* would need to be sufficient for effective monitoring by available instrumentation. This means the release rates should be in the range of 1.6 to 15.8 gallons per minute (0.1 to 1.0 kilograms per second). The depth of the release would need to be sufficient to allow the CO_2 in the rising droplets to dissolve before reaching the depth at which the CO_2 changes into vapor (approximately 1,375 feet, or 420 meters). In addition, the duration of testing at a defined set of conditions would need to be sufficient to attain a steady state around the discharge nozzle and to provide sufficient additional release time for making meaningful measurements. Computer models predict (see Section 5.2.1.4) that a steady state would be achieved within about thirty minutes, and a minimum of one hour would be needed to take measurements after achieving steady state conditions. Consequently, operational plans would consist of two-hour release periods, with close monitoring being carried out before, during, and after the release.

4.2.1.1 Carbon Dioxide Delivery System Concepts Considered

CO_2 could be delivered to the discharge nozzle in any of several ways. These include (i) from a land-based facility through a pipe laid along the bottom, (ii) from a vertical pipe attached to an oil platform, (iii) through a conduit from a surface vessel, and (iv) from a submerged tank. The advantages and disadvantages of these delivery concepts are discussed below.

4.2.1.1.1 Bottom-Mounted Pipe from Shore-Based Facility

A pipe constructed along the bottom from a shore-based facility to a release point would be the least technologically challenging of the options. The CO_2 could be handled onshore and any trouble-shooting of the delivery system could be conducted before the start of the *Field Experiment*, thereby minimizing time researchers would need to spend at the site. Offsetting these advantages would be the fact that a pipeline would need to negotiate a high-energy nearshore environment. Also, the potential would exist that construction activities or a pipe failure could adversely affect nearshore resources. The inability to readily access the release nozzle after deployment would be another drawback to this concept.

4.2.1.1.2 Platform-Mounted Pipe

Several oil drilling and oil pumping platforms reach to a depth of about 3,000 feet (900 meters). Some platforms float with anchoring tendons tied to the seafloor; other platforms have a central spar extending to the bottom. An advantage of a platform-mounted pipe would be that small diameter pipes already extend from the platforms to various depths, thus potentially simplifying construction. A disadvantage would be that the multitude of support structures surrounding the release pipe could produce perturbations in the flow regime and greatly complicate use of the ROVs that would carry video cameras and instruments needed to monitor the behavior of the CO_2.

4.2.1.1.3 Vessel-Mounted System

CO_2 delivery from a vessel would allow flexibility in the location of the release and in the ability to readily access the small platform on which the test nozzles would be mounted. This concept would possess technical challenges related to (i) design of CO_2 delivery tubing with the required strength and flexibility and (ii) maintaining accurate vessel position during the *Field Experiment* in order to ensure a fixed release point for the duration of each test.

4.2.1.1.4 Submerged Tank

CO_2 delivery from a submerged tank lowered to the seafloor would avoid all piping except for a short riser extending upward from the tank on which the discharge nozzle(s) would be mounted. Disadvantages include the fact that the entire volume of CO_2 could be released into the ocean in the event of a tank failure. Another complicating factor would be the relatively difficult engineering problems associated with designing a tank capable of withstanding both high internal pressures, when the tank would be filled with CO_2 on the surface, and high external pressures, when the tank would be on the seafloor.

4.2.1.2 Delivery System Concepts Eliminated from Further Consideration

After reviewing the advantages and disadvantages of these four concepts, the platform-mounted pipeline and the submerged tank approaches were eliminated from consideration. While the platform-mounted pipeline had originally appeared promising, excessive safety risk would be created when operating research vessels and submersibles near an oil-drilling platform, and the quality of scientific monitoring data would be suspect due to perturbations in water currents and flow regimes around the platform's support structures. Similarly, the reliability of a system supplying CO_2 from a submerged tank could not be assured, and the potential would exist for release of an entire tank load of liquid CO_2 in the event of a rupture. Thus, these concepts were eliminated from further consideration.

4.2.2 PHASE II: DETAILED SCREENING OF EXPERIMENTAL CONCEPTS

After the initial screening, two delivery system concepts remained as viable candidates for the experiment: (1) a bottom-mounted pipe from shore-based facility and (2) a vessel-mounted system. These design concepts were explored in more detail and evaluated further during a second stage of screening. The results of this effort are summarized in Section 4.2.2.1 for a bottom-mounted pipeline and in Section 4.2.2.2 for a vessel-mounted concept.

4.2.2.1 Bottom-Mounted Pipeline Concept

4.2.2.1.1 Possible Locations

Possible locations for an onshore facility using a bottom-mounted pipeline for the *Field Experiment* were evaluated in considerable detail in 1997 (Adams *et al*. 1997).[2] The analysis concluded that, in principle, near-field tests of nozzle, droplet cloud, and overall plume behavior could be tested at any of a number of ocean sites where hydrographic conditions would be representative of potential ocean sequestration sites. The report noted greater limitations on far-field tests, which could be influenced by site-specific patterns of ocean currents and turbulence.[3] The Adams *et al.* study identified several characteristics that would enhance suitability of a *Field Experiment* conducted using a shore-based facility and a bottom-mounted delivery pipe. Some of these characteristics were noted as being reduced in importance if the *Field Experiment* were conducted from a vessel.

The 1997 review by Adams *et al.* identified several candidate sites as having the requisite characteristics for a land-based *Field Experiment*. These included the northern shore of St. Croix in the U.S. Virgin Islands, Punta Tuna in Puerto Rico, and Ke hole Point in Hawai‘i. Each location was evaluated with respect to the required length of the CO_2 delivery pipe, surface currents, waves, wind speeds, the magnitude of bottom currents, and bottom conditions.

Consideration of potential locations for the experiment continued in 1998, with efforts focusing on two sites. One site was near the NASA facility on Cooper's Island at the eastern edge of Bermuda.

[2] The study was not intended to identify the very best place in the world to conduct the experiment. Rather, the goal was to identify locations where the activities could be conducted with reasonable ease and where they would have a high probability of producing scientifically valid results.

[3] In this context, the near field would comprise a zone where initial jet-momentum and gravity effects due to differential buoyancy (e.g., liquid CO_2 droplets, dense carbon rich water) would be strong. The dissolution of the dispersed phase (pure CO_2) should take place within the near field. Typical time scales of a few hours and spatial scales of a few hundred meters would be expected for these experiments. The far field would be the zone where the dissolved carbon would be further transported via advection (currents) and dispersion (turbulent diffusion). In simple terms, the far field would be defined as a size and time scale that exceeds the near field.

The other site was in the Ocean Research Corridor off Ke hole Point on the Island of Hawai‘i. Both sites were evaluated with respect to such factors as the difficulty of laying a pipeline from the shoreline to the potential release location, the suitability of oceanographic conditions, weather, the availability of support from local institutions, and implementation costs. The analysis showed that both locations had strengths and weaknesses relative to one another and concluded that either would be suitable for the *Field Experiment*.

4.2.2.1.2 Conceptual Design for Bottom-Mounted Pipeline

The test facilities required for a bottom-mounted pipeline would consist of four primary components: (1) refrigerated CO_2 storage tank; (2) a pump and metering system; (3) aboveground and submerged conduit; and (4) a moored nozzle array. Each of these is discussed briefly below.

- CO_2 Storage Tank. A single, refrigerated, storage tank would be installed a short distance inland from the shoreline to hold the CO_2 that would be required for the experiment. CO_2 typically is stored in tanks at about 20 to 22 bar[4] and -4°F (about -20°C). The storage tank would require a 3-phase electrical hook-up, consume about 25 kW, and might need to be installed on concrete pads. The liquid CO_2 would be purchased, and a refrigerated storage tank would be leased from a local firm. The storage tank system would consist of standard equipment that has safely been used for years by many industries and businesses, such as food and beverage companies and hospitals.
- Pump and Metering System. A pump would be needed to further pressurize liquid CO_2 extracted from the tank to compensate for pressure losses due to flow through the pipeline and valves, discharge losses through the nozzles, and density head (i.e., the added hydrostatic pressure at the bottom of the sea and the pressure due to differences in densities of the two liquids). Pressurizing CO_2 to a level equal to 70 bar or greater would preclude the possibility of CO_2 boiling in the conduit due to heat transfer from the warm (about 27°C during the summer) surface waters. The flow control and monitoring devices would consist of conventional hardware.
- Aboveground and Submerged Conduit. Conducting the *Field Experiment* from shore-based facilities would involve pumping pure liquid CO_2 through a small steel pipeline from the refrigerated storage tank on the shore to a discharge platform located at a depth of about 800 meters. The length of the pipeline would vary with location.[5] The conduit would rest on the seafloor. The candidate pipe (~1.5-inch internal diameter) would be a product manufactured for offshore oil and gas applications. The coiled pipe would be fabricated from alloy steel.
- Moored Nozzle Array. Specific designs have not been developed for the type of nozzle array that would be used with a bottom-mounted pipeline. However, some basic characteristics are known. A common manifold would be needed to feed the CO_2 into one of two or three different nozzles. The common manifold would need to be connected to the conduit by a swivel joint that would allow it to be disconnected from the pipe. Each nozzle would likely consist of a vertical riser (pipe) about 20 centimeters (cm) in diameter that ends in a blind flange with 10 to 60 small holes (discharge ports). This arrangement would generate an ensemble of CO_2 droplets. Submerged, electrically actuated valves would be needed to select a specific nozzle for testing.

4.2.2.1.3 Construction Activities for Shore-Side Facilities Needed for a Bottom-Mounted Pipeline

Construction of the shore-side facilities needed to use a bottom-mounted pipeline for the *Field Experiment* would involve the following activities:

- Grading of the selected site;
- Installing a temporary office trailer;

[4] One “bar” is nearly equal to normal atmospheric pressure at sea level, or 14.5 pounds per square inch.

[5] At NELH, for example, the pipe would need to have a length of about 1.9 kilometers (6,340 feet).

- Building several concrete equipment pads;
- Installing a temporary refrigerated tank to store liquid CO_2;
- Installing a pumping system to inject CO_2 through the submerged pipeline;
- Installing instruments; and
- Connecting the facilities to existing power and water systems.

A level outdoor area between 5,000 square feet (0.12 acres or 465 square meters) and 10,000 square feet (0.23 acres or 929 square meters) would be needed. A square plot of land with dimensions of 100 feet (30 meters) by 100 feet would be appropriate. Due to the relatively short duration of the experiment, mobile (i.e., easily removable and transportable) facilities would be employed wherever possible. The two major components that would be located in the outdoor area would consist of an office trailer with restroom and stairs [~ 3.7 meters x 17 meters (12 feet x 56 feet)] and a refrigerated CO_2 storage tank [~ 3 meters x 18 meters (10 feet x 60 feet)].

The liquid CO_2 pump and motor, valves, and flow rate meter would be mounted adjacent to the storage tank, probably on a concrete pad or wooden platform, and possibly with a roof for rain protection. The pump controller would be installed next to the pump in a weatherproof box with redundant controls in the trailer. The pump and motor footprint would be relatively small [~ 1 meter x 1 meter (3 feet x 3 feet)]. A concrete pad for the pump and other equipment might be necessary if the ground is not adequately hard and level. An insulated steel pressure pipeline would be installed above ground and follow the most direct path to the shoreline take-off point of the submerged conduit. The onshore section of the underwater power and signal cable would also follow this path.

4.2.2.1.4 Construction Activities for Bottom-Mounted Pipeline

Several factors would affect pipeline installation, including the physical character of the offshore area through which the pipeline would pass, the wave environment, and current fields. Several different techniques for deploying the pipeline were considered:

- Pulling spooled pipe and cables from shore;
- Laying pipe and cables from a ship moving toward shore; and
- Laying pipe and cables from a ship moving away from shore.

Pulling the pipe from a spool on shore was considered the most feasible approach. In this case, the bottom-mounted pipeline that would be used to deliver pressurized, liquid CO_2 to the injection nozzles would be a continuous steel conduit about 1.5-inch (3.8 centimeters) in diameter. Such a pipeline could probably be obtained on a single spool. Even filled with a gas, candidate CO_2 delivery pipelines would not be buoyant in seawater. Thus, a small-diameter (e.g., 4-inch, or 10 centimeter) high-density polyethylene (HDPE) conduit would need to be attached to the CO_2 delivery pipeline as it would be unreeled from a spool on the shoreline and pulled out to sea during deployment.[6]

Just like the CO_2 delivery pipeline, the HDPE conduit would be air-filled since its purpose would be to provide a significant amount of removable buoyancy. In fact, the HDPE conduit would need to be sufficiently buoyant to attach a power cable, which would also be on a reel. The pipeline bundle would be deployed as follows:

- All pipe reels would be secured on a concrete pad onshore, and a “launching ramp” would be installed over the shoreline cliff to control pipe curvatures.

[6] Spools containing 1,000-foot lengths of HDPE would be available for this type of conduit. These lengths could be joined together thermally, which would provide a significant advantage over similar operations using “traditional” 40-foot straight sections. This benefit would be complicated by the need for a more extensive shoreline working area, with about 8 HDPE pipe spools, the CO_2 delivery pipe spool, and the power cable reel stored next to one another.

- A tugboat would be positioned in shallow waters immediately offshore; the CO_2 discharge nozzle structure would be onboard.
- The coiled tube, the power cable, and the HDPE line would be simultaneously unspooled and tied together to form a buoyant bundle, which would be passed on to the tugboat by an auxiliary small craft.
- The end of the CO_2 delivery pipe would be connected to the CO_2 discharge nozzle structure, and the tugboat would pull away from the shoreline. The weight of the CO_2 discharge nozzle structure would provide the principal holding point for the buoyant bundle.
- The tugboat would continue moving away from the shoreline toward the site for the experiment until the bundle would be completely unspooled and floating on the water surface, with the shore end held under tension for proper alignment. The HDPE pipe sections would be fused together quickly, requiring only that pulling operations would be held for about ten minutes at a time.
- Once the pipeline achieves full extension, the tugboat would hold position until acceptably low (e.g., less than one knot) surface currents would exist. Seawater would then be pumped into the pressurized HDPE pipeline, causing it to sink slowly to the seafloor. The tugboat would adjust the line tension and position to control the touchdown path of the bundle. The bundle would progressively sink to the seafloor starting at the shoreward end of the assembly.
- To complete the deployment, a small crane on board the tugboat would lift the CO_2 discharge nozzle structure overboard into the water using a wire rope connected to an onboard winch. The discharge nozzle assembly and final length of pipeline would be lowered slowly under tension to the seafloor. Upon touchdown on the seafloor, the wire rope would be released and the entire assembly would be in place.
- Deployment of the pipeline and the CO_2 discharge nozzle structure would be expected to take just a few days.

If a shoreline cliff or topographic discontinuity should be encountered, a short, separate, shoreline section of pipeline might need to be installed to safely clear the shoreline. For the bottom-mounted pipeline, a self-anchoring pipeline (i.e., one that simply lies on the bottom with no permanent anchors), which would avoid the complications and costs associated with even the least obtrusive anchoring procedure, would be satisfactory. However, this advantage would need to be weighed against the possibility that pipeline damage near the shoreline could result from large swells that might be produced by an unusual storm.

4.2.2.1.5 Post Test/Site Clean-Up

The pipeline infrastructure deployed for this alternative would be removed immediately upon completion of the *Field Experiment*. Removal would proceed by reversing all deployment steps until the bundle floats at the ocean surface. Then, the bundle would be depressurized, pulled onto the shoreline, and cut into pieces for transport by truck to a landfill for disposal. Because of the proposed pipeline deployment method, no permanent structures would be placed on the seabed. Consequently, the only trace of the experiment that would remain following re-flotation and removal of the pipeline could be a small amount of surface abrasion of the seafloor.

4.2.2.1.6 Summary of Bottom-Mounted Pipeline

In summary, the shore-based alternative would be the least technologically challenging of the options and was extensively considered in defining the experimental methodology. The CO_2 would be handled onshore and any trouble-shooting of the delivery system could be conducted before the start of the *Field Experiment*, thereby minimizing time researchers would be needed at the site. Offsetting these advantages would be the fact that the pipeline would need to negotiate a high-energy, nearshore environment. Also, the potential would exist that construction activities or a pipe failure could adversely affect nearshore resources. The inability to readily access the nozzles following deployment of the pipeline would be another notable drawback to this alternative.

4.2.2.2 Vessel-Based Concept

While the characteristics needed for the release point using a vessel-based concept are essentially the same as for a land-based alternative, the flexibility that could be provided by ships means that many more locations would have suitable physical characteristics. Implementation of a vessel-based experiment would also involve a shorter overall duration than a land-based alternative. However, vessel-based experiments require more restrictive limits on weather and sea state than the land-based methods, due to a longer exposure time at sea while the complicated positioning, deployment, and recovery operations are completed.

In general, site characteristics required for a vessel-based *Field Experiment* would include:

- Water depth of approximately 2,600 feet (800 meters);
- Weather and wave regime that would allow research vessels to maintain position during the *Field Experiment* and not cause undue delays that might prevent completion within the limited time that the ships would be available;
- Proximity to (and availability of) land-based support facilities needed for research vessels and associated scientists; and
- Absence of particularly sensitive natural resources in the potentially affected area.

Examples of locations meeting these requirements include several sites offshore from the Hawaiian Islands, an offshore Norwegian site, and in the Gulf of Mexico offshore from Texas or Louisiana.

4.2.3 PHASE III: ELIMINATION OF THE BOTTOM-MOUNTED PIPELINE CONCEPT

4.2.3.1 Consideration of Bermuda and Hawai‘i Sites

After considering all technical factors (see Section 4.2.2.1.1) related to possible locations for a bottom-mounted pipeline at Bermuda and Hawai‘i, the Natural Energy Laboratory of Hawai‘i Authority’s (NELHA’s) Ocean Research Corridor at Ke hole Point, Hawai‘i, was determined to possess the most favorable characteristics for the *Field Experiment*, regardless of whether it were conducted from land-based facilities with a pipeline following the seafloor, as was then thought most likely, or from a vessel.

A deciding factor in this determination was the fact that the relatively high deep-water temperature found to exist off Bermuda would preclude the ability to properly investigate the potential for (and possible effects of) hydrate formation if the *Field Experiment* would be conducted at that location. In order to thoroughly assess the technical and environmental implications of CO_2 sequestration in ocean waters, the *Field Experiment* would need to produce scientific data at depths where temperature conditions could potentially result in hydrate formation. Also, the superior weather and sea-state conditions expected at the NELHA location were factors that supported the choice of a Hawai‘i site. In addition, the existence of an approved Ocean Research Corridor and the available oceanographic and environmental characterization data, as well as the *Field Experiment*’s compatibility with these established uses, were considered positive for the Hawai‘i site.

In September 1999, PICHTR filed a formal application to conduct the *Field Experiment* within NELHA’s Ocean Research Corridor. The NELHA Board approved the request at its October 19, 1999 meeting.

4.2.3.2 Elimination of NELHA Bottom-Mounted Pipeline Concept

In March 2000, after considering the relative merits of land-based and vessel-based alternatives for delivering carbon dioxide, the vessel-based concept was determined to be the preferred approach for conducting the *Field Experiment* and efforts to further consider a land-based experiment were suspended. PICHTR informed NELHA of this determination in April 2000.

The decision to suspend further studies of a land-based alternative was based on several considerations. Confirmation that the experiment could be successfully conducted using a vessel was an important factor in this decision. However, the information that had been obtained through the public outreach program and scoping conducted for the project was equally important. Those efforts made it clear that public concerns existed regarding use of a bottom-mounted pipeline that could have potential for adversely affecting nearshore resources. More specifically, for a land-based experiment at the NELHA location, public concern existed about possible impacts on traditional Hawaiian fishing and gathering activities, on historic properties within the existing archaeological preserve, on nearshore biota because of construction activities or pipeline failure, and on freedom of access along the shoreline. While mitigation measures could be implemented to address these concerns, practical mitigation measures would not be likely to completely eliminate all public concerns about the bottom-mounted pipeline. Hence, the bottom-mounted pipeline concept at NELHA's Ocean Research Corridor was eliminated from consideration.

This Environmental Assessment describes the potential environmental effects of the alternatives that remain under consideration for implementation as a result of the proposed action. They are:

- Vessel-Based *Field Experiment* at NELHA's Ocean Research Corridor site,
- Vessel-Based *Field Experiment* at a generic ocean site, and
- The No Action Alternative.

These alternatives are described in Sections 4.3 through 4.4 below.

4.3 VESSEL-BASED *FIELD EXPERIMENT*

This section of the Environmental Assessment (EA) describes the alternative for conduct of the *Field Experiment* from a vessel. Section 4.3.1 briefly describes the general characteristics and purposes of the NELHA Ocean Research Corridor site alternative. Section 4.3.2 briefly describes a more generic ocean site not in the NELHA Ocean Research Corridor. Section 4.3.3 identifies the basic equipment that would be employed and the types of activities that would occur during the *Field Experiment*, and Section 4.3.4 describes the sequence of events anticipated during the *Field Experiment*. The termination phase of the *Field Experiment*, during which the at-sea release system and the monitoring systems would be removed from the ocean, are described in Section 4.3.5.

A draft experimental plan for the *Field Experiment*, which includes more detailed descriptions of the anticipated experimental and monitoring activities, schedule, and contingency provisions, is presented in Appendix C. This plan was formulated through collaboration among the principal scientists in charge of the experiment and professional biological oceanographers with extensive experience investigating the marine ecosystems of the Hawaiian Islands. The *Field Experiment*, because of its planned short duration and low release rates of CO_2, would not provide adequate foundation for a comprehensive investigation of environmental impacts. However, some preliminary studies directed toward evaluating how some biota might respond to the releases are planned (see Section 5.3.2.1.1).

4.3.1 THE NELHA OCEAN RESEARCH CORRIDOR SITE

The Natural Energy Laboratory of Hawai'i Authority (NELHA) Ocean Research Corridor includes 2,940 acres of ocean waters and submerged lands located on Conservation Lands offshore from Ke hole Point (Figure 4-1). The State of Hawai'i Department of Land and Natural Resources

Figure 4-1. NELHA Ocean Research Corridor

(DLNR) issued a Conservation District Use Permit (CDUP HA-1862) to NELHA authorizing use of the Ocean Research Corridor, and NELHA has been continuously carrying out research activities consistent with this permit since it was issued in 1986. The permit authorizes activities within the Ocean Research Corridor that include the following:

> *"… temporary and permanent ocean research, alternative energy and mariculture research and commercial mariculture and energy activities and facilities; immediate construction and development of three ocean water pipelines and use of portions of two parcels of land for pipeline and utility easements, pump stations and road improvement and maintenance activities on and offshore of Ke hole Point."*

The *Field Experiment* would be consistent with these uses and, as related in Chapter 6, DLNR has determined that a Conservation District Use Permit would not be needed to conduct the vessel-based experiment. Moreover, the site is not in any wildlife sanctuary and is well removed from the shoreline and surface-water biological communities. Other factors that make the Research Corridor site appropriate for the *Field Experiment* include reliably calm seas and winds, easy access to deep water, local project participants and the excellent scientific research facilities available in Hawai‘i.

4.3.2 GENERIC OCEAN SITE

Potential locations for a vessel-based *Field Experiment* that would be beyond the Ocean Research Corridor, outside of Hawaiian or U.S. waters, or outside the territorial waters of any nation-state, are treated as a class rather than individually. These locations are analyzed in this Environmental Assessment as a "Generic Ocean Site."

Section 4.2.2.2 describes the characteristics that would be required for a vessel-based *Field Experiment*. As previously discussed, potential ocean sites considered for the *Field Experiment* in U.S. Territorial waters include sites further offshore from the Hawaiian Islands than NELHA's Ocean Research Corridor and sites in the Gulf of Mexico offshore from Texas or Louisiana. Although these sites meet most of the required characteristics, the anticipated wind and weather conditions at each site would be more severe than in the Ocean Research Corridor, and they would pose more difficult conditions for deployment and recovery of the discharge system, as well as for vessel positioning during tests.

4.3.3 PROPOSED EQUIPMENT

The equipment needed to conduct a vessel-based *Field Experiment* would be mounted on, and deployed from, ocean-going vessels chartered for the purpose. Figure 4-2 schematically illustrates the overall configuration of the experiment, which has been specifically tailored to the scale, duration, and scientific purpose of the proposed *Field Experiment.* Figure 4-3 is a diagram of the type of vessel most likely to be used.[7]

4.3.3.1 Carbon Dioxide Delivery Vessel

One vessel would carry the equipment used to release the liquid CO_2. This vessel would have good positioning capabilities, which means that it would have navigational and mechanical equipment needed to remain in a fixed position without use of an anchor. The equipment mounted on the vessel would consist of the following:

- A standard refrigerated CO_2 storage tank system of the type widely used by food and beverage companies and hospitals. The deck-mounted tank would keep the CO_2 at a pressure of 20 to 22 bars and -4°F (about -20°C).

[7] If conducted within the Ocean Research Corridor or at another ocean site near the Hawaiian Islands, the experiment could use vessels already based in Hawaiian waters or ones whose schedule would bring them through Hawai‘i during the expected time window for the experiment (fall of 2001). The choice would depend upon vessel availability and cost. Because of this, a detailed description cannot be provided at this time.

Figure 4-2. General Methods Used in the *Field Experiment*

Figure 4-3. Typical Vessel and Deck-Mounted Equipment.

- A pump, metering system, and high-pressure hose capable of delivering the liquid CO_2 from the storage tank into tubing through which the CO_2 would be transported to the discharge platform and nozzle on the seafloor.
- A reel holding approximately 3,940 feet (1,200 meters) of 1.5- to 2-inch (3.81 to 5.08 centimeter) outside diameter, coiled tubing,[8] a control cabin with hydraulic power pack, and a deck-mounted container housing controls for the other equipment.

A discharge platform, similar to one shown in Figure 4-4 would be carried on the deck of the ship. When the vessel would be in position for deployment, a test nozzle would be fitted to the end of the outlet pipe, and the inlet pipe would be connected to the end of the coiled tubing. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet (800 meters). The platform would be about six or seven feet wide by thirteen feet long (2 meters by 4 meters) and would weigh approximately 11,000 pounds (5 metric tons). The discharge platform would consist of the following:

- A flat, steel structure that would provide sufficient tension to the tubing during deployment to minimize drifting due to currents.
- A vertical steel pipe connected to the CO_2 supply tubing by a short, flexible hose secured by chains. The connection would also include a swivel joint to minimize torsion forces in the tubing.
- A trumpet-shaped guide to prevent kinking in the CO_2 supply line.
- Four pointed, steel legs to minimize horizontal movements on the hard seabed, which can have a slope of as much as 30 degrees.
- A discharge pipe to which the test nozzle would be attached; the discharge pipe would extend outward and upward from the side of the platform.
- Anti-backflow devices, such as a check valve, to prevent seawater from entering the pipe and causing hydrate blockages.

The platform may also be equipped with electric heaters to 'melt' any hydrates that form, transponders, and other small pieces of scientific equipment.

4.3.3.2 Other Support Vessels

Other vessels would be used to support the *Field Experiment*. These would include up to two mother ships for the remotely operated vehicles (ROVs) or submersibles that would be used to collect data during experimental tests (see Figure 4-5). In addition, a small boat would probably be chartered to carry scientists and samples between the research vessels and the shore. Small chemical and physical sensors, as well as ROV transponders, would be placed temporarily on the seafloor during the *Field Experiment*.

4.3.4 PROPOSED TEST SEQUENCE

The *Field Experiment* would consist of a series of test sequences, with each individual test designed to observe and evaluate the behavior of liquid CO_2 in seawater as release parameters vary under known physical conditions. Since nozzle design would influence the initial characteristics of the CO_2 droplets for a given release rate, varied nozzle designs would be used to widen the range of practical release parameters. Table 4-1 summarizes the most important characteristics of the planned tests. The currently proposed experimental plan is provided in Appendix C.

[8] The leading candidate would be a product manufactured for offshore oil and gas applications. The continuous, coiled tubing would be fabricated from alloy steel. All tubing would be tested at pressures greater than or equal to 6,000 pounds per square inch (414 bar) before shipment. Since the planned operating CO_2 pressures would be less than or equal to 80 bar, the safety factor would be greater than 5.

Figure 4-4. Discharge Platform

Figure 4-5. Type of ROV Used for Monitoring in the *Field Experiment*

Table 4-1. Preliminary *Field Experiment* Matrix

Duration of Each Test Release (approximate)	Two Hours.
CO_2 Flow Rates	1.6 and 15.8 gallons per minute (0.1 and 1.0 kg/s)
Number of Nozzle Designs Tested	2
Ambient Conditions	Conduct tests at range of current speeds, if possible
Number of Tests	12 to 20
Total Amount of CO_2 Released	Approximately 10,500 to 15,500 gallons (40 to 60 metric tons)
Source: Pacific International Center for High Technology Research (PICHTR)	

Tests would only be conducted when weather and sea conditions allow vessels to maintain their positions within a designated area. The relatively high frequency of moderate seas and calm winds in the lee of the Big Island make it particularly well suited for the *Field Experiment*.[9] Based on equipment requirements, the preferred surface current for conducting tests would be 2 knots (about 1 meter per second) or less.

The vessel deploying the platform would maintain station while the coiled tubing would be extended for a single experimental test series. In general, this means that the vessel would be stationary above the platform for periods ranging from 8 hours to several days. Radioactive substances would not be used in any of the experiments.

4.3.4.1 Deployment

Before the discharge platform would be lowered from the ship, one of the specially designed nozzles would be attached to the end of the CO_2 discharge pipe. Each nozzle would likely consist of a vertical riser (pipe) about 8 inches (20 centimeters) in diameter that ends in a blind flange with 10 to 60 small holes for release ports.

When prepared for deployment, the platform and attached coiled tubing would be slowly lowered into the water. The weight of the platform would result in a virtually vertical descent of the assembly.[10]

While deploying the platform, the ship would maintain station within a radius of approximately 80 feet (25 meters) over the platform's intended resting-place on the bottom. After the platform reaches the bottom, additional tubing would be deployed until approximately 650 to 1,000 feet (200 to 300 meters) of tubing would be laid on the seafloor. Laying out this additional tubing would provide an unobstructed space immediately above the discharge platform so that observers would have a clear

[9] A 3.28-foot (1 meter) wave height with periods from 4 seconds upward is deemed representative of the conditions that would be experienced during deployment and testing.

[10] Given the typical differences between surface and bottom currents, the maximum deflection in the tubing would be approximately 10 feet (3 meters) over the 2,600-foot (800 meter) length of tubing between the surface and the discharge platform.

view of the CO_2 plume. In addition, the ROVs or submersibles would be able to maintain a safe separation from the vertical segment of the tubing.[11]

The platform would be retrieved from the seafloor to change the discharge nozzle, perform maintenance on the nozzle or discharge platform instrumentation, or correct any operational problems. A maximum of 10 deployments of the discharge platform would be anticipated, but the most likely number of deployments would be fewer than half that amount.

4.3.4.2 Carbon Dioxide Release

Following proper placement of the discharge platform on the bottom, the CO_2 release through the nozzle being tested would begin. The design of each nozzle would generate a unique assemblage of CO_2 droplets at each release rate. As indicated in Table 4-1, the CO_2 would be released from the nozzle at flow rates ranging from about 1.6 gallons per minute (0.1 kilograms per second) to 15.8 gallons per minute (1.0 kilograms per second). Typically, each test sequence would be conducted over the course of a few days. However, unusual weather or other factors could prolong the duration of a test sequence.

Following each release, two distinct regimes of CO_2 behavior would result. The first regime would consist of rising droplets of liquid CO_2, with some droplets covered with hydrate films. The release rate and the design of the nozzle would largely control both the size and shape of the droplets and the extent of hydrate formation. The planned flow regimes and nozzle designs would be established to control the formation of "slush."[12]

The second regime would result as the buoyant droplets rise after being released from the injection nozzle. The droplets would gradually dissolve in seawater, because the natural concentration of inorganic carbon in ambient seawater is orders of magnitude below the solubility limit for liquid CO_2. As discussed in more detail in Chapter 5, at the release rates planned for the *Field Experiment*, the vertical rise of the liquid CO_2 droplets would cease within 1,000 feet (~300 meters) from the nozzle.

The dynamics of the ascending droplets would be complex, with some seawater being entrained upward by the momentum of the rising droplets. CO_2-enriched water along the edges of the rising plume would sink as dissolved concentrations of carbon in it increase. This relatively dense, carbon-rich seawater would stop sinking when sufficient mixing with lighter ambient seawater would bring the mixture to a neutrally buoyant equilibrium. Then, the carbon-rich water would drift with the current while being diluted further by turbulence. The predicted behavior of the discharge plume is discussed in Section 5.2.1.4.

4.3.4.3 Monitoring

During each test, staff on the vessel deploying the platform would: operate and monitor the CO_2 pump system and nozzle flow rate; maintain the vessel's position; and interface with project administrators and the ships from which the ROVs would operate.

The crew and staff of the vessel or vessels deploying the survey systems would: make ocean measurements; control and monitor the system location, provide feedback concerning the behavior of the release and the condition of the discharge platform; visually monitor the behavior of megafauna near the test release; and conduct related tests and measurements. Sampling bottles would be deployed and retrieved from the research vessels to collect water and sediment for chemical and biological (bacterial) analysis. Conductivity, temperature, and depth (CTD) measurements from the

[11] ROVs or submersibles would collect data during the *Field Experiment*. The vessel deploying the platform would not remain directly overhead while these instrument systems are operated to avoid the possibility of becoming entangled with the tubing or cables or collision with the ship itself.

[12] Slush in this context is an ice-like mixture of seawater and CO_2 where the two are bonded closely together.

research vessel would supplement the data obtained from small sensors moored temporarily on the bottom and from the mobile survey systems (ROVs and submersible).

The CO_2 droplets would be visible and tracked directly using video equipment. Dissolved carbon in the carbon-rich water plume would not be visible and would need to be monitored indirectly. Since CO_2 would increase acidity (lower pH) of the seawater as it dissolves, the plume would be distinguished from normal seawater by measuring the pH. Non-toxic tracers, such as fluorescent dyes, might be added to the CO_2 to facilitate optical monitoring.

Instruments mounted on mobile survey systems and instrument arrays moored temporarily on the seafloor would be used to monitor ambient conditions. The ROV instrument package would probably include video, conventional salinity, temperature, and pH probes. The instrument package might also include a modified Acoustic Doppler Velocimeter (ADV).

Data collected during each test would be used to produce detailed maps of the parameters under scientific investigation (e.g., pH, temperature, and salinity) and of the current fields. The mobile video systems and video lamps would provide flow images of the CO_2 droplet evolution over time. The ADV would obtain point measurements of fluid velocities for use in evaluating turbulence within the discharge plume. Small transponders on the seafloor would be used to track the underwater position of the mobile systems.

Data obtained on CO_2 droplet cloud dynamics, effects of hydrate films on droplet dissolution, and three-dimensional mapping of the dispersing, CO_2-enriched seawater would be used to assess the physical and chemical effects of CO_2 sequestration in ocean water.

To assess potential impacts of CO_2 sequestration on environmental health, variations in bacterial biomass, productivity, and growth efficiency would be determined and compared to water column pH. Measurement of nutrients (dissolved and particulate organic carbon and organic nitrogen) would be conducted for corollary analyses. These measurements would identify changes in substrate availability that could alter bacterial activity during injection of CO_2. The analyses of bacterial cycling rates would be combined with an analysis of the variation in bacterial genetic diversity to interpret stresses that might arise from pH changes. This information would provide a better understanding of the effect of water column acidification on the lowest levels of marine food chains.

Data would also be collected to confirm that the experiment preserves the water uses that the Water Quality Standards (HAR 11-54) for the State of Hawai‘i are intended to protect. The specific monitoring program that would be conducted (which is outlined in Appendix C) has been developed in consultation with the Department of Health, Clean Water Branch.

4.3.5 POST TEST/SITE CLEAN-UP

Because of the deployment method planned, the discharge platform, nozzle, and tubing would be removed from the seabed as soon as the test releases are completed. The small instrument packages and transponders that would be deployed around the test area would also be retrieved.

4.3.6 LOGISTICAL SUPPORT

One of the advantages of a vessel-based experiment would be that the vessels provide portable operations platforms. The specific types of required logistical facilities needed to support the vessels would depend on the location of the experiment and on the specific research vessels that would be used. However, the differences between conducting a vessel-based *Field Experiment* at different ocean sites would be minor.

4.4 NO ACTION ALTERNATIVE

Under the “No Action Alternative,” DOE would not participate in conduct of the *Field Experiment*, wherein DOE would be one party in an international agreement for collaboration to investigate the technical feasibility and to improve the understanding of potential environmental effects of ocean sequestration of CO_2.

No Action by DOE would result in withdrawal from the Project Agreement for International Collaboration on CO_2 Ocean Sequestration (see Appendix A), which would eliminate any role for the United States in effectively contributing to the direction of the *Field Experiment*. No Action would eliminate any official role for the U.S. government in ensuring that the *Field Experiment* would be conducted in a manner that (1) fully protects the interests of the United States and (2) fully and effectively communicates information to the public and to potential policy makers on the implications of both the *Field Experiment* and ocean sequestration of CO_2 as a viable option for controlling global climate change. Selection of the No Action Alternative would also convey a lack of commitment by the United States to an international study directed at evaluating potential solutions to global environmental problems and would diminish the role of the United States as a key leader in addressing important environmental issues.

Since DOE is a relatively minor financial contributor to the Agreement, providing only about 22% of the funding, the other parties to the Agreement could either provide the incremental funding needed to conduct the *Field Experiment* in the absence of DOE or abandon plans for the *Field Experiment*. If the other participants provide the U.S. share of funding for the Agreement, the environmental consequences would be identical to those established for the *Field Experiment* in this Environmental Assessment. The other parties to the Agreement would need to agree on a course of action in the absence of participation by DOE.

4.5 COMPARISON OF ALTERNATIVES

Table 4-2 compares potential environmental effects of the Vessel-Based *Field Experiment* at both NELHA's Ocean Research Corridor site and a Generic Ocean site and of the No Action Alternative.

Table 4-2. Comparison of the Anticipated Impacts of Alternatives

RESOURCE AFFECTED	*FIELD EXPERIMENT* At Ocean Research Corridor Site	*FIELD EXPERIMENT* At Generic Ocean Site	NO ACTION
Marine Water Quality	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	Cloud of liquid CO_2 droplets up to 1,000 feet from discharge nozzle; temporary depression of pH	No or similar effects
Seafloor	Local abrasion of surface due to platform and pipe emplacement and movement.	Local abrasion of surface due to platform and pipe emplacement and movement	No or similar effects
Benthic Marine Life	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	Potential for stress and mortality on benthic life immediately beneath discharge platform & pipeline and in areas subject to pH below 6.5	No or similar effects
Deep-Water Pelagic Marine Life	Very small loss of plankton and minor effects on mobile organism communities	Very small loss of plankton and minor effects on mobile organism communities	No or similar effects
Midwater Marine Life	Very minor stress on local plankton populations	Very minor stress on local plankton populations	No or similar effects
Surface-Water Marine Life	No adverse effects	No adverse effects	No or similar effects
Historical and Cultural Resources	No effects on archaeological or historic sites. Native Hawaiian groups believe it would adversely affect cultural values and fishing and other traditional uses	No effects on archaeological or historic sites. Depending upon location, native groups could believe it would adversely affect cultural values and fishing and other traditional uses.	No or similar effects
Air Quality and Climate	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	Emissions from engine exhaust. Experiment would help improve models used to evaluate climate change.	No or similar effects
Noise	No adverse effects	No adverse effects	No or similar effects
Marine Transportation	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	Slightly increased vessel traffic for short periods during two-week experiment; some limits on vessel movement.	No or similar effects
Land Use	No effects	No effects	No effects
Aesthetic Resources	No effects	No effects	No effects
Socioeconomic Resources	Inputs of goods and services to Hawai‘i communities; expenditures for goods where test equipment would be manufactured.	Inputs of goods and services to communities; expenditures for goods where test equipment would be manufactured.	No or similar effects
Public Facilities and Services	No effects	No effects	No effects
Public Safety & Health	No effects	No effects	No effects

Note: If, under the No Action Alternative the experiment would be performed without DOE support, then the anticipated impacts would be essentially the same as for the NELHA Ocean Research Corridor site.

5.0 AFFECTED ENVIRONMENT & ENVIRONMENTAL CONSEQUENCES

This chapter discusses effects of the alternatives described in Section 4. Section 5.1 contains an overview of the most relevant features of the environments that might be affected. Sections 5.2 through 5.13 discuss anticipated environmental impacts on natural and human resources. Section 5.14 discusses Environmental Justice issues as required by Executive Order 12898. Section 5.15 summarizes pollution prevention measures that would be employed.

The discussion concentrates on the key resources that have the potential to be affected by the *Field Experiment.* These include ocean water quality, benthic and pelagic biota, traditional cultural resources, and recreational and commercial uses of the ocean waters near the experiment. Factors likely to be affected to a lesser degree by the proposed activities are discussed in less detail. These include ocean navigation while the experiment is underway, health and safety, and historic and cultural sites. The analysis considers both normal operation and possible accident scenarios.

5.1 AFFECTED ENVIRONMENT

This section outlines the relevant factors for the Ke hole Point Ocean Research Corridor site that could be affected by the proposed action (Section 5.1.1) and reviews the most significant differences that would be expected at a Generic Ocean site (Section 5.1.2). A brief examination of the key concepts and models relevant to ocean sequestration of CO_2 is presented in Appendix D.

5.1.1 AFFECTED ENVIRONMENT AT THE NELHA OCEAN RESEARCH CORRIDOR SITE

The discharge platform for the *Ocean Sequestration of CO_2 Field Experiment* would be deployed onto the seafloor within the Natural Energy Laboratory of Hawaiʻi Authority's (NELHA's) Ocean Research Corridor, approximately 1.2 miles (~1.9 kilometers) offshore from Ke hole Point at a depth of about 2,600 feet (800 meters; Figure 5-1).

The following sections outline the key natural marine resources that have the potential to be affected by the *Field Experiment*. Section 5.1.1.1 reviews the primary physical and chemical characteristics of the marine environment that would interact with the *Field Experiment*. Sections 5.1.1.2 through 5.1.1.5 describe the biological resources that have the potential to be affected by the *Field Experiment.*

5.1.1.1 Physical and Chemical Environment

Factors within the Ocean Research Corridor relevant to ascertaining environmental effects include seabed characteristics, general oceanographic features of the overlying water column, and prevailing ocean currents throughout the water column. Each is discussed briefly below.

5.1.1.1.1 Seabed Characteristics

This site for the experiment lies on a slope of about 25º to 30º. Video taken in August 1999 by a remotely operated vehicle near the *Field Experiment* site indicates a seafloor composed primarily of coarse sand with occasional rock outcrops. The rocky outcrops appeared in the video to be projecting as much as 2 feet (60 centimeters) from the sediment surface.

Figure 5-1. Setting at the Ocean Research Corridor Site

5.1.1.1.2 General Oceanographic Conditions

The water column is typical of the tropical Pacific Ocean, with low levels of nutrients and a clearly stratified water column. The U.S. National Oceanographic Data Center (NODC) has 17 profiles in its database containing oceanographic data from the general vicinity (NODC 2000; Search Area, 19º - 20º N latitude; 156º - 156º20 W longitude), collected by various oceanographic research vessels between 1949 and 1979 (Figure 5-2).

As part of the preparation for the *Field Experiment*, total dissolved inorganic carbon (DIC) and acidity (pH) were measured off Ke hole Point during August 1999 (Figure 5-3). The data show depletion (due to efficient utilization by phytoplankton populations) of inorganic nutrients (represented by silicate, phosphate and nitrate in Figure 5-2), which is typical in surface waters. Relatively high pH (8.1) is found in surface waters where photosynthesis acts to increase pH. Lower pH values (approximately 7.6) are found at the 2,600-foot (800-meter) depth planned for the experiment, where no photosynthesis acts to increase pH. NELHA has monitored the intake water collected from about 2,000 feet (600 meters) water depths for several years. The pH values from that ongoing monitoring agree with the data collected for this study.

Data for Ke hole Point indicate presence of a surface-mixed layer between 300- and 650-foot water depths (about 100 to 200 meters) and confirm the presence of a primary thermocline (zone in which temperature decreases rapidly with depth) occurring at depths of 650 to 1,300 feet (about 200 to 400 meters). A persistent oxygen minimum layer occurs between 2,000 and 2,300 feet (approximately 600 to 700 meters). However, oxygen levels at these depths do not drop near the anoxic conditions that can occur in more equatorial ocean environments that have high levels of primary productivity (e.g., Riley and Chester 1971, 117).

5.1.1.1.3 Ocean Currents

In August and September 1999, several current meters were deployed on two temporary moorings near the Ocean Research Corridor site to measure ocean currents. On one mooring, Norwegian researchers provided an Acoustic Doppler Current Profiler (ADCP) and a single-point Doppler current meter (NIVA 2000). The ADCP recorded values for each 40-minute interval and provided information on the horizontal current velocities in the overlying water column (to minimum water depths of about 850 feet, or 250 meters) at intervals of about 20 feet (6 meters). The single-point Doppler current meter collected measurements at the seafloor site every 10 minutes. On the other mooring, Japanese researchers fitted three-dimensional Acoustic Current Meters (ACM) at three different depths through the water column, to sample the local current field at a high frequency (every minute).

Generally, the current speed was observed to increase from the seafloor vertically (Figure 5-4). Average speeds near the seafloor were about 0.08 knots (4 centimeters per second [cm/s]). During the 38 days the current meters were on station, the longest period during which the current speed was greater than 0.2 knots (10 cm/s) was 1 hour, while the average period during which currents were faster than 0.2 knots was 40 minutes. The current speed (averaged repeatedly over periods of 10 minutes) never exceeded about 0.4 knots (20 cm/s). An earlier current-meter deployment for a much longer duration (between June 1980 and April 1981) produced data that show essentially the same characteristics (Frye, Leavitt, and Noda 1981).

The currents off Ke hole Point are greatly influenced by the tidal flows and change direction frequently. By combining the speeds and directions for different water depths over time, the net transport at each water depth from which measurements were obtained can be estimated. The results of these estimates are presented in Table 5-1.

Figure 5-2. General Oceanographic Variables Near the Ocean Research Corridor Site

Figure 5-3. Dissolved Inorganic Carbon and pH at the Ocean Research Corridor Site

Figure 5-4. Ocean Current Speed and Water Depth

Surface currents can be significantly higher than those measured at the deep seabed site. The U.S. National Data Center reports data from a current meter deployed near the Ocean Research Corridor at a depth of 98 feet (30 meters) for a period of about 20 days in August 1968 and recording speeds every 15 minutes (NODC 1968). The average surface current speed during that period was 0.70 knots (36 cm/s), with a maximum speed of 1.6 knots (82 cm/s) recorded during one 15-minute period.

Table 5-1. Speed and Direction of Ocean Currents

Water Depth (feet) **Net Transport Direction**	**2,460** **SSE**	**1,640** **W**	**984** **NNW**
Average Velocity (Knots)	0.08	0.11	0.2
Residual Speed (Knots)	0.03	0.002	0.1
Net Transport Per Hour (Feet)	180	13	620
Net Transport Per Day (Feet)	4,300	300	15,000
Net Transport Per Week (Nautical Mile)	5	0.3	17
Source: NIVA 2000.			

Both anecdotal and scientific evidence indicate that upwelling (i.e., the vertical transport of water toward the surface) occurs from depths as great as 1,000 feet along the coast off Ke hole Point. However, as discussed below, there is no indication that upwelling normally occurs in water below that depth. This is why it is necessary to pump nutrient-rich water from greater depths to the surface for use by NELHA's tenants. A number of studies have examined the variability of deep-water parameters off Ke hole Point, including currents (Sundfjord and Golmen 2000; Maeda *et al*. 1999), temperatures (Nihous and Vega 1998), and nutrients such as phosphates, nitrates, and silicates (Price *et al*. 1988). These studies have concluded that at depths between 600 and 800 m offshore of NELH there is significant variability in the deep ocean currents, particularly with respect to their horizontal direction. However, none of the inferred water motions documented in these studies corresponds to upwelling from these depths.

A very unusual event occurred off Ke hole Point starting on the afternoon of Monday, December 13, 1999. At that time the seawater intake of NELHA's 40-inch pipeline (which is at a depth of approximately 600 meters) became very cloudy. The temperature stayed just below 6° C, indicating that the change was not caused by shallow seawater intrusion. The following day, when NELHA's pumps were started scientists also noticed an increase in turbidity in the seawater from the 18-inch pipeline, which is located about 800 meters south of the larger pipe and draws water from approximately the same depth. Water from this pipe never became as turbid as the water from the larger pipe, but was more turbid than the surface water, which is unusual. An analysis of the suspended solids that were causing the turbidity indicated that they were typical of those found on the underwater slope, with a high number of shallow water sediments.

Scientists at NELH originally thought that the extreme turbidity in the seawater from 600-meter depth was caused by some *in situ* event. However, the Volcano Observatory seismologist who they contacted reported no significant seismic events, and there was no evidence of a tsunami on the nearby tide gauges. The turbidity remained above normal for several weeks.

At the same time that NELH was experiencing increased turbidity in the seawater that it draws from a depth of 600 meters, American Divers was working with its two one-man submersibles off Kailua Bay, O'ahu. On December 13-16, 1999 the seawater at a depth of 1,400 feet (~425 m) was so turbid that they had to cancel a planned dive. The seawater was clear from the surface to a depth of about 1,200 feet (~365 m), then became very cloudy as they went deeper. While the crew of the submersible was reporting turbidity at depth, the boat crew on the surface observed what they characterized as strong "upwelling" currents that made it difficult to maneuver the boat. The boat crew guessed that a strong current heading toward the island might be stirring up the bottom as it ran up the slope. However, since the reports of unusual happenings from the submersible focused on the turbidity rather than strong currents, it is not clear that the two observations are related.

No completely satisfactory explanation of these events has been given. This was the only time that the deep seawater pumped up at NELH has lost clarity. Were such turbid conditions to occur during the conduct of the *Field Experiment*, they would be completely unacceptable for testing the release of CO_2 because visual observations of the droplet cloud would become impossible. Also, such an event must correspond to fairly strong deep water mixing, which would 'drown' any pH signal from carbon-enriched seawater. No CO_2 release testing would be conducted under such conditions.

5.1.1.2 Species of Particular Concern

Species of particular concern that may pass through the proposed study site off Ke hole Point include the following marine turtles and marine mammals. An asterisk denotes a species listed by the U.S. Fish and Wildlife Service as threatened or endangered.

- Green turtle (*Chelonia mydas agassizii*)*
- Pacific Hawksbill turtle (*Eretmochelys imbricata bissa*)*
- Olive Ridley turtle (*Lepidochelys olivacea*)*
- Loggerhead turtle (*Caretta caretta*)*
- Leatherback turtle (*Dermochelys coriacea schlegelii*)*
- Hawaiian Monk Seal (*Monachus schauinslandi*)*
- Humpback whale (*Megaptera novaeangliae*)*
- Finback whale (*Balaenoptera physalus*)*
- Blue whale (*Balaenoptera musculus*)*
- Bryde's whale (*Balaenoptera edeni*)
- Right whale (*Eubalaena glacialis*)*
- Sperm whale (*Physeter macrocephalus*)*
- Sei whale (*Balaenoptera borealis*)*
- Spinner dolphins (*Stenella longirostris*)
- Spotted dolphins (*Stenella attenuata*)
- Rough-toothed dolphin (*Steno bredanensis*)
- Bottlenose dolphin (*Tursiops truncatus*)
- Striped dolphin (*Stenella coeruleoalba*)
- Risso's dolphin (*Grampus griseus*)
- Melon-head whale (*Peponocephala electra*)
- Pygmy killer whale (*Feresa attenuata*)
- False killer whale (*Pseudorca crassidens*)
- Short-finned pilot whale (*Globicephala macrorhynchus*)
- Killer whale (*Orcinus orca*)
- Pygmy sperm whale (*Kogia breviceps*)
- Dwarf sperm whale (*Kogia simus*)
- Cuvier's beaked whale (*Ziphius cavirostris*)
- Blainville's beaked whale (*Mesoplodon densirostris*)

The threatened Newells' shearwater (*Puffinis auricularis),* and the endangered dark-rumpled petrel (*Pterodroma phaeopygia sandwichensis)* may also forage in the project area.

Species of concern to the sport-fishing community include representatives from several families including (but not limited to) snappers (*Lutjanidae*), pomfrets (*Bramidae*), jacks (*Carangidae*), dolphins (*Coryphaenidae*), mackerels and tunas (*Scombridae*), swordfishes (*Xiphiidae*), and billfishes (*Istiophoridae*).

5.1.1.3 Seafloor Marine Life (Depth range: 650 to 6,000 feet; ~200–1,900 meters)

The seafloor at a depth of 2,600 feet (800 meters) consists primarily of coarse sand with occasional rock outcrops for a distance of several miles around the Ocean Research Corridor site (Section 5.1.1.1.1). Such moderately deepwater habitats typically harbor complex sediment assemblages of microbes, meiofauna, macrofauna, and megafauna. Deposit-feeding and suspension-feeding polychaetes, bivalves, echinoderms, and crustaceans typically constitute most of the sediment-dwelling macro-organisms (Gage and Tyler 1991). Foraminifera and bryozoans may be abundant (Agegian and Mackenzie 1989). Macro-organisms dwelling on hard substrates include a variety of sponges, crinoids, deep-sea corals and other sessile cnidarians (Gage and Tyler 1991, Western Pacific Regional Fishery Management Council 1979). Organisms captured on video during the ROV examinations of the Ocean Research Corridor site in 1999 are listed in Table 5-2. Additional observations of benthic life, collected by researchers during submersible dives in October 2000, are presented in Appendix E.

Commercially and recreationally exploited species living and feeding on the seafloor at this depth potentially include the following:

- The deep-water shrimp, *Heterocarpus laevigatus*, with a depth range of 1,500 to 3,000 feet (about 450-900 meters, King 1987, Tagami and Ralston 1988);
- At least three species of snappers, *Etelis coruscans*, *Etelis carbunculus*, and *Pristiopomoides filamentosus*;
- Deep-sea precious corals, including pink (*Corallium secundum*, depth range 1,300 to 5,000 feet or 400-1,500 meters), gold (*Gerardia* sp., depth range 1,000 to 1,300 feet, or 300-400 meters), and bamboo (*Lepidisis clapa*, depth range 1,100 to 1,600 feet or 330-490 meters) corals (Western Pacific Regional Fishery Management Council 1979).

Commercially significant deep precious coral beds do occur on the west side of Hawai‘i (e.g., off Kawaihae; Grigg 1976). However, the nearest known beds are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (300 to 490 meters) (R. Grigg 2000, personal communication). Because deep-sea benthic species are distributed at similar depths on the slopes of all the main Hawaiian Islands, only a very small proportion of the total habitat of any of these species could conceivably be found near the Ocean Research Corridor site (Chave and Jones 1991). Scientists who have reviewed the videos taken from the submersibles investigating the area where the experiment would be conducted have not identified any precious corals.

Portions of the deep seafloor on the western slope of Hawai‘i and on similar slopes of other main Hawaiian Islands have been quantitatively studied between water depths of 650 to 6,000 feet (200-1,800 meters). These studies show that benthic megafauna is characterized by a low abundance of organisms (mean = 8 individual organisms per 1,000 square feet) and patchy distributions (Chave and Jones 1991, Chave and Malahoff 1998). Inspections of seafloor videotapes suggest that the habitat and biota at the Ocean Research Corridor site are typical of the slopes of the main Hawaiian Islands. The megafaunal species richness (75 reported species) of the ‘Alenuih h Channel is of the same order as the species richness on seamounts in the north central Pacific ($\leq$ 128 species reported) (Wilson and Kaufmann 1987). Checklists of deep-water organisms from the ‘Alenuih h Channel and the slopes of the Hawaiian Islands in general can be found in Chave and Jones (1991) and Chave and Malahoff (1998).

Table 5-2. ROV Observations of the Ocean Research Corridor Site, August 5, 1999

Time from Start	Biological Observation	Geological Observation
0:13:20	Nettastoma sp. (fish)	Basalt talus
0:14:00	*Beryx decacactylus* (fish)	
0:18:30	Small white sponges (max. density $7/m^2$ in one area	
0:21:15	Synaphobranchid eel, 2 shrimp, 4 small fish,other small midwater animals	
0:23:00	3 tan ophiuroids (brittle stars); small white sponges (max. density $0.1/m^2$), fish	
0:25:00		Fine sediment, many mounds and burrows
0:27:30	Clumps of white sponges, fish	
0:42:00		Fine sediment, sheet flow with sand patches
0:43:00	Small fishes	
0:44:30	Red Corallimorphus sp. *Asterodiscides tuberculosus* (sea star); 2 fish, Sergestes sp (shrimp); octopus	P hoehoe flow
0:46:00	3 Corallimorphus sp; *Paelopatides retifer* (sea cucumber)	On boulder
0:47:20	Gadid fish	Sheet flow
0:48:00	Godiasterid seastar	
0:51:00	Fish; brown anemone	
0:53:00	Shrimp; prawns	Fine sediment
0:55:00	Morid fish	Sand talus
0:57:30	Tan ophiuroids	Sheet flow
0:58:30	Crab	Line, anchor, cable
1:00:00	Red polychaete	Fine sediment; sheet flow
1:03:00	Tan ophiuroid; animal	
1:04:00	*Aristeus semidentatus* (shrimp); 6 tan ophiuroids; elopid fish	
1:05:00		Fine sediment; mounds; burrows
1:06:00	Hormathiid sp 2 (anemone); 3 Corallimorphus sp	Sand, talus

Source: Dr. E. Chave, Hawai‘i Undersea Research Laboratory, University of Hawai‘i at M noa

Several general characteristics of the deep-sea benthos in the Ocean Research Corridor area are relevant to predicting potential effects. First, deep-sea species typically are very broadly distributed, making it virtually certain that species occurring on the deep slope off Ke hole Point are distributed throughout the main Hawaiian Islands. Second, the seafloor near the Ocean Research Corridor site is a relatively high-energy environment by deep-sea standards; consequently, the benthos within the area is likely to be relatively well adapted to withstand water currents and mobile sediments. Because of low food availability and low temperatures in the deep ocean, deep-sea species typically have low metabolic rates (e.g., Gage and Tyler 1991). These low metabolic rates would be expected to allow deep-sea benthos to withstand CO_2 or oxygen stress for longer than species with higher metabolic demands. At the same time, deep-sea species also generally are characterized by low rates of growth, reproduction, and population recovery (Gage and Tyler 1991, Smith 1994). Thus, any effects resulting from the *Field Experiment* would tend to persist longer than effects in shallow-water settings.

No Federally listed endangered or threatened species (see Section 5.1.1.2) are known to occur at the deep seafloor near the experimental site or on the deep western slope of the Island of Hawai‘i.

5.1.1.4 Midwater Marine Life (Depth range: 650 – 3,300 feet, ~200 – 1,000 meters)

Below about 650 feet (200 meters), plankton biomass declines almost exponentially with increasing depth down to about 6,600 feet (2,000 meters) (Barnes and Hughes 1999). Organisms in this relatively poorly studied region depend on the mixed surface waters above for virtually all of their food. Some organisms in the upper half of this layer migrate to surface waters to feed at night; others feed on migratory animals or on organic material that sinks from surface waters.

In these very clear waters, sufficient light exists for very low levels of photosynthesis down to perhaps 1,100 feet (350 meters), though very little photosynthesis occurs below 500 feet (150 meters) and the effectiveness of color vision disappears below about 1,300 to 1,500 feet (400-450 meters). Below 1,500 feet (450 meters) animals see only a faint glimmer of light from above, and bioluminescence becomes common. Virtually no sunlight penetrates beneath this zone. Other environmental gradients in this zone include: (*i*) a decrease of temperature from about 80º F (27° C) at the surface in summer to about 40º F (5º C) at the bottom, (*ii*) an oxygen minimum zone between 2,000 and 2,300 feet (600 and 700 meters), and (*iii*) an increase in hydrostatic pressure of about 15 pounds per square inch (1 atmosphere) every 33 feet (10 meters).

Densities of vertebrates are very low at these depths, though some species of large, surface-associated fishes, marine mammals, and sea turtles may forage here. The most ubiquitous and visible organisms are the mesopelagic micronekton, which are composed primarily of small fishes, shrimps, and squids. The region off Ke hole Point may contain somewhat higher biomass of these animals than waters to the north or south because of the periodic formation of a cyclonic eddy centered a few tens of kilometers to the west of the Point. Such cyclonic flows may cause an upwelling of relatively nutrient rich waters from below the mixed layer (i.e., to a maximum depth of approximately 1,000 feet, or 300 meters) and stimulate primary production (Allen *et al.* 1996). These do not affect the water below that depth.

Reid *et al.* (1991) describe a ‘mesopelagic-boundary community’ found in Hawaiian waters at bottom depths of approximately 1,300 to 4,000 feet (400 to 1,200 meters). This community is composed of fourteen species of fishes (Argentinidae, Astronesthidae, Neoscopelidae, one species each; Sternoptychidae, four species; Myctophidae, seven species), five shrimps (*Gnathophausia longispina, Janicella spinicauda, Opophorus gracilirostris, Pasiphaea truncata, Sergia fulgens),* and four squids (*Chiroteuthis imperator, Abralia astosticta, Abralia trigonura, Iridoteuthis iris).* The mean biomass of the mesopelagic-boundary community sampled off O‘ahu was strongly dominated by shrimps (Reid *et al.* 1991). As the name implies, the offshore edge of this community marks the transition between Hawaiian and open-ocean midwater communities. The size of this midwater habitat greatly exceeds that of any other habitat in all of the Hawaiian Islands.

Federally listed endangered or threatened species that may occasionally occur in waters of this depth include Green (*Chelonia mydas agassizii)*, Pacific Hawksbill (*Eretmochelys imbricata bissa)*, Olive Ridley (*Lepidochelys olivacea),* Loggerhead (*Caretta caretta),* and Leatherback (*Dermochelys coriacea schlegelii)* sea turtles, as well as the Hawaiian Monk Seal (*Monachus schauinslandi*). Humpback whales (*Megaptera novaeangliae*) winter in Hawaiian waters; Finback (*Balaenoptera physalus*), Blue (*Balaenoptera musculus*), Right (*Eubalaena glacialis*), and Sperm (*Physeter macrocephalus*) whales are rarely sighted or detected by hydrophones in Hawaiian waters (Tomich 1986).

5.1.1.5 Surface Ocean Marine Life (depth: 0 – 650 feet, 0-200 meters)

The most abundant and the only ubiquitous organisms of the surface waters are planktonic organisms including, most prominently, bacteria, algae (phytoplankton), protozoans, and zooplankton (Karl 1999). Common zooplankton types in coastal Hawaiian waters include copepods, chaetognaths, appendicularians, shrimps, amphipods, pteropods, and a variety of other invertebrates, as well as larval fishes. Many of these organisms migrate to waters below the thermocline during the day. The clear blue offshore waters in Hawai‘i result from the very low densities of phytoplankton that are found in the oligotrophic waters of the North Pacific central gyre. Chlorophyll-a concentrations at the surface are low (about 0.1 micrograms/liter) in the waters off Ke hole Point. However, photosynthetic rates in the recurrent cyclonic eddy to the west of the Point have been found to be as much as two-thirds higher than in surrounding waters because of the presence of upwelled nutrients (Allen *et al.* 1996). Important phytoplankton taxa include prochlorophytes, coccolithophorids, flagellates, dinoflagellates, and diatoms.

A considerable diversity of fish exists in the nearshore waters around Ke hole Point, but the vast majority of these are directly associated with the shallow seabed. The surface waters above the Ocean Research Corridor site are the habitat of numerous pelagic fishes in a number of families, including tunas, jacks, billfishes, swordfishes, and dolphin fishes. Pelagic fishes are generally highly mobile and, while they may occur in large schools, they have overall very low average densities.

North of Ke hole Point, bathymetric contours diverge from the coastline. This defines an underwater ridge extending offshore. The local fishing community knows these waters as “The Grounds.” The area is famous for excellent fishing, especially when there is a prevailing Kohala (north running) current. The attribution of good fishing conditions to nutrient upwelling from great depths is unsubstantiated in the scientific sense, though it might be worth investigating in future research. At any rate, the Grounds near Ke hole Point seem to be an area of intense mixing within the surface layer with the formation of small-scale eddies. Such conditions apparently can lead to good fishing.

As previously mentioned, several threatened and endangered marine species can occur in the open ocean off Ke hole Point. The Humpback whale occurs routinely in the waters around the main Hawaiian Islands during the winter months (Marine Sciences Group 1986). Blue, Right, Finback, and Sperm whales also occur rarely in Hawaiian waters (Tomich 1986). The monk seal is endemic to Hawai‘i, but is largely restricted to the northwest Hawaiian Islands. No records of monk seal sighting near the Ocean Research Corridor site have been discovered.

The five species of sea turtles mentioned above (all endangered or threatened) have been reported in Hawaiian waters, but there are no known breeding or nesting areas for these turtles near Ke hole Point, the land nearest to the Ocean Research Corridor site (Marine Sciences Group 1986). Sea turtles are commonly sighted in the nearshore waters off Ke hole Point and have been seen by divers sleeping under overhanging outcrops on the coastal seabed.

5.1.2 AFFECTED ENVIRONMENT AT A GENERIC OCEAN SITE

Other possible locations for conducting the *Field Experiment* are discussed in Section 4.2.2.1.1. Evaluations of those locations concluded that, in principle, the *Field Experiment* could be tested at any of a number of ocean sites where hydrographic conditions would provide an environment with characteristics representative of potential ocean sequestration sites.

Consideration has also been given to locations where the *Field Experiment* could be performed from an ocean vessel outside the NELHA Ocean Research Corridor. As described in Section 4.2.2.2, these alternate locations would have the following specifications:

- Water depth of approximately 2,600 feet (800 meters);

- Weather and wave regime that would allow the research vessel to maintain position while the *Field Experiment* is being conducted and would not cause undue delays that might prevent the *Field Experiment* from being completed within the limited time that the ship would be available.
- Proximity to (and availability of) land-based support facilities needed for the research vessels and associated scientists.
- Absence of particularly sensitive natural resources.

A detailed description of the existing environment for a "generic" 2,600-foot (800-meter) site cannot be provided. The specifications required for such a site, however, suggest that environmental factors would be similar to the Ocean Research Corridor site in most respects. The general water-column characteristics of surface mixed zone, thermocline, and oxygen minimum zone would be similar for many tropical, open-ocean sites, although differences in nutrient levels and oxygen partial pressure would be expected at sites where primary productivity would be higher.

As described in Section 5.1.1.3, the benthic life of the deep seabed where the discharge would occur is similar over large geographic areas. If the generic ocean site were to be a tropical or semi-tropical location, similar taxonomic composition (at the generic level and above) and abundances would be expected. Mid-water and surface communities would probably exhibit more differences from the Ke hole site than the deep-water and benthic fauna. However, these differences would not be likely to change the overall nature of the environmental response.

5.1.3 NO ACTION ALTERNATIVE

As explained in Section 4.4, "No Action" means that the U.S. Department of Energy (DOE) would not participate in an international agreement covering the *Field Experiment*. Foreign government agencies participating in the agreement, however, have tentatively committed significant funds to the investigation and could increase their involvement to offset withdrawal by DOE. Since DOE does not have regulatory control over the *Field Experiment*, increased involvement by the other participants in the agreement would allow the *Field Experiment* to proceed, even in the absence of DOE action. Thus, the environmental effects of the "No Action" alternative range from no effects (if withdrawal from the agreement would result in cancellation of the *Field Experiment* by the other participants) to the same effects as those described in this Environmental Assessment.

5.2 WATER QUALITY EFFECTS

The release of liquid carbon dioxide (CO_2), the cornerstone of the *Field Experiment*, would produce a temporary and localized effect on water quality. The anticipated behavior of the carbon-rich plume and the resultant water quality changes are described below.[13]

5.2.1 EXPERIMENT-PHASE EFFECTS ON MARINE WATER QUALITY

Mathematical models, laboratory tests, and oceanographic measurements indicate that the principal effect of the *Field Experiment* would be the creation of a cloud of liquid CO_2 droplets and the subsequent dispersal of CO_2-enriched seawater. The primary goals of the *Field Experiment* would be to verify scientific principles and to provide data that can be used to improve the accuracy of existing predictive models. As discussed in Appendix D, several groups have been developing different approaches to modeling these complex processes. In the following discussion, the evaluation of potential impacts is based on the computer programs of Alendal *et al.* (1998). This model is fully three-dimensional and has benefited from more than two years of development.

[13] In reading the discussion for Section 5.2, it is important to remember the earth's oceans are the natural sinks for carbon dioxide, removing from circulation at least 7.3 billion tons of CO_2 annually.

The base case in computer simulations by Alendal *et al.* consists of a discharge rate for CO_2 of about 16 gallons per minute (1 kilogram per second), an initial droplet radius of 0.28 inches (7 millimeters), and a typical deep-water current of 0.1 knots (5 cm/s).[14] The model calculates the size distributions of the CO_2 droplets in the near field, as well as pH distribution in the near- and far-field.[15] Alendal *et al*.'s model predicts that after about 25 minutes the discharge plume would reach a stable size in the vertical and lateral directions, but would continue to lengthen in the down-current direction.

Liquid CO_2 injected by the *Field Experiment* would exist in three different forms: (i) droplets of liquid CO_2 with density lower than seawater; (ii) hydrates on the surface of CO_2 droplets; and (iii) CO_2 dissolved in seawater. The physical and chemical effects predicted by modeling for each form of liquid CO_2 are discussed separately below.

5.2.1.1 Droplet Phase of the Plume

When liquid CO_2 discharges under pressure through a nozzle, distinct droplets (similar to those from a water sprinkler) would be created. Because these droplets would be less dense than the surrounding seawater, the CO_2 droplets would rise from the discharge nozzle; thus, they would not affect the deep seafloor. Subsequent processes would dissolve and disperse the droplets, preventing them from reaching surface waters. The released carbon dioxide would be at essentially the same temperature as the ambient water. Consequently, no detectable cooling of the seawater surrounding the discharge platform would be expected.

Figure 5-5 shows a vertical cross-section of the predicted behavior of the droplet cloud for the base case (i.e., minimal hydrate formation). Here, the droplet cloud would be expected to persist for a distance of approximately 100 feet (30 meters) down current and to be about 200 feet (60 meters) high (thick). The width of the droplet cloud would expand from the size of the nozzle at the injection point to about 60 feet (18.5 meters) at 100 feet (30 meters) down current. Though CO_2 is colorless, water clarity within the droplet cloud would be reduced (CO_2 has a different refractive index than seawater, so the droplets would be visible). Discharge experiments that were carried out in a high-pressure vessel simulated the deep-water discharge (Masutani *et al.* 2000a, Masutani, *et al.* 2000b). Pictures of the droplet cloud generated in these experiments (Figure 5-6) provide a sense of the way the droplets in the *Field Experiment* would appear.

5.2.1.2 Formation of Hydrate Coating

Under certain conditions, CO_2 at the droplet surface can form solid complexes of water and carbon dioxide known as "hydrates." When hydrates coat a droplet, the droplet is partially isolated from the surrounding water; this isolation slows the overall dissolution process. Although pure hydrates have a slightly higher density than seawater, their effect on the net buoyancy of coated droplets can only be significant with extremely small initial droplets, for which the surface-to-volume ratio is large. Initial droplet size, in turn, is primarily controlled by the way CO_2 is released. During the *Field Experiment*, the CO_2 would be released in such a way that droplets would remain buoyant even with a hydrate coating. Thus, these droplets are not expected to impact the seafloor.[16]

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[14] The average deep-water current measured in August and September of 1999 at the Ocean Research Site was 0.08 knots (4 cm/s) (Section 5.1.1.1.3).

[15] For a definition of "near-field" and "far-field," see Section 4.2.2.1.1 (footnote 3).

[16] If unexpectedly large quantities of hydrates began to form on the droplets, the smallest could settle onto the seafloor, most likely falling close to the injection platform. The hydrates themselves would be unlikely to directly impact seafloor biota. Upon dissolution, hydrates would form small clouds of relatively dense, CO_2-rich, seawater that would be dispersed by mixing near the seafloor. Unexpectedly large quantities of hydrates would be readily visible, and the experiment would be modified if any such contingency develops.

Figure 5-5. Time Evolution of the Liquid CO_2 Droplet Cloud (Base Case)

Figure 5-6. Laboratory Generation of Liquid CO_2 Droplets

Figure 5-7 shows how the droplet cloud would behave if droplets corresponding to the same initial conditions as in Figure 5-5 were to develop a hydrate shell. In this case, dissolution would be slowed, which would allow the buoyant droplet cloud to rise further before fully dissolving in seawater.

The expected plume in this hydrate-coating scenario would be 400 feet (120 meters) high and have a down-current extent of 200 feet (60 meters). Thus, the formation of hydrates would cause the near-field plume to be larger than a droplet cloud generated without hydrate formation. Since the same amount of CO_2 would be discharged in both scenarios, the average concentration of droplets (and, therefore, their effect on pH after they dissolve) would be lower in the larger droplet cloud. This relationship (i.e., the larger the affected volume, the smaller the magnitude of the effect) would be true for all of the scenarios described herein.

5.2.1.3 Dissolution

The droplets and hydrates would ultimately be unstable and would dissolve in the deep seawater within 30 minutes of their release. The key chemical reactions of this process would be as follows:

a. CO_2(droplets) $\quad CO_{2(aq)}$

b. $CO_{2(aq)} + H_2O \quad H_2CO_3$

c. $H_2CO_3 \quad H^+ + HCO_3^-$

d. $HCO_3^- \quad H^+ + CO_3^{2-}$

As indicated by the equations, droplets would first dissolve into the water (a), react with water to form carbonic acid (b), rapidly dissociate partially both to bicarbonate and carbonate anions, and generate free acid, or protons (H^+) (c and d). Although a dissolved droplet would not be visible to the naked eye, the water containing the carbon dioxide could be distinguished from the rest of the seawater principally by a lowered pH (Stumm and Morgan 1981). A threshold of pH = 6.5 was chosen as the level below which acute effects on biota could occur as a result of exposure times of the approximate duration expected from the experiment. This threshold was based on experimental and field studies of the relationships between pH and marine life (Section 5.3.1.2, below). These dissolution reactions would have no substantial effect on the levels of dissolved oxygen in the affected seawater (C.S. Wong. 2000, Personal Communication).

Surface seawater has a typical saturation value of 33 mmol/l for total dissolved inorganic carbon (Teng *et al*. 1996). This corresponds to a pH of 4.88. Saturation value increases, and the corresponding pH value at saturation decreases, with increasing water depth. Degassing can occur only when the saturation value has been exceeded. The computer models (described in the following sections and in Appendix D) used to predict the behavior of the CO_2 released for the *Field Experiment* indicate that pH values well above 5 would be reached within 6 feet of the release point. Because of this, a sudden release of CO_2 into the atmosphere, similar to the dramatic and tragic release from Lake Nyos (Cameroon, Africa) that occurred in 1986 (Holloway 2000), would not be possible in the *Field Experiment*.

5.2.1.4 Advection, Dispersion, & Diffusion: The Spatial & Temporal Extent of the Plume

Deep-water currents would carry the CO_2-enriched seawater away from the site (termed advection). Turbulent eddies would mix the water with the surrounding seawater, dispersing it (also sometimes called "turbulent diffusion"). Finally, relatively slow molecular processes would mix the water through diffusion. Since molecular diffusion would be too slow to be relevant in the short time frame considered for this experiment, this analysis concentrates on the effects of advection and dispersion.

Figure 5-7. Time Evolution of the Liquid CO_2 Droplet Cloud (with Hydrate Formation)

As described in Section 5.1.1.1.3, the seafloor currents at the NELHA Ocean Research Corridor site vary between 0 and 0.4 knots (0–20 cm/s). Currents faster than 0.2 knots (10 cm/s) do not persist longer than about one hour. Figure 5-8, Figure 5-9, and Figure 5-10 depict the behavior of the released CO_2 with a constant current of 0.1 knots (5 cm/s).[17] The predicted extent of the discharge plume created in this process and the implications of these calculations for marine water quality are discussed below.

Figure 5-8 shows the base case, which assumes no hydrates have formed. Figure 5-9 depicts the horizontal extent of the base-case plume after the discharge has been underway for one hour, which is the maximum time for which graphical computer output has been obtained. As can be seen in Figure 5-8, the only significant change to the plume after the first half-hour would be an increase in its downstream length. Because of this dynamic stability in the plume, the plume from a two-hour discharge would be about twice as long as the plume produced by a one-hour discharge; all other dimensions would be about the same.

Using this line of reasoning the Alendal *et al.* model predicts that the approximate volume of water subject to pH levels of 6.5 or lower at the moment a two-hour discharge has ended (the time at which this water volume would be greatest) would be 1,200 feet long, 60 feet wide, and 100 feet high (360 meters by 18.5 meters by 30 meters). This represents a volume of about 260,000 cubic yards (200,000 m^3). If this plume contacted the seafloor at its maximum width for its entire length, it would have a footprint area of 8,000 square yards (6,660 m^2).

The plume would persist for a time after the discharge has ended, drifting with the ocean currents and dissipating with the natural processes of turbulent dispersion. Even using very conservative assumptions (including low rates of turbulent dispersion) to model the further dispersion, calculations indicate that the plume would be dispersed to the point where the entire volume would contain seawater with pH values higher than 6.5 less than three hours after the discharge has stopped. Assuming, for simplicity, that the 0.1-knot (5 cm/s) current persists during this three-hour period, the plume would be transported 1,800 feet (approximately 550 meters) downstream. Assuming further that the plume would remain unchanged until the end of this three-hour period, then the plume could affect a total seafloor area of about 4 acres (0.14% of the Ocean Research Corridor).[18] For the entire *Field Experiment*, a maximum of eight such maximum rate, 2-hour discharges would be possible. Assuming each discharge would affect a different area of the seafloor (i.e., that there would be no overlap between tests in the sequence), a total of about 33 acres could be affected.

This high-end estimate assumes that the maximum amount of CO_2 under consideration would actually be used and all of the CO_2 would be used for tests at the maximum release rate (1 kilogram/second). In reality, less than the maximum amount of CO_2 would probably be used and substantial amounts would be likely to be used for tests at lower release rates (which would produce less change in pH; see Appendix C for current plans). Because the model does not fully account for all of the factors that would tend to disperse the plume, the model almost certainly overstates the affected area. Thus, the actual effect would be less than indicated here.

Figure 5-10 shows the modeled plume if hydrate formation on the surface of the CO_2 droplets would slow the dissolution rate of the droplets by 50%.[19] The principal differences between this "with-hydrates" scenario and the base case previously described would be a greater plume thickness (height) (approximately 200 feet, or 60 meters). In either case, the affected volume would be the

[17] Note: The average current measured was 0.08 knots (4 cm/s).

[18] In reality, the plume would shrink over this entire three-hour period. This means that the area actually affected would be far less.

[19] A 50% reduction would be consistent with estimates made using theoretical models and with experimental results.

Figure 5-8. Time Evolution of the pH Field (Base Case)

Figure 5-9. Horizontal Plume Cross Sections, 1-25 Meters Above Ocean Floor (Base Case)

Figure 5-10. Time Evolution of the pH Field (with Hydrate Formation)

same, (200,000 m^3), implying that hydrate formation would reduce the seafloor area affected relative to the base case (i.e., would reduce the area subject to a pH of less than 6.5). Section 5.3 uses the larger area predicted by the base case (33 acres) to assess potential effects on marine life on the seafloor. Eight releases of this size[20] would produce an affected volume of 2 million cubic yards (about 1.6 million cubic meters). Overall, the model predicts that the pH levels of 6.5 or less would be expected to persist for no more than three hours after the CO_2 release has stopped the plume is while drifting down current to a distance of about 1,800 feet. The pH would return to ambient conditions everywhere (pH   7.6) in about 12 hours.

5.2.1.5 Other Water Quality Effects

Other activities carried out during the *Field Experiment* would include standard oceanographic investigations of the carbon dioxide plume's characteristics. These activities would include temporary deployment of instrument packages and one or two remotely operated vehicles (ROVs) or submersibles to measure key parameters. The U.S. National Oceanographic and Atmospheric Administration has determined that use of these instruments creates no potential for significant environmental effects, including effects on water quality (15 CFR 970.701a). Research vessels would be equipped with U.S. Coast Guard-approved marine sanitation devices (33 CFR 159) to preclude unauthorized discharges of sanitary wastes. Research vessels would comply with U.S. Coast Guard regulations (33 CFR 151) and other applicable Federal and State of Hawai‘i laws and regulations for the management of bilge and ballast water to minimize pollution and the introduction of non-indigenous or exotic species into waters at the site of the experiment.

As discussed in Section 5.2.1.1, the CO_2 droplets would cause a temporary, localized effect on water clarity within 100 to 200 feet of the release point. In addition, marker dyes, used to track the CO_2-enriched seawater plume, would contribute a localized effect on water clarity near the release point. Two types of dye are under consideration for use during some of the releases, rhodamine-WT and disodium fluorescein (trade name uranine). For many years scientists and engineers have used both of these tracer dyes in freshwater and seawater systems to track parcels of water. Either dye would create a visible color in the seawater within at most 300 to 500 feet of the discharge point. Beyond this distance, the dye would be diluted to where it would be only detectable using specific sensors designed for that purpose. The absence of potential for toxic effects from these dyes is discussed in Sections 5.3.1.3 and 5.3.2.1.4. Because the effects on water clarity caused by the CO_2 droplet cloud and by the tracer dyes would both be localized and temporary, they would not have a substantial effect on seawater quality.

5.2.1.6 Relationship to Applicable Water Quality Standards

For waters regulated by the State of Hawai‘i, which includes waters within the Ocean Research Corridor, the State of Hawai‘i Department of Health (DOH) has determined that the release of CO_2 into Class A waters constitutes an activity subject to HAR Section 11-54 (Water Quality Standards) and Section 11-55 (Water Pollution Control). DOH has indicated that due to the research nature of the experiment and to the fact that releases would be intermittent and of short duration, the State DOH may waive the requirement for a National Pollutant Discharge Elimination System (NPDES) permit if certain conditions are met (see Section 7.2.1). If the requirement is not waived, an NPDES permit and zone of mixing permit would be needed from the Department of Health.

The waters in which the proposed experiment would be conducted are classified by the State Department of Health as "oceanic waters".[21] HAR §11-54-06 (c) establishes water quality standards

[20] Only eight releases would be possible with the amount of CO_2 available in the operational plan at the maximum discharge rate (16 gallons per minute) and duration (2 hours). The actual number of planned tests (12-20) would result in tests of shorter duration or lower release rates.

[21] Oceanic waters are defined as all marine waters outside of the 183 meter (600 feet or 100 fathom) depth contour.

for these waters. These standards cover total nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, chlorophyll a, turbidity, dissolved oxygen, temperature, salinity, and pH.

The only one of these that the proposed experiment has the potential to affect is pH. The regulations stipulate that "pH Units - shall not deviate more than 0.5 units from a value of 8.1" (which is the pH typical of surface waters). Because the existing pH at the depth of the proposed experiment (7.6) is already at the extreme lower end of the range allowed by this standard, the water most affected by the proposed release would not comply with this standard. This would be true even if the allowable change was measured from the existing pH of 7.6.

HAR §11-54-04 establishes basic water quality standards for all State waters. It requires all waters to be free of substances attributable to domestic, industrial, or other controllable sources of pollutants. Named pollutants include:

- Materials that will settle to form objectionable sludge or bottom deposits;
- Floating debris, oil, grease, scum, or other floating materials; substances in amounts sufficient to produce taste in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to produce objectionable color, turbidity or other conditions in the receiving waters;
- High or low temperatures; biocides; pathogenic organisms; toxic, radioactive, corrosive, or other deleterious substances at levels or in combinations sufficient to be toxic or harmful to human, animal, plant, or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water;
- Substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life;
- Soil particles resulting from erosion on land involved in earthwork, such as the construction of public works; highways; subdivisions; recreational, commercial, or industrial developments; or the cultivation and management of agricultural lands.

As discussed in Section 5.2, the pH reduction that would accompany the release of CO_2 would cause only localized, short-term excursions outside the normal range. These would not substantially interfere with the uses that the standards are designed to protect.

HAR §11-54-01.1 states that it is the general policy of the state to prevent the degradation of water quality. This "antidegradation rule" states that *"…the quality of waters whose quality are higher than established water quality standards shall not be lowered in quality unless it has been affirmatively demonstrated to the director that the change is justifiable as a result of important economic or social development and will not interfere with or become injurious to any assigned uses made of, or presently in, those waters."* The environmental analyses conducted for this report indicate that the proposed experiment would not interfere with or become injurious to any assigned uses made of those waters in any substantial way.

If the State Department of Health were to decide not to waive the requirement for an NPDES permit, the Department has indicated that a "Zone of Mixing Permit" as provided for in HAR §11-54-09 would also be required. As used in these regulations, "zones of mixing" means limited areas around outfalls and other facilities to allow for the initial dilution and assimilation of *waste* discharges. Zones of mixing are normally used for the assimilation of domestic, agricultural, and industrial wastes. They are not normally associated with scientific experiments where the purpose of the experiment is to cause a temporary perturbation in water quality for the purpose of establishing the ocean's assimilative capacity.

Because the discharges normally governed by the regulations are wastes, the regulations require that these discharges (1) be determined to be necessary and (2) receive the best degree of treatment or control possible. The proposed *Field Experiment* is consistent with both of these provisions. First, for reasons described in Section 2.2, the experiment is needed in order to better understand basic physical processes that affect the assimilation of CO_2 in the deep ocean. Second, the experimental plan (see Appendix C) calls for the use of the lowest release rate and smallest total release volume that is believed necessary if the scientific objectives are to be met. Thus, the proposed action is consistent with these regulations.

5.2.2 ACCIDENT SCENARIOS (REASONABLE WORST CASE)

The flexible steel discharge tubing planned for use during the *Field Experiment* would be designed to withstand the stress of repeatedly lowering and raising the approximately 5-metric ton discharge platform, the internal pressure of the liquid CO_2, and the external, hydrostatic pressure in the deep sea. The tubing would be designed to be coiled and uncoiled up to 150 times (JMC 2000. Personal Communication). Nonetheless, while unlikely, the possibility of a tubing failure cannot be completely discounted.

If a failure were to occur, it would most likely happen at a point of greatest stress. In practice, this means the tubing would be most likely to fail either at the top or at the bottom; failure would also be most likely to occur while the platform is being raised or lowered or if the tubing were to become snagged on a protuberance from the seafloor.[22]

The important variables in evaluating the effect of a tubing failure would be the depth at which the break occurs and the amount of CO_2 that could potentially escape. While design of the tubing has not been finalized, the tubing would likely have an internal diameter of approximately 1.5 inches (3.81 centimeters). The volume of CO_2 contained within a 3,600-foot length of tubing with a 1.5-inch diameter would be 325 gallons (1.25 cubic meters).[23]

Failure Near the Surface. If the tubing would rupture at or near the surface (i.e., if the tubing develops a leak without being completely severed), the CO_2 would escape as a gas due to sudden depressurization. The rapid ascent of bubbles to the sea surface would probably prevent much CO_2 from entering the seawater. Hence, this scenario would have little potential to affect water quality. Once in the atmosphere, the CO_2 would rapidly disperse.

If completely severed at the surface, the tubing would fall to the seafloor. In reality, most of the liquid CO_2 in the tubing would vaporize, rise to the surface, and then vent into the atmosphere. Little CO_2 would dissolve into the water during this process. Once the broken end of the tubing would sink below 1,500 feet (450 meters), hydrostatic pressure would be sufficient to keep any remaining CO_2 that escapes in a liquid state. The tubing would move erratically during the fall, thereby dispersing the CO_2 over a large volume of water. Because of these forces, the CO_2 released in the event of such an accident would have little effect on water quality.[24]

Failure Near the Bottom. If the tubing were to fail near the bottom, the most CO_2 that could be released would be the entire volume of CO_2 (325 gallons) in the tubing. In reality, the pressure inside and outside the break would quickly equalize and less would escape. Such a failure could release, over a relatively short period of time, about the same volume of CO_2 as would normally be released during 15-20 minutes of a planned test at the maximum discharge rate contemplated.

[22] Video of the seafloor near the study site revealed numerous patches of rocky outcrops, many appearing to rise 1 to 2 feet above the sediments. If the surface vessel that deployed the platform were to move substantially to either side of a designated location, the tubing could become stuck on a rock and, in effect, anchor the vessel. This could cause the tubing to break.

[23] The tubing length used, 3,600 feet, accounts for the 2,600 feet of vertical distance needed to reach the ocean floor plus the 1,000 feet of tubing that would lie on the ocean floor.

[24] Even if an assumption is made that all CO_2 in the tubing would dissolve in the surface layer with no subsequent release to the atmosphere, the maximum dimensions of the parcel of water that would experience a pH = 6.5 would be no more than 30 meters (100 feet) on a side. Even this parcel would be very short-lived; nowhere would pH remain below 6.5 for longer than 17 minutes, and the affected parcel could travel no further than 440 feet (133 meters) before being completely dissipated by turbulent mixing.

The impacts on water quality would depend upon many factors, including whether or not the broken tubing would remain attached to the platform and the extent to which hydrate formation around the break would restrict the rate of release. However, in any event, the water quality effect would only be a fraction of the modeled situation presented in Section 5.2.1. The probability of these failures is not known. Such an experiment has not been conducted, and yet the handling and transport of liquid CO_2 is commonplace worldwide. No specific statistics for failure of such marine transport and handling systems were available for this study.

5.2.3 CLOSURE/TERMINATION-PHASE EFFECTS ON MARINE WATER QUALITY

The activities that would take place during the closure/termination phase of the *Field Experiment* would not affect water quality. The discharge platform, pipe, and monitoring instrumentation would be removed with no further activities anticipated at the site. These activities would have no measurable effect on water quality.

5.2.4 WATER QUALITY EFFECTS AT A GENERIC OCEAN SITE

Differences between the predicted effects of conducting the *Field Experiment* within the NELHA Ocean Research Corridor at Ke hole Point or at another location would probably arise mostly from differences in the ocean current regime at the sites. Higher currents and levels of turbulence would disperse the discharge plume more rapidly, while lower current speeds and turbulence would have the opposite effect. Hydrographic conditions selected for the experiment would need to be below levels that could pose operational problems. Therefore, any generic ocean site selected for the experiment would possess a current regime similar to that at the NELHA Ocean Research Corridor site. Generally, then, the effects on water quality at a generic ocean site would be quite similar to predictions made for the Ocean Research Corridor site.

5.2.5 WATER QUALITY EFFECTS OF NO ACTION ALTERNATIVE

If the *Field Experiment* was not conducted due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no changes in existing water quality would occur. If the *Field Experiment* was conducted without DOE participation, then the water quality effects would be similar to those presented for the Ocean Research Corridor.

5.3 EFFECT ON MARINE RESOURCES

The primary environmental effects of the *Field Experiment* would be on the marine biological resources near the *Field Experiment* site. Section 5.3.1 provides a general overview of the project elements that have potential to affect marine biological resources. Section 5.3.2 discusses the effects of conducting the *Field Experiment* at the NELHA Ocean Research Corridor site. Section 5.3.3 briefly examines how these effects might differ at a generic ocean site. Section 5.3.4 describes the anticipated effects on marine biological resources under a No-Action decision by DOE.

The *Field Experiment* would not be expected to have a substantial adverse affect on the North Pacific Humpback whales (*Megaptera novaeangliae*). Additional discussion on Humpback whales is presented in Section 7.1.6. The absence of potential effects on sea turtles is discussed in Section 7.1.5.

5.3.1 PROJECT ELEMENTS WITH POTENTIAL TO AFFECT MARINE BIOTA

This subsection summarizes key aspects of the *Field Experiment* that have the potential to cause environmental effects. Section 5.3.1.1 describes the direct effects anticipated to result from emplacement of the discharge platform and tubing. Section 5.3.1.2 outlines the state of knowledge regarding the interaction between lowered pH levels in ocean water and marine life. Section 5.3.1.3 describes the characteristics of the oceanographic monitoring equipment that would be used for the

Field Experiment, and Section 5.3.1.4 considers the scale of, and probable results from, accidental releases of CO_2 that could result from equipment failure or operational errors.

5.3.1.1 Area Subject to Abrasion from the Discharge Platform and Tubing

The discharge platform (Figure 4-4), measuring about 7 by 13 feet (approximately 2 by 4 meters) and weighing 5 metric tons, could be lowered onto the seafloor as many as 10 times, though the current experimental plan calls for only two such deployments (see Appendix C). During each landing, the platform would likely leave an imprint in the seabed if it lands on soft substrate. The preliminary platform design incorporates a pointed leg at each corner. This configuration, which is intended to help affix the platform to the steeply sloping seafloor, would minimize the area over which the platform would contact the bottom. If all four legs would land on bare substrate each time the platform would be deployed, the contact area for 10 deployments would be minimal, probably no more than 40 square feet (4 square meters). Even if the platform unexpectedly landed on soft bottom during each of the 10 deployments so that the entire bottom rested on the seafloor, the contact area would be no more than 860 square feet (80 square meters), which would be too small to have a substantial deleterious effect on the benthos.

The tubing laid on the seafloor during each deployment of the platform would affect a larger area. Figure 4-2 shows the general methods that would be used for deployment of the tubing and discharge platform. Figure 5-11 illustrates the worst-case estimate of the area that would be impacted. Tubing could extend approximately 1,000 feet (300 meters) away (as measured horizontally) from the platform. This horizontal displacement would keep the vertical segment of the tubing (i.e., the part that extends through the water column from the surface vessel to the seafloor) well clear of the space in which the ROVs and submersibles would operate. Figure 5-11a shows the situation after complete deployment of the platform.

While the vessel used for the deployment would have very good position-keeping capability, the vessel would not remain perfectly motionless for the entire duration of each deployment. The experimental design specifies that the vessel would remain within 80 feet (25 meters) of a desired position. Combined with the length of tubing that would rest on the seafloor, this position-keeping capability would define the maximum sector across which the tubing could sweep. This sector (with the platform as its center and the length of tubing on the seafloor as its radius) is sketched in Figure 5-11b. A seabed area of about 1.84 acres (0.06% of the Ocean Research Corridor) could be impacted.

However, the vessel and platform would probably not be in precisely the same location each time the platform would be deployed (although they are likely to be close). Thus, the tubing could affect a different part of the seafloor during each deployment of the platform. Assuming that absolutely no overlap would exist between successive deployments of the platform and tubing (a highly unlikely assumption) and that a maximum of 10 deployments would be made, then loose rocks could be displaced and mounded sediments could be disturbed over a maximum seafloor area of 18 acres (0.62% of the Ocean Research Corridor seafloor).

5.3.1.2 Mechanism Through Which Lowered pH Could Affect Marine Life

Injection of very large amounts of anthropogenic CO_2 into seawater over a long period could affect the rate of deposition or loss of calcium carbonate by organisms. The *Field Experiment* would involve far too small a release and far too short a time to cause such chronic effects. Organisms that live at the depth where the *Field Experiment* would be conducted are accustomed to an environment where calcium carbonate is stable. The temporary depression of pH caused by the *Field Experiment* CO_2 release would briefly produce chemical instability, but the relatively slow process of carbonate dissolution would not be substantially affected.

Figure 5-11. Benthic Impact Area Estimate

The kind of short-term CO_2 release planned for the *Field Experiment* would theoretically be capable of affecting development, reproduction, and survival of marine organisms through physiological effects of acidosis. The potential for such acute effects is discussed below. Studies of the effects of increased CO_2 levels on marine organisms have only been recently initiated and few data are available. Most prior research into the effects of depressed pH on marine organisms has concentrated on the effects of acid discharge from industrial outfalls and the release of acidic wastes from barges. Auerbach *et al.* (1997) reviewed available laboratory studies on the effects that lowered pH can have on different sorts of marine life. Figure 5-12 presents a summary of these laboratory studies.

Perhaps the best available natural analog to a release of anthropogenic CO_2 in the deep sea are the plumes of hydrothermal fluid emanating from vents on the Hawaiian seamount L ‘ihi, located about 20 nautical miles southeast of the Island of Hawai‘i. The fluids venting from L ‘ihi contain CO_2 concentrations as high as 18 parts per thousand (by weight) at a depth of about 3,300 feet (~1000 m; Karl *et al*., 1988; Sedwick *et al*., 1992).

Over a period of two weeks in 1997, injection of CO_2 into the deep-sea water near Hawai‘i by Pele's Vents (located on L ‘ihi) was on the order of 340 to 5,500 short tons (McMurtry 1998). This mass is a minimum of 6 times the amount that would be injected over the course of the *Field Experiment*. There are no known reports of substantial adverse effects on marine organisms in the water column as a consequence of the L ‘ihi vents, where animals passing through the vent field in the water column above the vents would not be adapted to the high CO_2 levels, and where the pH would be as low as the pH likely to be experienced in the *Field Experiment*. Moreover, this is true even though the release from the L ‘ihi vents occurs over very long periods of time and is accompanied by other factors that are even more inimical to biological activity.

The existence of naturally occurring releases of large amounts of dissolved carbon in deep hydrothermal vents of volcanic origin on L ‘ihi may prove very useful in future evaluations of the potential chronic environmental effects of ocean sequestration of CO_2. However, the lack of a pure phase (liquid CO_2) at release points on L ‘ihi would eliminate strong buoyancy effects, the role of hydrate formation, the influence of dissolution kinetics, and other processes that are the objects of study for the *Field Experiment*. Also, there would be a lack of necessary experimental control, because the venting occurs sporadically at variable flow rates and at multiple sites.

A critical assumption of this analysis is the pH at (and below) which marine metazoans would begin to die after a brief exposure. Information on this subject is limited. In a study of the effects of CO_2 concentration on two echinoid and one gastropod species, Shirayama *et al.* (1999) reported very low mortality relative to controls at pH levels ranging from approximately 6.5 to 7.8. Significantly, no experimental organisms died during the first week of exposure to any of the reduced pH levels in this range (i.e., to an exposure period that would be much longer than any produced by the *Field Experiment*).[25]

In a study of the effect of pH on eggs, larvae, juveniles, and adults of flounder (*Paralichthys olivaceus*), Kita *et al.* (1999) reported that the younger life stages were the most sensitive. Approximately 40% of flounder larvae were found to survive exposure to 6.5-pH seawater for 6 hours, and about 20% survived exposure to 6.5-pH seawater for 24 hours. Auerbach *et al.* (1997) used literature data to report on the effect of pH and exposure time on a variety of holo- and meroplanktonic organisms; no mortality was predicted for those organisms after a 24-hour exposure to seawater with pH as low as 5.7. Mortality did not occur in the copepod *Temora longicornis* after 24-hour exposure to acidified seawater until the pH was reduced below 6.0 (Grice *et al.* 1973).

[25] The report notes that, at the highest acidity concentrations, the echinoderms appeared to be paralyzed for some time prior to death (after about 2 weeks). The report does not state either the length of time between initial exposure to decreased pH and the onset of paralysis or the response that might result if conditions returned to normal in less than two weeks.

Figure 5-12. Biological Mortality Due to pH Exposure

Taken as a whole, the data suggest exposure to seawater with a pH as low as 6.5 for periods of time less than 24 hours would not result in substantial levels of mortality for marine macrofauna and plankton. The data do suggest that water with pH levels below 6.5 would have some potential to harm certain marine organisms if they are exposed for a sufficient period of time. The limited studies also suggest that exposures to the greatest pH depression that would be produced by the fastest discharge rate over the time that a CO_2 plume would persist (a few hours) would have the potential to harm (including kill) some marine organisms. Unfortunately, insufficient data exist to establish precise dose-response relationships.

5.3.1.3 Experimental Monitoring Devices

The other activities carried out during the *Field Experiment* would include standard oceanographic investigations of the discharge plume characteristics. These activities would include deployment of seafloor-moored instrument packages, ROVs, and submersibles to measure the key parameters of the discharge. The U.S. National Oceanographic and Atmospheric Administration has, through many years of conducting and observing such activities, determined that they have no potential for significant environmental effects (15 CFR 970.701a).

The tracer dyes planned for use in the *Field Experiment* are non-toxic at the concentration levels anticipated (<5 mg/l at a distance of 3 feet from the release point). Extensive testing of the dyes using a variety of aquatic organisms showed no toxic effects at concentrations below 10 mg/l (Keystone Corporation 2000).

5.3.1.4 Mechanism Through Which Accidental Releases Could Affect Marine Life

Accidental releases of CO_2, either on the sea surface or at the seafloor, would be of very short duration and cause only minor perturbations on surface or deep seawater. Accidental releases would not be expected to cause adverse impacts.

5.3.2 EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.3.2.1 Anticipated Seafloor Effects

The planned *Field Experiment* could potentially affect deep seafloor communities through (i) direct CO_2 effects, (ii) disturbance from repeated platform emplacement, (iii) seafloor scour by the CO_2 delivery tubing, and (iv) other miscellaneous effects. All of these effects would be localized.

5.3.2.1.1 Direct CO_2 Effects on the Seafloor

As discussed in Section 5.2.1.4, small patches of seafloor near the platform could be subjected to pH levels below 6.5. Some mortality of benthic organisms dwelling within these patches would be likely, but they would be very difficult to detect due to the low densities and the high spatial variability characteristic of deep-sea sediment assemblages (Gage and Tyler 1991). Mortality on similar spatial scales frequently occurs naturally in deep-sea communities due to mounding and digging activities of seafloor animals (Kukert and Smith 1992). A potential for a seafloor impact from the *Field Experiment* would be created from the formation of plumes of CO_2-enriched seawater with pH $\leq$ 6.5. Conservative plume-dispersion calculations previously outlined in Section 5.2.1.4 indicate that the plume from a test at the highest planned release rate could produce pH levels below the 6.5 threshold over a seafloor area of about 4 acres (0.14% of the Ocean Research Corridor) for one test, and 33 acres (1.12% of the Ocean Research Corridor) for the entire *Field Experiment*.

The same conservative calculations show that the maximum time during which any seafloor organism would be exposed to pH of that magnitude would be three hours. The evidence presented in Section 5.3.1.2 from Auerbach *et al.* (1997) indicates that this exposure could stress some organisms but would be unlikely to be lethal. Shirayama *et al.* (1999), on the other hand, have reported toxicity to megafaunal organisms from such an exposure. Marine biologists recognize that they have imperfect knowledge of the precise pH dose-response characteristics of the organisms that populate the seafloor at the depth of the planned *Field Experiment*. Moreover, deep-sea communities that would be affected are characterized by very low rates of recolonization because of the low food availability at the deep seafloor (Smith and Hessler 1987, Kukert and Smith 1992).[26] Finally, while the seafloor area that the conservative modeling and assumptions indicate could experience pH $\leq$ 6.5 during an experimental release would be tiny from the perspective of the total area of similar habitat that is present in the region, several tens of acres would be involved.[27]

When all factors are considered, the CO_2 released during the *Field Experiment* would not be likely to have a substantial effect on benthic fauna. However, in view of the uncertainty inherent in any research endeavor, one or more of the following actions could be implemented if needed to provide additional protection against unanticipated adverse effects:

- Monitor the actual behavior of the plume of seawater having a reduced pH if any substantial plume characteristics that were not predicted by preliminary modeling studies should be identified;
- Monitor acute effects on animals near the CO_2 release point during the course of the experiment;
- Include in the experimental protocol provisions to modify the release (with respect to rate, timing, current speed, location, or other factors) in response to any unanticipated adverse effects.

The feasibility and specific methods of implementing these actions are being developed by the project team in collaboration with the State of Hawai‘i Department of Health as well as with other State and Federal agencies. The draft experimental plan describing these protocols and monitoring activities is presented in Appendix C.

One aspect of the work undertaken to monitor benthic ecosystem response to the *Field Experiment* discharge is a component of the existing *Field Experiment* scientific program. Coffin, *et al.* (1999) are developing the means to determine how the basic metabolic processes in ambient bacterial populations at the site would be affected by the CO_2 discharge. The work would include measuring ratios and abundances of naturally occurring carbon isotopes[28] (^{13}C and ^{14}C) in bacteria at the site before and after the *Field Experiment*, as well as laboratory culturing of the bacteria and measurement of how their growth rates vary with changes in pH. The object of these experiments would be to obtain information about how this very basic level of the ecosystem would be affected. Sampling and testing activities were conducted at the Ocean Research Corridor site and at other sites in the Hawaiian Archipelago during October 2000. These measurements would be repeated in conjunction with the *Field Experiment.*

5.3.2.1.2 Seafloor Effects of Repeated Platform Emplacement

As discussed in Section 5.3.1.1, the total area that could be physically impacted by 10 deployments of the discharge platform would range from 5 square yards (4 square meters) to 100 square yards (80 square meters). Complete recovery of the disturbed patches to background levels of faunal abundance and diversity could take a number of years. However, disturbance on this scale would not cause any long-lasting negative impacts to any of the seafloor fauna at the population or species level.

[26] Depending on their shape and size, areas that would experience 100 percent mortality could require on the order of 5-30 years to achieve full recovery.

[27] Seafloor species living at the depth of the planned experiment typically occur over depth ranges between 1,300 and 4,000 feet (400-1,200 meters; Gage and Tyler 1991). If the western side of the Island of Hawai‘i has an average slope of 22^{o} between these depths, the total seafloor habitat within this depth zone between M hukona and Ho‘ p loa, an alongshore distance of 67 miles (108 kilometers) is about 85,000 acres (345 square kilometers). Thus, even using conservative assumptions, the total area that could be impacted by the plume would be less than 0.04% of available similar seafloor habitat on the west side of Hawai‘i alone. The species found at this depth range on the western slope of Hawai‘i are also almost certainly found throughout the main Hawaiian archipelago (Chave and Jones 1991).

[28] Radioactive substances would not be used in any of the experiments.

5.3.2.1.3 Seafloor Scour by the Injection Tubing

As discussed in Section 5.3.1.1, an area of about 18 acres (8 hectares) of seafloor could be impacted by the maximum number of possible deployments of the platform and tubing. Movement of the tubing on the seafloor would adversely affect animals living on hard substrates. Video taken near the study site revealed few, if any, organisms attached to the rocks. Organisms that might be expected to occur on such substrates include non-hermatypic corals, sponges, and ascidians. Such organisms could be completely or partially destroyed by the movement of the tubing, or they could receive partial or complete protection from irregularities in the rock surface. Organisms with temporary or no attachments such as crinoids, echinoids, ophiuroids, holothurians, and decapods could be damaged, killed, or simply dislodged by the movement of the tubing.

Movement of the tubing could also affect animals living on or in soft sediments. Macrofauna could be damaged, killed, or simply dislodged by the movement of the tubing. Some infauna (predominantly small polychaete worms, peracarid crustaceans, and mollusks) could be damaged or killed by sediment disruption caused by the movement of the tubing; others would merely be temporarily dislodged.

Another potential effect of tubing movement would be the leveling of small-scale sediment features created from movement, feeding, and defecation by sediment-dwelling animals. Such features often persist in the deep sea because of the sluggish currents found at depth, and may provide locally important habitat diversity for infaunal invertebrates. The obliteration of such features is a commonly reported effect of trawling, which impacts vast tracts of the seafloor in many regions of the world's oceans.

Complete recovery of hard and soft substrate fauna following tubing disturbance would likely require months to several years. Because tubing disturbance would not cause complete defaunation of the area impacted, recovery rates would likely be more rapid than if the seafloor were completely denuded.

5.3.2.1.4 Miscellaneous Effects

Other activities during the *Field Experiment*, such as the emplacement and operation of the acoustic net and instrument packages, the collection of seafloor samples for bacteria, introduction of tracer dyes, and the operation of the ROV or submersible, are routinely conducted during research programs throughout the oceans. The instrument mooring anchors would occupy a very small area and would be composed of non-toxic materials (concrete or iron). After the instrument packages are retrieved at the end of the *Field Experiment*, the remaining anchors would provide hard-substrate outcrops, which could harbor colonizing benthic organisms. These activities would not have a substantial effect on seafloor communities.

5.3.2.2 Anticipated Deep to Midwater Effects

5.3.2.2.1 Direct Deep to Midwater pH Effects

Invertebrate zooplankton have no means of detecting or avoiding the plume of reduced-pH water that the *Field Experiment* would produce and thus could be affected by testing. As previously discussed, a pH of 6.5 may be considered as the threshold above which no effect would be anticipated; a pH below 6.5 could stress or kill some zooplankton if exposure is sufficiently long. The volume of the plume having a pH below 6.5 (200,000 m^3) represents the maximum size of the zone of potential effect for one discharge; this volume would be about 2 million cubic yards (1,600,000 m^3) for eight discharges. The maximum exposure time would be three hours.

The greatest concentrations of zooplankton generally occur within 800 feet (250 meters) of the surface. Copepods have sometimes been observed in high concentration at depths of 1,300 to 2,300 feet (400 to 700 meters; Davis and Wiebe 1985, Longhurst 1985, Beckman 1988). At the expected depth of the bulk of the plume (2,300 to 2,600 feet, or 700 to 800 meters) zooplankton density would be expected to be very low.

Combining the small likelihood that the reduced pH would be of sufficient magnitude and duration to adversely affect zooplankton with the fact that the zooplankton density at the affected depth would be very low, the likelihood of substantial adverse effects on these animals would be minimal.

Some studies have indicated fish and nektonic shrimp react to and avoid water with sub-lethal pH levels (Portman 1970, Davies 1991). If these results are typical of organisms at the *Field Experiment* site, then the *Field Experiment* should harm few fish and nektonic decapods because they would reverse direction upon encountering the plume. Scientists do not know if squid have the same ability to detect low pH water. Investigations by Shirayama *et al.* (1999) indicate that fish that would swim very near to the discharge nozzle, where pH levels would be low, and remain for a time, would probably be killed.

Between July and September 1986, soon after the operation of the 40-inch deep-water intake pipe began at NELH, a total of 29 stingrays were found at the facility intake sump at the discharge of the pipe (T.H. Daniel 2000, Personal Communication). No stingrays have been found in the sump since this initial period. The rays are believed to be a well-known species (*Plesiobatis daviesi*), which has commonly been observed in similar water depths (700 m) by deep diving submersibles throughout the Hawaiian Islands (D. Chave, 2000, Personal Communication). If such stingrays are present at the *Field Experiment* site, they might be affected if they do not move from the vicinity of the release point or if they are attracted to the carbon-rich plume.

Species of concern to the sport-fishing community include representatives from several families including, but not limited to, <u>snappers</u> (Lutjanidae, discussed below in this section), <u>pomfrets</u> (Bramidae, including monchong-*Taractichthys steindachneri* and *Eumegistus illustris*), <u>jacks</u> (Carangidae, including *halahala Trachiurops crumenopthalamus, lai-Scrombroides sancti-petri, kamanu- Elegatis bipinnulatus, ulua- Caranx cheilio, and ulua kihikihi- Alectis ciliaris*), <u>dolphins</u> (Coryphaenidae, including *mahi-mahi- Coryphaena lippurus and Coryphaena equisetis*), <u>mackerels and tunas</u> (Scombridae, including *ahi- Thunnus albacares, ahi palaha- Thunnus alalunga, aku- Katsuwonus pelamis, akule- Trachiurops, kawakawa- Euthynnus affinis, ono- Acanthocybium solandri, opelu- Decapterus pinnulatus,*and *po`onui- Thunnus obesus*), <u>swordfishes</u> (Xiphiidae, such as the *a`uku- Xiphins gladius*), and <u>billfishes</u> (Istiophoridae, including *a`u- Makaira nigricans and Makaira indica*).

The depth ranges are not precisely known for many of the species of interest to local anglers, but depth data for several species from time-depth recorders and observations are available and are discussed below. The centers of distribution of the families listed above occur well above the CO_2 release depth. Some species may occasionally descend to a depth at which they might encounter the plume, but it is unlikely that the experiment would result in any substantial mortality to these sport-fishes. The depth is simply too great and the persistence of sub pH 6.5 water too short.

- Block *et al.* (1992) found that blue marlin fish equipped with depth and temperature transmitters exhibited a preference to remain in the surface mixed layer (above the thermocline). One fish was found to remain near the surface in 81º F (27° C) water during daylight hours and make numerous dives between 160 and 330 feet (50 and 100 meters) at night.
- Studies using ultrasonic depth telemetry recorders off the west coast of Hawai‘i on yellowfin tuna (*Thunnus albacares)*, skipjack tuna (*Katsuwonus pelamis*), blue marlin, and striped marlin, suggest that these species limit their vertical movements to remain in waters within 14ºF (8ºC) of surface water temperatures (Brill *et al.* 1993, 1998). Brill *et al.* (1998) reported that five tagged yellowfin tuna remained shallower than 330 feet (100 meters) 80% of the time and shallower than 400 feet (125 meters) 90% of the time. A similar study found that blue and striped marlin spent

85% of the time at depths shallower than 300 feet (90 meters) and limited their descent to a maximum depth of <560 feet (170 meters; Brill *et al.* 1993).

- Bigeye tuna and swordfish reportedly forage routinely to depths as great as 1,600 feet (500 meters) (Carey 1990). This water depth would be above the expected upper margin of the area affected by the *Field Experiment*.
- Six species of *lutjanids* (snappers) are found in Hawaiian waters. These include *uku* (gray job fish or gray snapper; *Aprion virescens*), gindai (also known as *ukiuki* or Brigham's or flower snapper; *Pristipomoides zonatus*), *to`au* (blacktail snapper; *Lutjanus fulvus*), *ta`ape* (blue striped snapper; *Lutjanus kasmira*), *ehu* (squirrelfish snapper; *Etelis carbunculus*), and the Spotted rose snapper (*Lutjanus guttatus*). These fishes are found above 1,000 feet (300 meters; Haight 1989). Hence, they would not be expected to encounter waters with depressed pH.
- Similarly the deep snappers and other bottom fish such as *ula ula* (*onaga* or long red tail snapper; *Etelis coruscans*), *opakapaka* (pink snapper; *Pristipomoides microlepis*), *kalekale* (Von Siebold's snapper; *Pristipomoides sieboldii*), and the *hapu'upu'u* (the Hawaiian grouper; *Epinephelus quernus*) are not generally found in water depths deeper than 1,000 feet (Fresh Island Fish Company 2000; DLNR-DAR 2000).

The deep-scattering layer is composed primarily of species that migrate to surface waters at night and to depth during the daytime (the aforementioned snappers are generally associated with the seafloor, not the open water that would be above the platform). The deep-scattering layer occurs between 300 and 1,600 feet (100-500 meters). The daytime depth of different species is determined by their center of distribution and swimming speed. Swiftly swimming animals would be able to descend to deeper depths during the day than the slowly swimming species that exist in the same depth range at night. Throughout much of the world's oceans, the deep-scattering layer is composed largely of euphausiids, sergestid shrimps, small bathypelagic fishes, squids, and copepods. The *Field Experiment* would not affect water visited by organisms found in the deep-scattering layer.

5.3.2.2.2 Threatened and Endangered Species

The threatened or endangered species in the vicinity of the planned *Field Experiment* would all be air-breathers (reptiles and mammals) that are not normally found at depths that would experience changes in water quality. Even if they were to reach such depths, their need to return to the surface to breathe would severely limit the time during which they would be exposed to reduced pH. In addition, because they are air breathing, CO_2 would not be exchanged across their respiratory membranes. The pH levels of the *Field Experiment* would not be expected to be caustic to their body surfaces because of the relatively low expected acidity and persistence. Hence, they would be very unlikely to be affected unless the CO_2 droplets would be directly ingested or the animals exposed their eyes very close to the nozzle.

5.3.2.2.3 Deep to Midwater Tubing Effects

The vertical segment of tubing that would pass through the deep-to-midwater zone would result in effects similar to those created by a Fish Aggregation Device (FAD) mooring line. The tubing would not be expected to have a deleterious effect on marine organisms.

5.3.2.2.4 Other Deep to Midwater Effects

Other effects could result from the movement of a remotely operated vehicle (ROV) or submersible within the study area and the use of acoustical navigational aids. Procedures and techniques for these types of activities have been used without any apparent negative effects during the course of thousands of oceanographic investigations.

5.3.2.3 Surface-Layer Effects

5.3.2.3.1 Direct CO_2 Effects on the Surface Layer

As planned, the experimental injection of CO_2 would not be expected to cause any measurable changes in pH or CO_2 concentrations at depths shallower than about 1,600 feet (500 meters). Thus, no impacts on biota or habitats in the surface layer of the ocean, 0 to 650 feet (0-200 meters), would be expected. Coral reefs and reef fish communities (including such species as *uhu*- Scaridae species, *Lauwiliwilinukunuku-'oi'oi- Forcipiger Longirostris*, and many others) would not be affected by the *Field Experiment*. Similarly, nearshore ecosystems familiar to divers and hosting such species as manta rays (*Manta birostris*) would be too remote from the *Field Experiment* site to have the potential to suffer any adverse effects.

5.3.2.3.2 Other Surface Layer Effects

The various operations conducted in the surface layer, 0 to 650 feet (0-200 meters), during the experiment (e.g., running support vessels, platform lowering and raising, ROV or submersible operation, transponder nets) would be similar, or identical, to oceanographic research operations repeatedly conducted in Hawaiian waters. No unusual (or measurable) impacts to the biota or habitats of the surface ocean would be expected to result from these activities. Concern has been expressed regarding the potential effects of ships and transponders on dolphin activity. The auditory systems of sonar using Odontoceti are adapted for the high ultrasonic frequencies that these animals employ for echolocation. The auditory system of these animals is necessarily robust in that, within milliseconds of producing loud sounds, they receive and process very faint echoes (Au *et al*. 1997, Richardson *et al*. 1995). Responses by cetaceans to the vessels used in this study would not be expected to differ from their response to other similarly sized vessels in Hawaiian waters. It is possible that the activities carried out for the *Field Experiment* could attract dolphins to the site, thereby slightly increasing their normal density in the area.

Collision with the ships or discharge pipe would be more likely to cause harm to these organisms. Pipe collision would be relatively unlikely especially for the sonar capable Odontoceti. Ship collision is a known source of mortality for sea turtles and marine mammals, but usually only when the ships are underway. Spotters will be on duty during the ship transits to help minimize the potential for such collisions.

5.3.2.4 "Worst-Case" Accidental Release

The nature of possible accidental releases is discussed in Section 5.2.2. The potential biological impacts are discussed below.

5.3.2.4.1 "Worst-Case" Accidental Release from Tubing Rupture at the Surface

In the worst case scenario of a rupture or break in the tubing at or near the ocean's surface, nearly all of the CO_2 would vaporize into the atmosphere[29] and have virtually no effect on pH or marine biota.

5.3.2.4.2 "Worst-Case" Accidental Release from Tubing Rupture Near the Seafloor

If the tubing fails near the seafloor, the entire volume of CO_2 in the tubing could rapidly discharge. Due to the relatively small volume of CO_2 that would be contained in the tubing, the effects would be much more limited in scale than those previously described for planned tests.

[29] This would not constitute discharge of a regulated air pollutant.

5.3.2.4.3 Other Accidents

The risks and potential impacts from other accidents (e.g., associated with vessel, ROV and submersible operation) would be similar to those potentially resulting from any of many research expeditions conducted regularly in Hawaiian waters.

5.3.2.5 Response to Accidental Releases

Shipboard personnel would be briefed on the characteristics and risks associated with the high pressure CO_2 system. At the first indication of an unintentional release, the CO_2 holding tank would be secured and remedies to the situation would be implemented, as appropriate. If any spills of petroleum products occur from vessels used for the *Field Experiment*, the U.S. Coast Guard would immediately be notified.

5.3.2.6 Summary of Effects on the Ecosystems in the NELHA Ocean Research Corridor

The overall impact of the *Field Experiment* on the ecosystem of the area would be extremely small. Traces of CO_2 would be expected to be undetectable in the water column within 12 hours; evidence on the deep sea floor would disappear within months to a few years. Some mortality of midwater organisms may result from CO_2 effects (pH below 6.5) within a total volume of water of 1.6×10^6 m^3. This entire impacted volume would be below a water depth of 500 m (i.e., it would be restricted to the deep ocean where biomass levels are extremely low). Because of the open and dynamic nature of pelagic ecosystems, it is expected that any measurable effects on the midwater biota within the NELHA corridor would dissipate to undetectable levels within hours. No impacts whatsoever would be expected for the fishing “Grounds” off Ke hole Point, nor to any nearshore habitats (e.g., coral reefs).

Impacts to the seafloor from the *Field Experiment* would be more persistent than those in the water column, with seafloor community recovery possibly requiring years. The potential seabed area impacted within the NELHA corridor would be so small that no significant impacts to the general ecosystem are conceivable. For example, the ranges of species and populations of all seafloor organisms potentially impacted by the *Field Experiment* would include slope regions on many (most likely all) of the Hawaiian Islands, so the chances of significant population or species level stress would be miniscule. There is no ecological evidence that anticipated small disturbances to the NELHA corridor ecosystem, such as would result from the *Field Experiment,* would result in permanent (or long-term) ecosystem changes.

5.3.3 GENERIC OCEAN SITE

5.3.3.1 Differences in Marine Biota

As discussed in Section 5.1.2, other ocean locations with the required characteristics for the *Field Experiment* would be likely to have benthic communities similar to those within the Ocean Research Corridor.

5.3.3.2 Differences in Potential Effects

Differences between predicted effects at the Ocean Research Corridor site and those at a generic ocean site would probably arise mostly from differences in the ocean current regime. Higher currents and levels of turbulence would disperse the discharge plume more rapidly, while lower current speeds and turbulence would have the opposite effect. Hydrographic conditions selected for the experiment would need to be below levels that could pose operational problems. Therefore, it is probable that the current regime at a generic ocean site would be similar to the Ocean Research Corridor. Generally, then, the effects on marine life at an alternate ocean site would be quite similar to those predicted in Section 5.3.2.

5.3.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no changes in existing marine life, such as those that could be created by conduct of the experiment, would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on marine life would be similar to those presented for the Ocean Research Corridor.

5.4 EFFECTS ON HISTORIC AND CULTURAL RESOURCES

5.4.1 NELHA OCEAN RESEARCH CORRIDOR SITE

5.4.1.1 Existing Historic and Archaeological Remains at *Field Experiment* Site

The bottom area on which the platform and about 1,000 feet (300 meters) of tubing would rest during the course of each test was explored in August 1999 using a video camera mounted on a remotely operated vehicle. Images were captured for approximately one hour and covered essentially the entire area that would be potentially affected by the *Field Experiment*. No physical historic or cultural remains of any kind were visible within the survey area. The absence of such remains is not surprising, particularly in view of the great depth and the absence of any folklore or other information that might indicate the presence of a shipwreck. It is also consistent with findings of other NELHA studies.[30]

5.4.1.2 Existing Historic and Archaeological Features on Land in the Ke hole Area

Although the project would not have a visible physical impact on the land in the Ke hole area, several archaeological and historic features deserve mention because they are in the *ahupua'a* immediately inland. These include the M malahoa (the old Government Road) and *ala loa*, now referred to as *Ala Kahakai* trails. Various trails led from Ke hole to Hual lai Mountain. Some of the trails had large blue rock stepping-stones. Previous oral interviews with area residents also tell of burial sites in the area, but these have not yet been located.

Stories note the presence of a fishpond known as *Pa' iea* in the Ke hole area, but it is thought to have been destroyed by lava flows, especially the flow of 1801. The following narrative by Kihe (in *Ka H k o Hawai'i* translated by Maly) describes some of the cultural features of the area:

> "It was at Ho'on that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one of the canoe landings of the place. Today it is where the light house of America is situated. Pelek ne is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *p hoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today."

Translations completed by Kumu Pono Associates (1998) include documents that tell of the traditional significance of this area. These include the writings of J.W.H. Isaac Kihe and John Ka'elemakule, portions of which are cited throughout this part of the report. These were native authors writing in Hawaiian newspapers between 1907 and 1929.

Other compilations of oral histories include *A Social History of Kona: Volumes I and II* (University of Hawai'i Ethnic Studies Program, 1981). That report documents the results of the Ethnic Studies Program's oral history project in Kona. Its emphasis is on the general experiences of the individuals interviewed. While it provides little specific information on issues relating to shoreline access or historic sites, it does provide insights into land use and economic activity during the early part of the

[30] It should be noted that many Hawaiian elders consider the ocean itself as a cultural, as well as a physical and biological, entity.

20th century. The interviews highlight the importance of fishing to native residents of the Kona coast during that time.

5.4.1.3 Anticipated Effects on Historic and Cultural Sites

The Historic Preservation Division of the State Department of Land and Natural Resources (SHPD), the Office of Hawaiian Affairs (OHA), and Hui M lama were contacted during preparation of this Environmental Assessment. Copies of the correspondence are reproduced in Appendix G. The SHPD agreed that the *Field Experiment* would not have any effects on historic properties; it offered no discussion on cultural properties. Hui M lama, another native Hawaiian organization that was contacted, did not provide comments.

5.4.1.4 Methodology Followed in Identifying Traditional Uses and Rights

While there is general agreement that the proposed experiment is unlikely to affect physical remains, public comments on the Draft EA for the project indicated concerns that it might adversely affect other resources important to native Hawaiians. This possibility had not been discussed in the Draft EA because it had been believed that the offshore location would prevent any substantial effects on such resources.

In order to address the questions that had been raised, a cultural impact assessment analysis was prepared to determine the nature and extent of these possible effects (Social Research Pacific, Inc., November 14, 2000). The assessment used an ethnohistorical approach, with the primary emphasis placed on oral interviews with individuals who could share knowledge about traditional uses of the project area. While the primary method of obtaining information was through the oral interviews, literature was also reviewed to identify issues of known historic and cultural significance. This study is reproduced here as Appendix F.

Consistent with State Environmental Council guidelines for conducting cultural impact assessments, efforts were made to contact individuals and organizations which have expertise concerning the types of cultural resources, practices and beliefs found within the vicinity of Ke hole (these include the *ahupua'a* of Makalewena, Mahai'ula, Haleohi'u, Kalaoa, 'O'oma, and Kohanaiki). Efforts were made to select individuals who specifically had knowledge of the proposed project area; this included six *k puna* from the Island of Hawai'i. Oral interviews (7 formal and 7 informal) were conducted with informants who possessed historical knowledge about the area and/or who could recommend bearers of cultural information, and a follow-up meeting was held with *k puna* in response to requests made during the initial round of contacts. Documentary research, particularly on the location of cultural and historical uses of the area, was conducted on O'ahu and Hawai'i.

Since the project area is located in the ocean, and since a major objective of the study was to identify traditional fishing sites (as requested by the State Historic Preservation Officer), efforts were made to interview *k puna* who had been fishermen in these waters.[31] All of the *k puna*, except for Eddie Ka'ana'ana who is from the village of Miloli'i, have been fishing in the area since they were children. The significance of the interviews with the *k puna* is that these are men who are still actively using the waters in and around the project area for their fishing activities.

Both formal and informal interviews were conducted; these took place between September 28 and October 24, 2000. The goals of the formal interviews were to:

- Identify traditional uses of the project site and surrounding area;
- Identify traditional fishing sites in the project area;

[31] Selection of people to interview was done primarily by locating individuals and families of Hawaiian ancestry, who had lived in the Ke hole area and/or had knowledge about the waters off Ke hole Point. The Office of Hawaiian Affairs (OHA) was first contacted for recommendations of individuals to interview. Interviews with *k puna* on Hawai'i were identified and arranged for by Mr. Kep Maly.

- Identify cultural features (other than ocean-bound) in the area;
- Identify stories, legends, and beliefs that may describe traditional uses of the area; and
- Obtain information on if and how the proposed project might affect traditional practices in the area.

The formal interviews began with personal introductions. The interviewers then solicited recollections and narratives of the traditions and uses of the area. The interviewers followed this with a summary description of the proposed experiment (including a map of the project area). The final portion of the interviews entailed questions and answers directed at the interviewer about the project. This allowed the interviewer to elicit responses directed towards determining whether the individuals participating in the interviews felt the proposed experiment would cause specific cultural impacts.

In addition to formal interviews, discussions and informal interviews were held with individuals and groups who provided names of Hawaiian *k puna* and/or knowledgeable community residents. Among these were individuals who have knowledge about the proposed project and shared their views, not necessarily based on personal experience in the area, but based on knowledge and interest in the general cultural traditions and practices of Hawaiians. Many of the individuals in this group had previously expressed their concern or outright opposition to the proposed experiment.

5.4.1.5 Traditional Uses Identified Through the Research and Interview Process

The information gathered through the investigation is summarized below. For clarity, the discussion is divided into three types of "traditional uses" that informants recalled or verified from the area: (i) deep sea fishing, (ii) *ko'a* – traditional fishing grounds or stations, and (iii) Ke hole Point.

5.4.1.5.1 Deep Sea Fishing

All of the *k puna* recall fishing from Ke hole out to the deeper ocean. It is an area where both traditional and modern types of fishing continue to the present day. The fishermen described ahi grounds extending from K holo to Ke hole. The following are among the findings:

- The traditional fishing grounds extended well beyond the 1+ mile marker shown on a 1981-82 Loran marker map. They indicated that *"…the main current heads north…these are where the aku grounds are…north side of the island. This area was once both aku and ahi grounds. Hawaiians used to go fishing way out…maybe about 5-6 miles, and would judge their whereabouts by the clouds. If you weren't with an experienced navigator, you'd be dead out there."*
- Fish are much less abundant today than they were in the first half of the 20^{th} century. Whereas they were once easy to find, now fishermen must look hard. Moreover, when they find the fish, they are generally in smaller numbers than was once the case.
- Writings from the Kona elder, John Ka'elemakule (1854-1935), tell of the importance of deep-sea fishing in the early 20^{th} century. Among the important fishing practices of Kekaha were *aku* fishing, *ahi* fishing, and fishing for *' pelu* with nets. This type of fishing was done at the *ko'a ' pelu* (*' pelu* fishing station or grounds) that was not too far out from shore. The famous *ko'a lawai'a* (fishing ground) of Kekaha, known by the name "Haleohi'u" was beyond that.

5.4.1.5.2 Ko'a – Traditional Fishing Grounds or Stations

Ko'a are fishing grounds or stations out at sea, and knowledge about them is passed on through generations of fishermen. There are several within the Ke hole region still used by fishermen. The following narrative from Kihe (October 11-18, 1923) as translated by Maly (Kumu Pono Associates, March 1998), describes the *ko'a* off Ke hole.

> "It is not a large place, this point, Ke hole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (*ka wili-au*) that flow with the passing current…And there in front of this point, is deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (*muliwai*), and then flow out. It is on that side, that you will find the *koʻa* (fishing stations) for *aku*, *ahi*, *k hala*, *pakapaka*, and such. Among these *koʻa* are *Paoʻo*, *ʻ pae*, *Kahakai*, *Kapapu*, *Kanaha-ha*, *Kaluahine*, *Kanukuhale*, *Kahoʻowaha*, *Honu*, *Muliwai* (from where one peers upon the dirt of H ena, Kohala) and *Kaihuakala*, Maui…There are many other *koʻa*, but these that I've mentioned, are the famous *koʻa*. There are many deep *koʻa* all in a line, from the Point of Ke hole to the Point of Upolu and the *heiau* of Moʻokini in Kohala."

These same *koʻa* were referenced by the *k puna* during the oral interviews. They indicated that more than one *koʻa* could be used while using the fishing grounds in the Ke hole area. Some of the fish mentioned (e.g., *pelu* and *weke laʻo*) are typically caught close to shore. Other, larger fish are generally further out. The *k puna* indicated that the *koʻa* out there [is] the *koʻa weke*. The *k puna* indicated that they did not want any desecration in that particular area.

Along with knowledge about when and where to fish, the *k puna* interviewed shared some of their traditional methods of attracting and replenishing fish. They indicated that they always used fresh bait; they never used *pilau* (stink bait or rotten bait) for catching fish. They stressed how important it was to eat fresh food and to show the same courtesy to the fish. They noted that they would traditionally feed the *koʻa* (i.e., leave food offerings at them) on a regular basis to keep the fish "at home." These *koʻa* extended from near shore at Ke hole to Honok hau and were located as far as two miles from shore. The fishermen indicated that they were careful to *hoʻomaʻa*, or let the grounds rest, as a means of being careful that they did not take too much from the sea.

Fishing using both traditional and modern methods remains common in the nearshore area to the present day. While these nearshore fishing grounds are far from the site of the proposed experiment, the persons interviewed expressed concern that deep currents would cause the *Field Experiment* to affect shoreline areas.

5.4.1.5.3 Ke hole Point

According to the *k puna*, Ke hole translates as: *Ke* (the), *hole* (water banging together). holehole means "water banging together," where two currents blend together. They said that the area is very seldom calm, usually it is "bubbling/boiling," and that the naming of Ke hole is after this unique current. The special current off of Ke hole Point that causes the "boiling" is referred to as *Lelewai*, and *Hoʻon* is the calm place to the right of this current. The importance of Ke hole's unique currents is captured in the following excerpt from Kihe:

> *"It is not a large place, this point, Ke hole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current…And there in front of this point, is deep waves where this current swirls."*

Maly uses the following story of Ka-Miki to further illustrate the importance of Ke hole's unique currents:

> "…the bonito lure fishing grounds which extended from Kaulana to *Hoʻon* , fronting Ke hole, which is the source of the supernatural currents *Ke-au-k* (the current which strikes), *Ke-au-k naʻi* (the current of smooth waters), and *Ke-au-miki* (the current which pulls out to deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by *M k lei*."

The *k puna* also recounted stories of canoes often coming into the long-buried *P ʻaiea* fishpond to avoid the current. According to the *k puna*, currents were also very significant in determining which place to fish. The location of ‘ *pelu*, for example, could be determined by the current/undercurrent. They reported that the “white current” approximately 100 yards off Ke hole Point is where ‘ *pakapaka*, *‘ula ‘ula*, and *kumu* are found.

The *k puna* also correlated specific currents with the availability of fish. They said: “*If the current’s not right, you can sit there 2 to 3 hours and nothing will happen. When the current starts to move however, you’re only given about 1½ hours to fish and its plenty good at that time.*” “*Kona kai m ‘oki ‘oki*” (the streaked sea of Kona) are current lines from Kekaha. The *k puna* spoke of the black current lines that appear off of Ke hole, saying that these lines reflect the shape of the seafloor. They said that when you see an upwelling in the current, that’s when the nutrients reach the surface and attract feeding fish. Hawaiians traditionally observed these currents both by watching the waves from markers on shore and from out at sea.

In addition to influencing where they fished and how they reached the fishing grounds, the currents sometimes determined where they could come back to shore as well. The following description of *Ho‘on* indicates that it offered a place of refuge when the waters became too rough:

> “*Ho‘on* was the place where calm waters mix…its about ¾ to a mile out to sea, the place where the waters mix. We had a song for Kona that we used to sing when fishing out there. We went down to *Ho‘on* because we couldn’t come back in. We were stuck there for about 4-5 hours and the captain said that we should get back before dark fall [when the lights go out…during the war period]. *Ho‘on* is a quiet area, so it was used as a waiting grounds before trying to go back into shore.”

In addition to the deep-sea and *ko‘a* fishing described above, several other types of subsistence activities related to fishing took place off and near the shores of Ke hole. These included shellfish collecting (Kona crabs, ‘ *pihi*, *wana*), *limu* gathering, and gathering salt from salt pans along the shoreline. Some of these practices, such as gathering salt and *limu*, continue today. Some practices have been abandoned due to lesser availability of and/or access to resources and for other reasons.

In addition to oral histories from individual sources, documentation exists on traditional fishing rights in the area; these were established during Kamehameha III’s rule. The *konohiki* fishing rights granted use of the area extending from the beach to the outer edge of the reef, or one geographic mile seaward. Kamehameha III also recognized traditional deep sea fishing grounds (*ko‘a*), in waters up to 1,800 feet (MacKenzie 1991).[32] A number of traditional and current fishing sites are located in the Ke hole area. Many of these sites have been previously documented (see the writings of J.W.H. Isaac Kihe and John Ka‘elemakule cited in this study).

5.4.1.6 Additional Contacts With Native Hawaiians

During the interview process it became apparent that, despite the extensive informational effort that had been undertaken and the numerous articles that had appeared in local newspapers, many of the *k puna* did not understand exactly what activities the project would entail. In an effort to improve understanding, representatives of the project team met with native Hawaiian families (traditional and customary practitioners) — *kama‘ ina* of the Kalaoa-Ke hole Fisheries and Adjacent Lands (Kekaha Region, North Kona District, Island of Hawai‘i) on December 7, 2000.[33]

[32] The analysis conducted for this report focused principally on the area seaward (*makai*) of the shoreline. The traditional Hawaiian concept of *ahupua‘a* encompasses both land and sea areas. In this instance, DOE believes that expanding the scope of the analysis to include a detailed analysis of land-based resources is not needed for a full understanding of potential effects.

[33] Participants included *Kama‘ ina*: Valentine K. Ako, Elizabeth Ako, Lily Ha‘anio-Kong, Isaac & Tammy Harp, George Kinoulu Kahananui Sr., Robert Ka‘iwa Punihaole Sr., Annie Coelho, Hanohano Punihaole-Kennedy, and David Kahelemauna Roy. Gerard Nihous, Ph.D. (PICHTR), Jeff Summers (Department of Energy), and Perry White (Planning Solutions, Inc.) represented the experimental team. Because the meeting was intended primarily to afford individuals already familiar with the cultural investigations for the experiment an opportunity to obtain additional information and to

The project team began the meeting by providing the detailed overview of the proposed experiment that participants had requested. They also responded to questions that were asked by the *kama‘ ina*. Key points made by the *kama‘ ina* participants in the meeting are summarized below. Strong objections to the proposed experiment being conducted in the vicinity of the Kalaoa-Ke hole fisheries were voiced throughout the proceeding.

- Participants reiterated (1) their knowledge of traditional and customary practices; (2) the on-going use of the Kalaoa-Ke hole Fisheries; and (3) their recommendation that the proposed *Ocean Sequestration of CO_2 Field Experiment* not be conducted at the Kalaoa-Ke hole location.
- Those present indicated that they understand concerns regarding global warming, but said that measures that reduce CO_2 generation are preferable to efforts to accommodate continued CO_2 emissions at present or higher levels.
- They said that the three primary factors that make Ke hole suitable for the proposed experiment (access to deep waters, predictable calm seas and winds, and good logistical access) exist elsewhere as well, making it unnecessary to carry out the work where it might affect the Kalaoa-Ke hole Fisheries. It was strongly suggested that the experiment be relocated to an area that was distant from population areas and active fisheries. The Johnson or Wake Island vicinity, or other areas that had already been "desecrated," were suggested as possible alternatives.
- They reiterated that the Kalaoa-Ke hole Fisheries (which they characterized as extending from the shore to six and more miles at sea) are of traditional and customary significance and said that they are cultural resources that are highly valued by the native families of the lands. They also said that the fisheries are not only of past traditional and customary value, but remain the most significant small boat fishery in Hawai‘i today.
- One of those present described the fisheries and ocean as a part of a sacred landscape, a feature of religious significance, dedicated to Kanaloa and other *akua* that he calls upon.
- Those present expressed concern that the effects of the experiment on the fisheries could not be established with enough certainty for them to be comfortable. They cited the unpredictable effects of the strong and variable currents in the area and concerns about potential impacts on the micro-organism-plankton life forms that are the foundation of the entire food chain (fish to human consumers). By the close of the meeting, the *kama‘ ina* participants remained dissatisfied with the explanations and skeptical about the proposed experiment. They asked who would be responsible if something went wrong, and what could possibly be done to fix it? The project team explained the care that was being taken to begin with the smallest releases and proceed to the highest flow rate only if monitoring showed that it was not having an unexpected adverse effect, but this did not fundamentally change the belief of the *kama‘ ina* who were present that the potential threats outweigh the value of the experiment.

5.4.1.7 Summary of Potential Effects on Traditional Uses and Rights

In summary, the Hawaiian *k puna* and other members of the Hawaiian community who participated in the interviews and meetings believe the area in which the proposed experiment would be conducted is highly significant as a traditional and current fishing ground for native Hawaiians. The most significant cultural/traditional features are the *ko‘a* – fishing grounds/stations at sea, which lie within the boundaries of the project area. Although the frequency of their use may differ between generations and fishing objectives, knowledge about them and their significance has carried into the present times. The most significant cultural practice is fishing – through time this has ranged from being subsistence-based to a highly valued sport. It is also a common commercial activity in the project area. The most significant aspect of the cultural lore, as it pertains to the physical uniqueness

ask questions, invitations were not widely distributed. At the same time, the team followed a policy of leaving attendance open (i.e., of excluding no one). Mr. Curtis Tyler III, the county council member representing North Kona, also attended.

of the project area, is knowledge about the currents. Lastly, the *k puna* themselves are a highly valued cultural resource.

While this may not be the only grounds for highly valued fish such as *aku*, *ahi* and *' pelu*, on the island of Hawai'i, it has continued to be the preferred fishing grounds from traditional to modern times for these and other fish. The *k puna* also believe that it is connected, largely by association, to a larger repertoire of traditions and practices associated with the lands of the area. The interviews indicate that, overall, there is strong sentiment against the proposed project.

More specifically, the organizations and individuals who were contacted stated that the area is a highly valued fishing ground, and there is great concern about the impact that the proposed experiment might have on this fishery. These concerns are related to the entire food chain, not simply the species that are commercially exploited or used for subsistence. The worry stems in part from the "unknowns" associated with the experiment. In the absence of knowledge about the proposed project, the idea of an "experiment" increases doubts and questions about its possible effects. Native Hawaiians speaking about the experiment express the belief that it does not need to be conducted off Ke hole Point in particular or in Hawaiian waters in general. Some of the misgivings appear to be related to perceived adverse effects of past activities within the NELHA research corridor.

Generally, all waters extending seaward for 5-6 miles from the coastline were identified as traditional fishing areas. This encompasses an area that is routinely exploited by native and non-native Hawaiians and visitors for commercial fishing and other marine recreational activities. No specific features were identified in the area where the experiment would be conducted. The ocean activities required for implementation of the proposed experiment would not restrict continued exercise of traditional fishing by native Hawaiians. The vessels required for the experiment would be typical of vessels that pass through the waters within the large traditional fishing area and would be stationed at the site proposed for the experiment for a maximum period of two weeks.

The concerns expressed by native Hawaiians regarding potential effects on the fisheries in their traditional fishing areas are elements of the overall concern for potential effects on marine life, which are described in Section 5.3.2. An analysis of the relationship between ocean currents in the proposed test area and the releases of carbon dioxide is presented in Section 5.1.1.1.3.

5.4.2 GENERIC OCEAN SITE

In general, traditional uses of the deep sea are confined to fishing. The *Field Experiment* would constrain fishing operations in the immediate vicinity of the release while the tests would be performed, due simply to the presence of the research vessels. Information from any seafloor surveys at an alternate generic ocean site would be reviewed to determine the likelihood of any potential effects on historic resources. Shipwrecks and other officially designated unique and special historic or cultural sites would be avoided in the design of a *Field Experiment*.

5.4.3 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no effects on historic and cultural resources or traditional uses would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on historic and cultural resources or traditional uses would be similar to those presented for the Ocean Research Corridor.

5.5 EFFECT ON AIR QUALITY & CLIMATE

5.5.1 PROJECT ELEMENTS WITH POTENTIAL TO IMPACT CLIMATE OR AIR QUALITY

5.5.1.1 Vessel Operations

The vessels used in the *Field Experiment* would produce air emissions from their power plants. These vessels would comply with appropriate U.S. regulations, as well as the Diesel Engine Requirements contained in Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).

5.5.1.2 Planned Emissions and Releases

None of the liquid CO_2 discharged on the seabed would be expected to escape into the atmosphere. Hence, the *Field Experiment* would not have the potential to affect air quality.

The more important aspect of the *Field Experiment*'s potential effect on air quality is associated with the contribution that the experiment would make to an understanding of the ability of the oceans to assimilate anthropogenic CO_2. As previously discussed in Sections 3.1 through 3.3, the fundamental purpose of the *Field Experiment* would be to investigate at a small-scale one potential method for mitigating the potential climatic effects of atmospheric emissions of CO_2.

5.5.1.3 Accidental Releases & Discharges

If the discharge tubing ruptures near the sea surface, a maximum of about one metric ton (1.1 short ton) of CO_2 could potentially be released to the atmosphere over a short period. Possible effects of this release are discussed below (Section 5.5.2.3). If the rupture occurs deeper, the CO_2 would not reach the surface and would not, therefore, affect air quality.

5.5.2 AIR QUALITY & CLIMATE EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.5.2.1 Effect of Vessel Operations

The air emissions from the research vessels would be a very small percentage of the emissions expected from the normal vessel traffic in the area. At least eleven large (>50 feet) charter boats operate out of Honok hau Harbor alone (the closest harbor to the Ocean Research Corridor), and at least one fishing tournament is held each month (Kona Sportfishing Promotional Group 2000). Substantial numbers of smaller boats operate from Honok hau Harbor and from other locations along the Kona Coast. The U.S. Army Corps of Engineers (COE 1996) reported 734 vessel arrivals (not including domestic fishing boats) in 1996 (the latest available report) at Kawaihae Harbor, just to the north of the Ocean Research Corridor. The emissions from the research vessels would have no substantial effect on air quality.

5.5.2.2 Anticipated Effects of the *Field Experiment*

As noted above, none of the CO_2 released during the planned *Field Experiment* would reach the surface. Instead, the CO_2 would be expected to dissolve completely into the deep seawater and not affect air quality.

5.5.2.3 Potential Effects of Accidental Releases & Discharges

As discussed in Section 5.5.1.3, an accidental rupture of the discharge tubing could release about 1.6 cubic yards (1.25 m^3, approximately 1 metric ton) of CO_2 at the surface. If this release would occur on the ship, CO_2 would vent under high pressure. This quantity would be too small to have an adverse effect on general air quality.[34] Hence, the only real concern would be for a slow leak that

[34] To place this in perspective, the largest possible amount that the experiment could release into the atmosphere represents approximately 0.02% of the present average daily man-made CO_2 emissions on the Big Island (DBEDT and DOH

would allow CO_2 to build up without awareness by the ship's crew. Standard precautions taken in maintaining and monitoring high-pressure tanks aboard a ship would be sufficient to reduce this threat to a minor level.

5.5.3 GENERIC OCEAN SITE

The air-quality effects of vessel operations during the *Field Experiment* and accidental releases for a generic ocean site would be expected to be the same as those predicted for the Ocean Research Corridor site.

5.5.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, then no effects on air quality would occur. If the *Field Experiment* was conducted without DOE participation, then the effects on air quality would be similar to those presented for the Ocean Research Corridor.

5.6 NOISE AND VIBRATION EFFECTS

5.6.1 PROJECT ELEMENTS WITH POTENTIAL TO CAUSE NOISE AND VIBRATION

5.6.1.1 Vessel Operation and Oceanographic Data Acquisition

Noise would be generated from research vessels used during the *Field Experiment*. Diesel generators and ships' engines, winches and other handling gear, ROV or submersible servos and electric motors, and acoustic telemetry devices would all create noise during conduct of the *Field Experiment*.

Open ocean ambient noise levels range from 74-100 dB (broadband power levels in 20-1000 Hz, reference 1 µPa @ 1 m; Federation of American Scientists, 1998). Sound energy measured from a purse seiner fishing boat, a vessel likely to be of similar size to the research ships to be used in the *Field Experiment*, was 120 dB while underway, concentrated below 2 kHz with a strong peak at 360 Hz. Noises from other equipment associated with the *Field Experiment* would be emitted at lower decibel levels. Normal noise levels from speedboats reach 120 to 125 dB with the strongest peak at about 2 kHz. Propeller boats at chase speeds cause the sound to pulsate and to reach a maximum of 130 dB (Awbrey *et al*. 1977). The speedboat sound levels are likely to be similar to many of the recreational and fishing boats to be expected in the NELHA Research Corridor. A tug pulling a fully loaded barge into Kawaihae Harbor might have a source level of about 170 dB (Richardson *et al*. 1995).

5.6.1.2 Experimental Discharge

The CO_2 discharge would not be expected to produce high levels of noise, either on the sea-surface site or at the seafloor discharge site, since the release would consist of a liquid being discharged into another liquid medium. The acoustical energy produced by these activities would consist principally of noise from vibrations of the nozzle, extension and recovery of the tubing, and operation of surface valves and pumps associated with the delivery of liquid CO_2 to the seafloor.

1997). Because of the large amount of CO_2 emitted by the Island's volcanoes, it is only 0.002% of all average daily CO_2 emissions from Big Island sources (USGS 2000).

5.6.2 NOISE & VIBRATION EFFECTS AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.6.2.1 Vessel and Oceanographic Data Acquisition

The activities carried out by the research vessels while acquiring oceanographic data would consist of standard practices that are carried out commonly by research ships worldwide. The engine and equipment noises and the acoustic telemetry systems would all produce relatively low-level sounds that would not carry far through seawater or air. These sounds would be comparable to the noises made by fishing vessels, cargo vessels, and other ships that commonly pass through the area. The noise levels would not be audible on land, and they would not be of the magnitude that has been observed to disturb marine organisms.

5.6.2.2 Experimental Discharge

The high frequency, low-level sounds expected from the discharge system would only be audible within a few hundred yards of the discharge site. Marine life within the immediate vicinity of the discharge would not be expected to be adversely affected by the temporary presence of this noise.

5.6.3 NOISE & VIBRATION EFFECTS AT A GENERIC OCEAN SITE

The equipment and procedures to be used at an alternate site would produce very similar levels and frequencies of sound as those anticipated at the Ocean Research Corridor site. Marine life within the immediate vicinity of the discharge would not be expected to be adversely affected by the temporary presence of this noise.

5.6.4 NOISE & VIBRATION EFFECTS: NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no noise or vibration effects would occur. If the *Field Experiment* was conducted without DOE participation, then the noise and vibration effects would be similar to those presented for the Ocean Research Corridor.

5.7 EFFECTS ON TRANSPORTATION FACILITIES

5.7.1 PROJECT ELEMENTS WITH POTENTIAL TO AFFECT TRANSPORTATION FACILITIES

5.7.1.1 Mobilization and Construction

Fabrication of the tubing, discharge platform and associated deployment machinery would take place at suitably equipped manufacturing facilities. Custom pieces of equipment, such as the discharge platform and other necessary hardware, would be shipped to a staging port for assembly and checkout before being loaded onto the vessels. All shipping would be via commercial carriers. The staging port would be selected to minimize transportation, storage, and vessel transit and lease costs. It would be equipped with lifting equipment adequate to stage the materials dockside. Loading onto the ships would be accomplished using either dockside cranes or the handling gear aboard the vessels.

5.7.1.2 Experimental Activities

Vessels deploying the discharge platform, tubing, and ROV or submersible would have restricted mobility for periods as long as a few days while the platform would be deployed, checked out, and operated. These ships would observe the standard practice of showing the proper signal flags and lights to communicate their situations during these periods. While on site, the vessels would be serviced as necessary only by small craft running in and out from Honok hau or Kawaihae Harbors. These service calls would be expected to be limited to necessary transfers of personnel and delivery of emergency replacements.

5.7.2 TRANSPORTATION AT NELHA OCEAN RESEARCH CORRIDOR SITE

5.7.2.1 Mobilization and Construction

Mobilization and construction activities would be expected to take place at a remote site properly equipped and established to carry out the necessary fabrication, handling, and checkout activities. Because the needed facilities would already exist and the needed activities would be part of the normal course of business at those facilities, only minor effects would be expected to result.

5.7.2.2 Experimental Activities

The *Field Experiment* would be carried out over two weeks or less. The Ocean Research Corridor site would not be in a constricted navigation channel or a major shipping route. Fishing boats frequent the area where the experiment would be conducted. The movement of fishing boats and other vessels operating in the area would be constrained slightly by the need to provide suitable clearance around the research vessels during deployment of the platform. This would not prevent fishing boats and other vessels from carrying out most of their normal activities.

5.7.3 TRANSPORTATION AT GENERIC OCEAN SITE

Mobilization and construction activities would be very similar regardless of the location of the *Field Experiment*. The specific locations of transportation activities at a generic ocean site would be dictated by the particular constraints of schedule, budget, and facility availability posed by the selected site. The effects on transportation corridors at a generic ocean site for the *Field Experiment* would be similar to those expected at the Ocean Research Corridor site.

5.7.4 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no transportation effects would occur. If the *Field Experiment* was conducted without DOE participation, then the transportation effects would be similar to those presented for the Ocean Research Corridor.

5.8 EFFECTS ON LAND USE

5.8.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND OTHER GENERIC OCEAN SITES

The *Field Experiment* would be conducted using vessels operating well offshore. The limited shore side activities (e.g., project administration) would be conducted using existing facilities. Consequently, no measurable effects on land use would occur from conducting the *Field Experiment* within the Ocean Research Corridor or at a generic ocean site.

The relationship between the project team and NELHA has been established with the full knowledge that sensitive mariculture activities are taking place there. NELH tenants were the first group with which the project held a formal presentation, in August 1999. This took place before an application to host the project was submitted to NELHA. The approval was granted from NELHA in October 1999. The project staff for the *Field Experiment*, in collaboration with NELHA and its tenants, is formulating a specific monitoring plan for the NELH deep-water intake, which would be carried out during the *Field Experiment* CO_2 release activities to ensure that the *Field Experiment* poses no risk to the NELH activities.

5.8.2 NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE's withdrawal from the international agreement under which the *Field Experiment* would be conducted, no land use impacts would occur. If the *Field Experiment* was conducted without DOE participation, then the land use impacts would be similar to those for the Ocean Research Corridor.

5.9 AESTHETIC EFFECTS

The *Field Experiment* would not alter landscape or other visual amenities on the land. The vessels conducting the *Field Experiment* would operate well offshore. Consequently, the *Field Experiment* would not have the potential to cause aesthetic impacts.

5.10 SOCIOECONOMIC IMPACTS

5.10.1 PROJECT-RELATED EMPLOYMENT AND BUSINESS ACTIVITY

About $2.4 million U.S. dollars would be directly expended in the State of Hawai‘i for conduct of the *Field Experiment* within the Ocean Research Corridor. About $2 million from this total would be devoted to labor salaries, services, local researchers’ activities, and administrative expenses. In addition, out-of-state expenditures would be made for purchasing some materials (e.g., the tubing).

5.10.2 ADEQUACY OF EXISTING LABOR SUPPLY AND SUPPORT BUSINESSES

Scientific and ship personnel staffing the *Field Experiment* would be employed at existing institutions and organizations. Local businesses would possess more than sufficient capacity to provide the support services that would be needed for any of the alternatives under consideration.

5.10.3 OTHER SOCIOECONOMIC EFFECTS

Since 1970, the catch rate for the Hawaiian International Billfish Tournament (HIBT) has varied significantly from year to year, but there has been no significant drop during that period either in total catch rate or catch per unit effort (Pacific Ocean Research Foundation, 2000). From 1959 to 1994, over 30% of the blue marlin caught in the HIBT were caught in the general vicinity of Ke hole Point (Davie 1995). In 1995, only 7.5% of the HIBT landings were caught in that area (Seki in preparation). Nonetheless, the area remains important to the sport-fishing industry.

As discussed elsewhere in this chapter (for example, Section 5.3.2.2), the *Field Experiment* would not have the potential to affect the fish on which the industry depends and would not constrain fishing activities, except for a short time in the immediate vicinity of the research vessels. Consequently, the *Field Experiment* would not be expected to affect the industry adversely.

Because the *Field Experiment* would not affect the shoreline or nearshore waters, it would not impact shoreline fishing, SCUBA diving, snorkeling, or swimming. The *Field Experiment* would be only of a short duration in a very limited area, and it would not have a substantial effect on sailing or charter boat operations.

Currently, there are no other active ocean-based research programs with the potential for conflict with the *Field Experiment* in the Research Corridor, and the *Field Experiment* would not be expected to have any effect on other research uses of the Corridor. The DUMAND (Deep Underwater Muon and Neutrino Detector) program, which did undertake a number of oceanographic deployments in the area between 1981 and 1995, currently has no field expeditions planned. The *Field Experiment* has no direct relationship with other research programs that have been undertaken in the area in recent years, including the acoustic studies carried out by the U.S. Navy. A new cold-water intake pipe is scheduled for installation in the Research Corridor sometime during 2001. The *Field Experiment* would be scheduled such that there would be no conflict between the two activities.

5.11 EFFECTS ON PUBLIC FACILITIES AND SERVICES

5.11.1 PROJECT-RELATED NEED FOR PUBLIC FACILITIES & SERVICES

In general, the *Field Experiment* would not require the use of any public facilities or services. The only possible exception could occur in the event of a shipboard accident that would require medical treatment. In the unlikely event that such an accident would occur, the type of physical injury that would be expected would almost certainly be similar to injuries that occasionally occur during ship operations. Examples include fractures, contusions, and sprains.

5.11.2 PUBLIC FACILITIES AND SERVICES EFFECTS: NELHA OCEAN RESEARCH CORRIDOR SITE

Existing West Hawai‘i medical facilities are equipped to stabilize patients with injuries of the kinds that could occur during the *Field Experiment* and to provide the care needed until patients could be released or transferred to a larger medical facility for specialized care. Air transport that might be needed to carry patients with severe injuries to the large metropolitan hospitals on O‘ahu would be available.

5.11.3 PUBLIC FACILITIES & SERVICES EFFECTS: GENERIC OCEAN SITE

Access to emergency medical care would vary at alternate sites. At some locations (e.g., Gulf of Mexico), the ready availability of emergency helicopter service would make air transport for emergency medical treatment equivalent to that available in West Hawai‘i. At other locations, the distances to emergency medical facilities, and thus the time delays before treatments, would be greater.

5.11.4 PUBLIC FACILITIES AND SERVICES EFFECTS: NO ACTION ALTERNATIVE

If the *Field Experiment* was not carried out due to a No-Action decision by DOE, which would result in DOE’s withdrawal from the international agreement under which the *Field Experiment* would be conducted, no effects on public facilities and services would occur. If the *Field Experiment* was conducted without DOE participation, then the impacts on public facilities and services would be similar to those for the Ocean Research Corridor.

5.12 PUBLIC AND WORKER SAFETY & HEALTH

5.12.1 OVERALL WORKER HEALTH AND SAFETY ISSUES

None of the activities that would be conducted during the *Field Experiment* would have the potential to affect the general safety of the public.

With respect to worker safety, fabrication of the platform, CO_2 storage tank, and tubing that would be used to deliver the CO_2 to the seafloor, and other experimental equipment would involve medium-to-heavy industrial activities. These activities would be carried out in facilities with the proper equipment and procedures, and the contractors would be required to comply with applicable Occupational Safety and Health Administration (OSHA) regulations and other workplace requirements. None of the required manufacturing or assembly activities would be unusually dangerous or hazardous. The CO_2 required for the experiment would be the same type used in many industries and hospitals, would be purchased from existing suppliers, and would not require unusual activities or delivery procedures. Hence, little potential for adverse effects on worker safety and health would result.

Because of the motions imparted by ocean waves, limited on-deck space, and other factors, activities carried out at sea would be inherently more dangerous from the viewpoint of worker safety than the same activities carried out on land. The operators of the research vessels would be accustomed to these risks, however, and would typically require stringent training and safety procedures designed to minimize the additional risk.

5.12.2 SAFETY ISSUES RELATED TO *FIELD EXPERIMENT*-SPECIFIC ACCIDENT AND RELEASE

5.12.2.1 CO_2 Storage Tank

While the liquid CO_2 would be stored under relatively high pressure, the pressure level would be well within the range for tanks commonly used for regular industrial and recreational activities. A SCUBA tank, for example, stores air at approximately 2,300 pounds per square inch, or about seven times the pressure of the CO_2. Thus, the potential for a catastrophic failure would be remote.

If a slow leak was to develop, the transformation of CO_2 from a liquid to a gas would cool the area around the leak, possibly even causing ice to form, which would draw immediate attention to the leak. Hence, there would be little likelihood that CO_2 could escape unnoticed. Even if a leak was to go unnoticed, the fact that the tank would be stored on deck in the open air means that the CO_2 would not collect in occupied spaces. Instead, the CO_2 (which is heavier than air) would spill over the deck and eventually disperse into the atmosphere. Consequently, a storage tank leak would not constitute a hazard to shipboard personnel.

5.12.2.2 Tubing Failure

If the tubing was to fail, the escaping CO_2 could act as a jet, moving the tubing about violently. If a break would occur well below the surface of the ocean, the drag of the water would attenuate the motion of the tubing to the point where it would not be a concern. Consequently, the greatest safety hazard would arise from a possible break several tens of feet from the ship. In this case, gas escaping from the tubing could whip the tubing about, possibly causing an impact to equipment or people on the deck of the ship.

This type of hazard would be similar to the movement that would occur if a cable breaks under tension (as would occur if a line used by a tug to pull a barge breaks). Crews routinely take precautions to keep deck space clear of unnecessary activity under such circumstances, which would reduce the potential for injury. The system used for the *Field Experiment* would minimize the possibility of injury from such an accident by having an automatic cutoff valve that would immediately terminate the flow of CO_2 into the pipe if a rapid depressurization occurs.

5.13 BIODIVERSITY AND ENVIRONMENTALLY SENSITIVE RESOURCES

While ocean waters are considered sensitive environments, as discussed in previous sections of this chapter, the *Field Experiment* would be conducted in (and would affect) a subsurface area that does not contain especially sensitive resources. The activities required for conducting the *Field Experiment* would also not have an adverse effect on biodiversity.

The *Field Experiment* would be conducted well offshore and at a depth of approximately 2,600 feet (800 meters). The changes in water quality that would result from the experiment would be undetectable above a depth of approximately 500 meters and then only close to the *Field Experiment*. Reef-building corals are limited to water depths far above this; hence, no adverse effect on reef-building corals would be possible. Most deep-sea precious corals also occur only at depths above 500 meters. Some, such as the pink coral (*Corallium secundum*), are found at this depth and below. The closest known deep-sea precious coral beds on the west side of Hawaiʻi are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (~300 to 500 meters). No precious corals have been seen during the submersible and ROV inspections of the site. Consequently, the *Field Experiment* would have no potential to affect deep-sea precious corals and would be consistent with the provisions of Executive Order 13089: Coral Reef Protection (see Section 7.1.8).

The *Field Experiment* would take place outside the 100-fathom isobath and beyond the southernmost limit of the Hawaiian Islands Humpback Whale National Marine Sanctuary. As discussed in Section 5.2.1.4, the CO_2 that would be released during the *Field Experiment* would only affect water quality at substantial depths, and the plume would not travel sufficiently far from the point of release to enter the Sanctuary. This means that there would be no potential for substantial adverse effect on the Sanctuary habitat or Humpback whales themselves (see Section 7.1.6).

Over the long term, the information that the *Field Experiment* would be designed to collect would assist in providing a better understanding of the ability of the oceans to assimilate anthropogenic CO_2. This information could be critically important in identifying and developing measures that could slow or prevent anthropogenic climate change. Unchecked, such changes would have far greater potential to reduce biodiversity and disrupt environmentally sensitive resources than would the *Field Experiment.*

5.14 ENVIRONMENTAL JUSTICE

5.14.1 APPLICABLE REQUIREMENTS (EXECUTIVE ORDER 12898)

Executive Order 12898 is intended to make achieving environmental justice part of the mission of Federal agencies by requiring agencies to identify and address, as appropriate, the potential for disproportionately high or adverse human health or environmental effects on minority or low-income populations.

5.14.2 COMPLIANCE SUMMARY

The *Field Experiment* would be conducted well offshore in deep ocean waters. No minority populations reside in the area. Members of minority groups do fish within the Ocean Research Corridor and might fish at another ocean site. The *Field Experiment* would not involve activities that would have an adverse effect on persons in the area. In view of the foregoing, the *Field Experiment* would be consistent with Executive Order 12898. No disproportionately high or adverse effects on minority or low-income populations would result from the proposed action.

5.15 SUMMARY OF POLLUTION PREVENTION MEASURES

5.15.1 FEATURES INCORPORATED IN THE FUNDAMENTAL EXPERIMENTAL DESIGN

Efforts to minimize the potential for pollution began at the outset of defining the concepts for a *Field Experiment* and have continued throughout the evaluation and definition of those concepts. The goal of these efforts was to identify pollution-limiting approaches and to integrate these approaches into plans for the *Field Experiment*. To achieve this goal, the following tenets were established:

- The experiment would be designed to use the smallest possible amount of CO_2 consistent with achievement of the scientific objectives. Thus, the 44-66 short tons (40-60 metric tons) included in the preliminary plan for the experiment is considerably less than the amount (100 to 300 metric tons) initially considered as being required to achieve scientific objectives.
- The duration of the experiment has been shortened from the month-long series of tests that was originally envisioned to 10 to 14 days.
- Individual test releases of CO_2 would be limited to the smallest rates (1.6 to 16 gallons per minute) and the shortest durations (2 hours) possible while still providing some assurance that the required scientific measurements could be made.

- The experimental concept would include consideration of an advanced, vessel-based deployment system that would eliminate the need to construct and operate a pipeline through a nearshore environment.
- Test facilities used for the experiment would be completely removable at the conclusion of the testing.

5.15.2 ADDITIONAL POLLUTION PREVENTION MEASURES

The computer modeling that has been done by scientists from around the world using a variety of computer models and data sources provides reasonable assurance that the water quality effects of the experiment would fall within the predicted envelope. As with any enterprise designed to expand scientific understanding of natural processes, some uncertainty remains.

Because of this uncertainty, the experimental plan (see Appendix C) would require real-time monitoring of the releases. While complete details of this monitoring program are still being developed, the program would include items such as: (1) pH monitors to determine if a release reduces pH to a greater or lesser extent than anticipated; and (2) visual observations of the release platform and surrounding waters to indicate if megafauna are being acutely affected by the release.

The experiment would involve the use of a high-pressure system for the CO_2. Pressure sensors connected to automatic shut-off valves would constantly monitor the system. If an unexpected loss of pressure would be detected, the sensors would send a signal that would immediately close the valves. This would limit the amount of CO_2 that could be released to only slightly more than the amount present in the pipeline.

The State Department of Health (DOH) has determined that the release would be subject to Hawai‘i Administrative Rules Section 11-54 (Water Quality Standards) and Section 11-55 (Water Pollution Control). DOH has indicated that due to the research nature of the *Field Experiment* and the fact that the release would be intermittent and of short duration, the requirement for an NPDES permit may be waived under certain conditions. One of those conditions would be the submission to, and approval by, DOH of a satisfactory monitoring program for the *Field Experiment*. The DOH-approved program would be expected to identify specific control measures and to make them legally enforceable.

As previously noted, shipboard personnel would be briefed on the characteristics and risks associated with the high pressure CO_2 system. At the first indication of an unintentional release, the CO_2 holding tank would be secured.

The research ships and the vessel that would deploy the discharge system would notify the U.S. Coast Guard immediately should any spills of petroleum products occur.

Public notices concerning the planned experiment would be published before the beginning of the experiment. Information concerning the timing and nature of project-related ship movements would be included in these notices. If possible, the notices would be posted at the Honok hau small boat harbor and at other locations from which boat operators might begin operations requiring use of waters within the NELHA Ocean Research Corridor.

6.0 CONSISTENCY WITH FEDERAL, REGIONAL, STATE, & LOCAL LAND USE PLANS, POLICIES, & CONTROLS

6.1 NELHA OCEAN RESEARCH CORRIDOR SITE

6.1.1 CONSISTENCY WITH LOCAL LAND USE PLANS, POLICIES, & CONTROLS

The NELHA Ocean Research Corridor site is outside the jurisdiction of the County of Hawaiʻi. Hence, there are no applicable local land use plans, policies, or controls.

6.1.2 CONSISTENCY WITH STATE LAND USE PLANS, POLICIES, & CONTROLS

The NELHA Ocean Research Corridor site is located within the Conservation District (Figure 4-1). The State of Hawaiʻi Department of Land and Natural Resources (DLNR) has determined that a Conservation District Use Permit would not be needed for the *Field Experiment* because of its temporary nature of less than fourteen days on the seafloor. The use of this area for the *Field Experiment* would be consistent with the overall purpose of the approved Ocean Research Corridor, which is intended for activities that include temporary ocean research.[35]

6.1.3 CONSISTENCY WITH FEDERAL LAND USE PLANS, POLICIES, & CONTROLS

There are no Federal land use policies covering the proposed NELHA Ocean Research Corridor site.

6.2 OTHER GENERIC OCEAN SITES

6.2.1 CONSISTENCY WITH LOCAL LAND USE PLANS, POLICIES, & CONTROLS

Local jurisdiction typically ceases at the shoreline. Consequently, all of the other locations at which the *Field Experiment* could be conducted would also be outside local jurisdiction.

6.2.2 CONSISTENCY WITH LAND USE PLANS, POLICIES, & CONTROLS OF STATES OR FOREIGN NATIONS

Generic ocean sites at which the *Field Experiment* could be conducted may be subject to controls by other State or National jurisdictions. Should the research be conducted at one of these locations, DOE and other project sponsors would work with the entities having jurisdiction to insure that the project would be consistent with applicable plans, policies, and controls.

6.3 NO ACTION ALTERNATIVE

If the *Field Experiment* is not carried out, no concerns about consistency would exist. If the *Field Experiment* would occur without DOE participation, the same consistency criteria for the project site would apply. That is, acceptability of any site would depend on the *Field Experiment* being consistent with the existing land use plans, policies, and controls that apply to that site.

[35] The existence of the Ocean Research Corridor and the oceanographic and environmental data that have been collected within the Corridor are among the factors that influenced interest in this location.

7.0 COMPLIANCE WITH OTHER REGULATIONS

7.1 FEDERAL REQUIREMENTS

The *Field Experiment* would be planned and conducted in compliance with the National Environmental Policy Act (NEPA). The *Field Experiment* would also be subject to review under several other Federal regulations. These include:

- Section 401 of the Federal Clean Water Act;
- Section 402 of the National Pollutant Discharge Elimination System;
- Department of the Army Permit, for activities subject to regulation under Section 404 of the Federal Clean Water Act and Section 103 of the Marine Protection, Research, and Sanctuaries Act;
- Section 106 of the National Historic Preservation Act of 1966;
- Section 7 of the Endangered Species Act of 1973, as amended;
- Provisions of the Fish & Wildlife Coordination Act; and
- National Invasive Species Act of 1996.

7.1.1 NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

This Environmental Assessment (EA) has been prepared in conformance with NEPA. The EA was developed through a process of internal and public scoping and consultation with cognizant Federal, State, and local officials. DOE and other project participants also coordinated with resource management agencies and members of the public following publication of a draft EA to determine their concerns. In accordance with the tenets of NEPA, development of concepts for the *Field Experiment* has been substantially modified in response to suggestions that have been received. These changes included suspending consideration of shore-based alternatives that would have required a pipeline through nearshore waters, reducing the anticipated number of pipeline deployments and increasing the ecological monitoring component of the planned tests.

7.1.2 SECTION 401 OF THE FEDERAL CLEAN WATER ACT AND SECTION 402 OF THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

The Federal government has delegated responsibility for enforcing the Clean Water Act and handling National Pollutant Discharge Elimination System (NPDES) permits to the State Department of Health. Compliance with these regulations is discussed in Section 5.2.1.6 and Section 7.2.1.

7.1.3 DEPARTMENT OF THE ARMY PERMIT

The U.S. Army Corps of Engineers has determined that the *Field Experiment* would not require a Department of the Army permit (see letter in Appendix G).

7.1.4 NATIONAL HISTORIC PRESERVATION ACT OF 1966; NATIVE AMERICAN GRAVES PROTECTION AND REPATRIATION ACT OF 1990

A Federal review process, administered by the National Advisory Council on Historic Preservation and the State Historic Preservation Officer, has been established to ensure significant historic properties are considered during Federal project planning and execution. In accordance with guidance issued for that process, the State Historic Preservation Division of the Department of Land and Natural Resources, the Office of Hawaiian Affairs (OHA), and Hui M lama I Na K puna O Hawai'i Nei ("Hui M lama") were contacted about conducting the vessel-based *Field Experiment* at the NELHA Ocean Research Corridor site. The purpose of these consultations was to identify potential effects of the *Field Experiment* on significant historic, cultural, or religious properties.

The Office of Hawaiian Affairs is a semi-autonomous, "self-governing body" authorized by Chapter 10 of Hawai‘i Revised Statutes. OHA was established as a public trust, mandated to better the conditions of native Hawaiians and the Hawaiian community. OHA is funded with a *pro rata* share of revenues from state lands designated as "ceded" – such as NELHA's Ocean Research Corridor. Hui M lama is a private, not-for-profit native Hawaiian organization dedicated to the proper treatment of ancestral native Hawaiians. In the enabling legislation, the U.S. Congress explicitly cites these two organizations as examples of the kinds of organizations that should be considered as possible consulting parties for both the National Historic Preservation Act (36 CFR §800) and the Native American Graves Protection and Repatriation Act (25 CFR §3001). As mentioned in Section 3.4.3 and Section 3.4.4, and discussed further in Appendix B, the extensive public participation program that has been initiated in conjunction with planning for the *Field Experiment* is a further effort to insure that individuals with special concerns about potential impacts on historic, religious, or cultural resources are able to make their concerns known.

As described in Section 5.4 of this EA, the State Historic Preservation Division has confirmed there is no record, and little likelihood, of historic properties in the offshore area proposed for the *Field Experiment*. Review of other environmental documentation for the area does not indicate the presence of physical remains that might be of cultural or historic concern in areas that could be affected by the proposed activities, so long as activities would be restricted to the offshore site (HURL 1991, 1999).

The *Field Experiment* project team initially contacted the OHA Trustee for the Island of Hawai‘i on July 7, 1999. In OHA's July 13, 1999 response, the agency stated the letter and information had been forwarded to their Land and Natural Resources Division for review. No further correspondence from OHA was received at that time. Once the decision to pursue a vessel-based experiment was made (March 2000), the project team notified OHA regarding the project change and requested further consultation. No formal response was received prior to the publication of the draft EA.

Beginning in late August, project team members held various meetings with OHA and exchanged letters and information (see Appendix G). The results of this correspondence are discussed in the impact analysis for Historical and Cultural Resources (Section 5.4.1) and in a Cultural Impact Assessment Study, presented in Appendix F.

7.1.5 OTHER KEY RULES ADMINISTERED BY THE U.S. FISH & WILDLIFE SERVICE AND THE NATIONAL MARINE FISHERIES SERVICE

In compliance with the Section 7 of the Endangered Species Act and the Fish and Wildlife Coordination Act, DOE consulted with the U.S. Fish & Wildlife Service and with the National Marine Fisheries Service during preparation of the Environmental Assessment. The written correspondence from this consultation is reproduced in Appendix G. DOE has confirmed that, in conducting the *Field Experiment*, it would comply with the Migratory Bird Treaty Act (16 USC, Section 703 *et seq.*) and with the National Invasive Species Act of 1996 (Public Law 104-332). The *Field Experiment* activities would be short-term, localized, and focused primarily on the deep seabed at water depths of about 2,600 feet. These activities would not substantially affect threatened, endangered, or migratory birds or the marine food chains that help support these species. As outlined in Section 5.2.1.5, ships used for the *Field Experiment* would comply with all applicable laws and regulations designed to prevent the introduction of exotic species into coastal marine waters.

DOE has contacted the National Marine Fisheries Service (NMFS) concerning potential effects on sea turtles and other listed species under its jurisdiction. Potential effects on Humpback whales are discussed in Section 7.1.6. DOE submitted an Essential Fish Habitat Assessment to the NMFS in accordance with requirements of the 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (Public Law 94-265).

As discussed in Section 5.3.2.2.2, the threatened or endangered species in the vicinity of the planned *Field Experiment* are all air-breathers (reptiles and mammals) that are not normally found at depths that would experience changes in water quality. Even if these animals were to reach such depths, their need to return to the surface to breathe would severely limit the time during which they would be exposed to reduced pH. In addition, because they are air breathing, CO_2 would not be exchanged across their respiratory membranes (see Section 5.3.2.2.2). The pH levels of the *Field Experiment* would not be expected to be caustic to their body surfaces because of the relatively low expected acidity and persistence. Hence, they would be very unlikely to be affected.

Collisions with ships or the transport pipe would be more likely to harm these organisms. Pipe collision would be relatively unlikely especially for the sonar capable Odontoceti. Ship collision is a known source of mortality for sea turtles and marine mammals, but usually only when the ships are moving. Spotters would be on duty during ship transits to minimize the potential for such collisions.

7.1.6 OCEAN DUMPING ACT

The Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) has two basic aims: to regulate intentional ocean disposal of materials and to authorize related research. Title I of the Act, which is often referred to as the Ocean Dumping Act, contains permit and enforcement provisions for ocean dumping. Passed in 1972, the Act provides a framework for managing ocean dumping activities and for conducting basic oceanic research. The law bans ocean dumping of radiological, chemical, and biological warfare agents and high-level radioactive wastes. Amendments in 1988 extended this ban to sewage sludge, industrial wastes, and medical wastes. The law provides a mechanism for meeting U.S. commitments under the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters, an international ocean dumping treaty signed by 80 countries. The Act authorizes research on the effects of ocean dumping, pollution, over-fishing, and other human-induced stressors, including oil spills.

The experimental release of CO_2 for scientific research that is proposed as part of the *Field Experiment* is not believed to fall within the definition of "dumping" as defined in 40 CFR Part 220.2.[36] If activities proposed under the *Field Experiment* are determined to be regulated by the Ocean Dumping Act, however, a research permit would be pursued.

7.1.7 COAST GUARD REGULATIONS

Research vessels for the *Field Experiment* would be equipped with U.S. Coast Guard-approved marine sanitation devices (33 CFR 159) to preclude unauthorized discharges of sanitary wastes. The research vessels would comply with all applicable U.S. Coast Guard safety procedures and required navigational lighting and day shapes for operating vessels in restricted maneuverability and at night. Research vessels would comply with U.S. Coast Guard regulations (33 CFR 151) and other applicable Federal and State of Hawai'i laws and regulations for the management of bilge and ballast water to minimize pollution and the introduction of non-indigenous or exotic species into U.S. waters.

7.1.8 EXECUTIVE ORDER 13089: CORAL REEF PROTECTION

In 1998, the President issued Executive Order 13089: Coral Reef Protection.[37] Its purpose is to preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral

[36] …It [ocean dumping] does not mean the … intentional placement of any device in ocean waters or on or in the submerged land beneath such waters, for a purpose other than disposal, when such construction or such placement is otherwise regulated by Federal or State law or occurs pursuant to an authorized Federal or State program.

[37] The Executive Order is intended to support the purposes of various U.S. laws and regulations. These include the Clean Water Act of 1977, as amended (33 USC. 1251, *et seq.*), Coastal Zone Management Act (16 USC. 1451, *et seq.*), Magnuson-Stevens Fishery Conservation and Management Act (16 USC. 1801, *et seq.*), National Environmental Policy Act of 1969, as amended (42 USC. 4321, *et seq.*), and National Marine Sanctuaries Act (16 USC. 1431, *et seq.*).

reef ecosystems and the marine environment. It defines coral reef ecosystems as those species, habitats, and other natural resources associated with coral reefs in all maritime areas and zones subject to the jurisdiction or control of the United States (e.g., Federal, State, Territorial, or commonwealth waters), including reef systems in the south Atlantic, Caribbean, Gulf of Mexico, and Pacific Ocean.

The Executive Order requires Federal agencies whose actions may affect U.S. coral reef ecosystems to:

- Identify actions that may affect U.S. coral reef ecosystems;
- Utilize their programs and authorities to protect and enhance the conditions of such ecosystems; and
- Ensure (to the extent permitted by law) that any actions they authorize, fund, or carry out will not degrade the conditions of such ecosystems.

The *Field Experiment* would be conducted well offshore at a depth of approximately 2,600 feet (800 meters). The changes in water quality that would result from the experiment would be undetectable above a depth of approximately 500 meters and, then, only close to the *Field Experiment*. Reef-building corals are limited to water depths far above this and occur only well beyond distances where dispersion of releases from the experiment could have an effect. No adverse effect on reef-building corals would be possible.

Most deep-sea precious corals also occur only at depths above 500 meters. Some, such as the pink coral (*Corallium secundum*), are found at this depth and below. The closest known deep-sea precious coral beds on the west side of Hawaiʻi are at least 7.5 nautical miles (14 kilometers) from the Ocean Research Corridor site at water depths of 1,000 to 1,600 feet (~300 to 500 meters). The *Field Experiment* would have no potential to affect deep-sea precious corals and would be consistent with the provisions of Executive Order 13089: Coral Reef Protection.

7.1.6 HAWAIIAN ISLANDS HUMPBACK WHALE NATIONAL MARINE SANCTUARY

The waters around the main Hawaiian Islands constitute one of the world's most important North Pacific Humpback whale (*Megaptera novaeangliae*) habitats. These waters are the only place in the United States where Humpbacks reproduce. Scientists estimate that two-thirds of the entire North Pacific Humpback whale population (approximately 4,000-5,000 whales) migrates into Hawaiian waters to breed, calve, and nurse. While in Hawaiʻi, usually between November and May with a peak season in January and February, Humpback whales are most often found in shallow coastal waters, at depths usually less than 300 feet (~100 meters).

The U.S. Congress, in consultation with the State of Hawaiʻi, designated the Hawaiian Islands Humpback Whale National Marine Sanctuary on November 4, 1992. This designation was finalized with the formal approval by Hawaiʻi Governor Ben Cayetano on June 15, 1997. The Hawaiian Islands National Marine Sanctuary Act is intended to:

- Protect Humpback whales and their habitat within the Sanctuary;
- Educate and interpret for the public the relationship of Humpback whales and the Hawaiian Islands marine environment;
- Manage human uses of the Sanctuary consistent with the Hawaiian Islands National Marine Sanctuary Act and the National Marine Sanctuary Act; and
- Provide for the identification of marine resources and ecosystems of national significance for possible inclusion in the Sanctuary.

The National Marine Sanctuary regulations are found at 15 CFR 922. As defined by Section 922.181, the Hawaiian Islands Humpback Whale National Marine Sanctuary consists of the submerged lands and waters off the coast of the Hawaiian Islands seaward from the shoreline, cutting across the mouths of rivers and streams. In the waters off the Big Island, the Sanctuary extends from ‘Upolu Point southward to Ke hole Point, where it ends to the north of the Ocean Research Corridor site. The Sanctuary extends from the shoreline to the 100-fathom (600 feet or ~183 meters) isobath.

The regulations make it unlawful for any person to conduct or cause to:

- Approach within 100 yards of any Humpback whale except as authorized under the Marine Mammal Protection Act (MMPA);
- Operate any aircraft above the Sanctuary within 1,000 feet of any Humpback whale except as necessary for takeoff or landing from an airport or runway, or as authorized under the MMPA and the Endangered Species Act (ESA);
- Take any Humpback whale in the Sanctuary except as authorized under the MMPA and the ESA;
- Possess within the Sanctuary (regardless of where taken) any living or dead Humpback whale or part thereof taken in violation of the MMPA or the ESA;
- Discharge or deposit any material or other matter in the Sanctuary;
- Alter the seabed of the Sanctuary; or
- Discharge or deposit any material or other matter outside the Sanctuary if the discharge or deposit subsequently enters and injures a Humpback whale or Humpback whale habitat.

The *Field Experiment* would take place well outside the 100-fathom isobath and beyond the limit of the Hawaiian Islands Humpback Whale National Marine Sanctuary. As discussed in Section 5.2.1.4, the CO_2 that would be released during the *Field Experiment* would only affect water quality at substantial depths, and the plume would not travel sufficiently far from the point of release to enter the Sanctuary. This means that there would be no potential for adverse effect on the Sanctuary habitat or Humpback whales themselves.

7.1.7 COASTAL ZONE MANAGEMENT PROGRAM

Hawai‘i’s Coastal Zone Management (CZM) Program is carried out in accordance with the National Coastal Zone Management Act of 1972, as amended, and with Chapter 205A, Hawai‘i Revised Statutes. In Hawai‘i, the coastal zone includes the water seaward from the shoreline to the seaward limit of the State’s jurisdiction. The Ocean Research Corridor site would be located within this coastal zone.

The National Coastal Zone Management Act requires Federal activities and development projects to be consistent with approved State coastal programs to the maximum extent practicable. Also, Federally permitted, licensed, or assisted activities occurring in, or affecting, the State’s coastal zone must be in agreement with Hawai‘i’s CZM Program objectives and policies. Federal agencies cannot act without regard for, or in conflict with, State policies and related resource management programs that have been officially incorporated into the State CZM program.

DOE funding for the experiment is not subject to formal CZM consistency review. Nonetheless, the experiment’s consistency with the program’s ten policy areas has been evaluated. The results are summarized below. Each of the ten objectives is presented in italics. This is followed by a discussion of the project’s consistency with that objective.

<u>Recreational Resources Objective</u>: *To provide coastal recreational opportunities accessible to the public and protect coastal resources uniquely suited for recreational activities that cannot be provided elsewhere.* The *Field Experiment* would not harm coastal recreational resources. It would not have an adverse effect on marine biological communities relevant to recreation. The presence of research vessels within NELHA’s Ocean Research Corridor for a period of 10 to 14 days would not interfere with fishing or other recreational uses of this area.

Historic Resources Objective: *To protect, preserve, and where desirable, restore those natural and manmade historic and prehistoric resources in the coastal zone management area that are significant in Hawaiian and American history and culture.* There are no historic or cultural sites in areas that might be affected by project-related activities. Native Hawaiians have expressed concern about the *Field Experiment*'s effects on traditional and current fishing grounds at the Ocean Research Corridor site.

Scenic and Open Space Resources Objective: *To protect, preserve, and where desirable, restore or improve the quality of coastal scenic and open space resources*. The proposed activities would not have the potential to affect these resources.

Coastal Ecosystems Objective: *To protect valuable coastal ecosystems, including reefs, from disruption and minimize adverse impacts on all coastal ecosystems*. As discussed in detail in Section 5, the proposed activities would not have the potential to alter water quality or otherwise modify the marine environment sufficiently to have an adverse effect on these resources.

Economic Uses Objective: *To provide public or private facilities and improvements important to the State's economy in suitable locations and ensure that coastal dependent development such as harbors and ports, energy facilities, and visitor facilities, are located, designed, and constructed to minimize adverse impacts in the coastal zone area.* The proposed activity is not related to this objective.

Coastal Hazards Objective: *To reduce hazard to life and property from tsunami, storm waves, stream flooding, erosion, subsidence, and pollution.* The proposed activity is not related to this objective.

Managing Development Objective: *To improve the development review process, communication, and public participation in the management of coastal resources and hazards.* The proposed activity is not related to this objective.

Public Participation Objective: *To stimulate public awareness, education, and participation in coastal management; and maintain a public advisory body to identify coastal management problems and provide policy advice and assistance to the CZM program.* The proposed activity is not related to this objective.

Beach Protection Objective: *To protect beaches for public use and recreation; locate new structures inland from the shoreline setback to conserve open space and to minimize loss of improvements due to erosion.* The proposed project would not have the potential to adversely affect beaches or other shoreline areas that are used for recreational purposes.

Marine Resources Objective: *To implement the State's ocean resources management plan.* The proposed activity is not related to this objective.

7.1.8 OCEANS ACT

The Oceans Act of 2000 (Public Law 106-256; effective date January 20, 2001) was enacted on August 7, 2000, for the purpose of developing a coordinated and comprehensive national ocean policy. Included among the policy objectives that will be pursued under the Act are actions to promote the following:

- Protection of the marine environment and prevention of marine pollution;
- Expansion of human knowledge of the marine environment, including the role of the oceans in climate and global environmental change; and
- Preservation of the role of the United States as a leader in ocean and coastal activities and, when in the national interest, cooperation by the Unites States with other nations and international organizations in ocean and coastal activities.

Policy development activities will be based on equal consideration of environmental, technical feasibility, economic, and scientific factors. Under the Act, a 12-member Commission on Ocean

Policy that will be appointed by the President in 2001 will develop policy recommendations. This Commission, in developing ocean policy recommendations, could potentially benefit from technical and environmental information resulting from the proposed *Field Experiment*.

7.2 STATE REQUIREMENTS

Conducting the *Field Experiment* at the NELHA Ocean Research Corridor site would make it subject to certain State regulations. These include Chapters 11-54 (Water Quality Standards) and 11-55 (Water Pollution Control) of the Hawai‘i Administrative Rules and the Historic Preservation requirements established by Chapter 6E, Hawai‘i Revised Statutes.

7.2.1 STATE WATER QUALITY REGULATIONS

Project personnel have met with the State Department of Health (DOH) to discuss issues relating to water quality should the *Field Experiment* be conducted at the location off Ke hole Point. DOH determined that the release of CO_2 would constitute an activity subject to Chapter 342D of Hawai‘i Revised Statutes and Hawai‘i Administrative Rules (HAR), Section 11-54 (titled Water Quality Standards) and Section 11-55 (titled Water Pollution Control). The Department concluded that the requirements for an NPDES permit might be waived if certain conditions are met. This tentative determination took into consideration that the proposed action would constitute a research project, would be located within the Ocean Research Corridor, would involve a discharge that would be both intermittent and of short duration, and would be conducted under proper control. The conditions noted in DOH’s letter include:

- Being consistent with the purposes of the NELHA Ocean Research Corridor.
- Compliance with the State’s Anti-Degradation Policy as specified in HAR Section 11-54-01.1, properly addressing this issue through the processing of environmental impact documentation.
- Consulting with and complying with applicable rules administered by the U.S. Fish & Wildlife Service, National Marine Fisheries Service, and Division of Aquatic Resources of the State Department of Land and Natural Resources.
- Submitting results of preliminary sampling of biota and bacteria populations in the immediate vicinity of the discharge nozzle to the Clean Water Branch.
- Obtaining DOH approval of final plans for the *Field Experiment*.
- Obtaining DOH approval of a monitoring and assessment plan.
- Submitting a final research and study report to DOH upon completion of the *Field Experiment*.

Should the *Field Experiment* be conducted at a Generic Ocean site within areas under State jurisdiction, then a similar review for compliance at that location would be needed before undertaking the project. Other regulations could apply if the *Field Experiment* were conducted elsewhere.

7.2.2 STATE HISTORIC PRESERVATION LAW

Chapter 6E-1, Hawai‘i Revised Statutes (HRS), establishes State regulations for historic and cultural properties, consistent with the National Historic Preservation Act of 1966**,** as amended. Properties of traditional religious or cultural importance are among those that can be determined to be eligible for recognition as historic properties. Such properties include districts, sites, buildings, structures, and objects of significance in American history, architecture, archaeology, engineering, and culture. Chapter 6E-1 notes that the Constitution of the State of Hawai‘i recognizes the value of conserving and developing the historic and cultural property within the State for the public good and makes it public policy to promote the use and conservation of such property for the education, inspiration, pleasure, and enrichment of its citizens.

HRS 6E-5 provides for the Governor to appoint a State Historic Preservation Officer (SHPO). It makes the SHPO responsible for the comprehensive historic preservation program and for being the liaison officer for the conduct of relations with the Federal government and the respective states with regard to matters of historic preservation.

As discussed in Section 7.1.4, DOE and other project participants have consulted with the SHPO. The SHPO has no record of historic sites at the Ocean Research Corridor site and believes that the probability of any kind of historic property at this depth and location seems remote (see consultation letter in Appendix G). DOE and the SHPO agree that the proposed project would most likely have no effect on significant historic sites.

7.3 HAWAI‘I COUNTY REQUIREMENTS

No Hawai‘i County ordinances or regulations are directly applicable to the *Field Experiment*.

7.4 INTERNATIONAL AGREEMENTS

Sites that are within the Territorial waters of nation states (typically at least 12 miles) are not directly subject to the provisions of international agreements. Most of the locations under consideration for the *Field Experiment* fall into this category.

8.0 SECONDARY & CUMULATIVE EFFECTS AND LONG-TERM ENVIRONMENTAL CONSEQUENCES

8.1 SECONDARY (INDIRECT) EFFECTS

Secondary, or indirect, effects are effects caused by actions that occur later in time or farther removed in distance, but which are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

As described in Section 5 of this report, the effects of the *Field Experiment* would be limited to direct short-term perturbations in seawater chemistry and localized impacts on marine biota. The *Field Experiment* would not represent a commitment to larger-scale tests or to actual use of ocean sequestration as a disposal technology. Consequently, no substantial secondary effects are anticipated.

8.2 CUMULATIVE EFFECTS

The Council on Environmental Quality's (CEQ) regulations for implementing the National Environmental Policy Act (NEPA) define cumulative effects as the impact on the environment which results from the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such other actions (40 CFR, Section 1508.7).

No similar activities have taken place at the NELHA Ocean Research Corridor site, no additional similar experiments are planned for that area, and no activities with effects that, when added to the consequences of the proposed action could lead to adverse impacts, are known to be planned by others. Because of this and the fact that the *Field Experiment*'s effects would be localized, there would be no potential for cumulative effects at this location. Due to the unique aspects of the proposed experiment, cumulative effects would also not be expected at a generic ocean site.

8.3 LONG-TERM ENVIRONMENTAL CONSEQUENCES

The *Field Experiment* would be designed to provide needed technical information related to potential mitigation of atmospheric emissions of CO_2. By itself, the *Field Experiment* would have no long-term environmental consequences. If the *Field Experiment* were completed successfully, it would have the potential of providing policymakers and the public with better capability for judging the feasibility and effectiveness of marine CO_2 sequestration. Such enhanced capability would make it more likely that informed and environmentally beneficial policy decisions could be made than would otherwise be possible without the results from the *Field Experiment*. A discussion of the scientific context for the *Field Experiment* is presented in Appendix D.

9.0 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

9.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND GENERIC OCEAN SITE

The principal natural resources affected by the *Field Experiment* would be the deep-sea marine life near the CO_2 discharge. Some fraction of the benthic life in this area would be stressed to an important degree, and some mortality would be expected. Because of rapid recolonization due to mixing with surrounding waters, the effect on organisms inhabiting the water column would likely be very short. To the extent that the benthos would be affected, recovery to background levels of biomass and diversity would take longer. While substantial effects would not be anticipated, the depressed pH level that would result from the CO_2 plume would be expected to kill zooplankton and possibly other fauna within a small area. Even under the worst assumptions, recovery would occur within a period of years.

Emplacements of the discharge platform would likely crush or bury the fauna living on and in the underlying seafloor. The disturbed patches would be expected to return to pre-experiment conditions in periods ranging from a few weeks to a few years. Disturbance on this scale would not cause any long lasting negative impacts to any of the seafloor fauna at the population or species level.

As discussed in Section 5.3.2.1.3, additional areas would be impacted by the repeated deployments of the platform and tubing. The effects caused by the tubing moving over the seafloor would include the obliteration of small-scale sediment features that result from movement, feeding, and defecation by sediment-dwelling animals. Disruptions of this sort are commonly reported effects of trawling, which affects vast tracts of the seafloor in many regions of the world's oceans. While recovery of hard and soft substrate fauna following disturbances would likely require months to several years, the disturbances would not be permanent.

Resources irreversibly and irretrievably committed to the *Field Experiment* would also include research funds and the time, scientific knowledge, and energy of the individuals involved in carrying out the work. Devoting vessel time to the *Field Experiment* would preclude use elsewhere.

As discussed in Chapter 5, deep-sea biological communities are similar over large parts of the ocean floor. Because a vessel-based *Field Experiment* would be carried out essentially the same way at any ocean site, very similar commitments of natural resources would be expected. However, since calm seas and predictable winds would not be nearly so favorable at other sites as at the NELHA Ocean Research Corridor, increased commitments of research funds would probably be required at other locations.

9.2 NO ACTION ALTERNATIVE

No commitments of resources would be predicted if the *Field Experiment* is not conducted due to the withdrawal of DOE participation. The absence of the scientific knowledge that the planned *Field Experiment* would provide could lead to poor decisions that misuse scarce resources. If the *Field Experiment* were carried out in the absence of DOE participation, then the same commitments of resources as required for conduct of the experiment in the Ocean Research Corridor would be expected.

10.0 RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

10.1 NELHA OCEAN RESEARCH CORRIDOR SITE AND GENERIC OCEAN SITE

The *Field Experiment* would occupy a localized area of the seafloor for a period of two weeks or less. After completion of the *Field Experiment*, the research ships, all instrumentation, and discharge equipment would be removed. If the *Field Experiment* is successful in obtaining the data sought, the results could have important implications for future, long-term policy decisions regarding mitigation of atmospheric emissions of CO_2.

The balance between the short-term use of the sea and seafloor and the potentially long-term benefits of the *Field Experiment* would be essentially the same if the *Field Experiment* were conducted at any ocean site. The probability of success for the *Field Experiment* may be lower at a site outside the Ocean Research Corridor, however, due to the superior wind and wave conditions expected at the Ocean Research Corridor site.

10.2 NO ACTION ALTERNATIVE

If the *Field Experiment* is not conducted due to withdrawal of DOE participation resulting from a No-Action decision, there would be no action to consider. If the *Field Experiment* is carried out in the absence of DOE participation, then the balance between short-term uses and long-term productivity of the environment would be the same as that for the Ocean Research Corridor.

11.0 SIMILAR ACTIONS AND ACTIONS BEING CONSIDERED UNDER OTHER NEPA REVIEWS

The proposed action, which would involve participation by the U.S. Department of Energy (DOE) in the conduct of the *Ocean Sequestration of CO_2 Field Experiment*, is not similar to any other action being considered by (or currently being implemented by) DOE and is not a segment of any other action for which review under NEPA would be required.

Many policy options and technological concepts have been identified as possible approaches to address causes of climate change induced by human activity, including carbon taxes, emission caps and emission trading systems, incentive programs to promote changes to low- or zero-carbon emitting technologies, and a variety of geochemical/engineering concepts for mitigating the warming of the atmosphere. Also, geochemical and engineering concepts for reducing carbon emissions would include options such as use of renewable energy sources or fuel switching, improving the efficiencies of systems for both energy supply and energy utilization, and sequestering carbon.

DOE has historically supported research and development projects that focus on creating less carbon-intensive and more efficient methods for generating energy. Although technologies that could result from these activities may help reduce emissions of greenhouse gases, given the importance of developing adequate strategies for mitigating climate change, other approaches, such as carbon sequestration, if successfully developed, may offer additional potential as an option for future consideration in planning strategies for reducing the buildup of greenhouse gases in the atmosphere. As noted in Section 3.2.1, DOE is conducting research to establish an adequate scientific understanding of candidate approaches for carbon sequestration.

DOE has identified several possible concepts to sequester carbon dioxide. However, to validate the feasibility of these options, a knowledge base on the concepts needs to be developed. To establish that knowledge base, research on a variety of concepts must be performed, and such research has been initiated through a number of separate projects to determine the viability of a variety of options for carbon management. The proposed *Ocean Sequestration of CO_2 Field Experiment* is one of those projects.

The purpose of DOE's research on carbon sequestration is to identify and evaluate concepts that could help meet any future challenges potentially resulting from global climate change. This research has been, and continues to be, exploratory in nature, to study the technical merits and to assess the potential economic and environmental consequences of various options for capturing, storing, and reducing emissions of greenhouse gases, particularly carbon dioxide. Sequestration options dealing directly with carbon dioxide can be separated into the following categories of research:

- <u>separation and capture</u>, to identify approaches that could potentially improve greenhouse gas collection and reduce their costs,
- <u>sequestration in geologic formations</u>, to identify and address the technical and environmental potential for sequestering CO_2 in oil and gas reservoirs, coal seams that cannot be mined, and deep saline formations,
- <u>ocean sequestration</u>, to study approaches for injecting CO_2 into deep areas of the ocean, for stimulating natural carbon absorption from the atmosphere, or for converting CO_2 into ocean-stable minerals,
- <u>terrestrial sequestration</u>, to enhance the natural CO_2 absorbing processes of soils and vegetation,
- <u>other concepts</u>, to examine novel chemical or biological methods for converting CO_2 into commercial products or inert, stable compounds, and
- <u>modeling and assessment</u>, to develop improved methods to assess the costs, risks, and potential of various CO_2 sequestration options. These methods would be used to evaluate sufficiently the

advantages and disadvantages of research options in order to establish whether or not they warrant further development.

In addition to the proposed *Field Experiment*, DOE is providing funds for research on a variety of projects in each of these areas, with each of the separate projects being performed by a university, research institute, DOE laboratory, or industrial organization. Projects are currently being examined in the following areas:

<u>separation and capture</u>

- membrane approach for separating CO_2 from gas streams
- capture of CO_2 from gas streams using chemicals

<u>sequestration in geologic formations</u>

- studies and tests of CO_2 storage in coal seams
- study of saline reservoirs to assess CO_2 storage capabilities and environmental risks
- development of subterranean imaging technology

<u>ocean sequestration</u>

- analysis of natural ocean deposits of CO_2 hydrates on the seafloor
- investigation of analytical techniques to determine long-term fate, biological responses, and sediment effects of CO_2 hydrate in the deep sea

<u>terrestrial sequestration</u>

- evaluation of reclamation and re-forestation approaches that would sequester CO_2 in trees or abandoned mines

<u>other concepts</u>

- evaluation of photosynthetic organisms in specially designed bioreactors for enhancing the rate of CO_2 conversion
- evaluation of species of micro-algae for photosynthesis of CO_2 from power plant exhaust gases

<u>modeling and assessments</u>

- development of a computer model to assess sequestration options and costs
- development of a data base to catalog CO_2 source-to-sequestration information

These research projects are independent elements of DOE's effort to identify potential approaches that could assist in future efforts to control buildup of greenhouse gases in the atmosphere. A variety of approaches are being investigated to assess their technical, economic, and environmental viability. None of these separate research projects, including the proposed *Field Experiment*, is an integral element of an established commercialization plan for the large-scale sequestration of carbon dioxide.

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13.0 APPENDICES

APPENDIX A: **PROJECT AGREEMENT FOR INTERNATIONAL COLLABORATION ON CO_2 OCEAN SEQUESTRATION**

APPENDIX B: **PUBLIC OUTREACH PROGRAM**

APPENDIX C: **DRAFT EXPERIMENTAL PLAN FOR THE OCEAN SEQUESTRATION OF CO_2 *FIELD EXPERIMENT***

APPENDIX D: **CONCEPTS AND MODELS RELEVANT TO THE *FIELD EXPERIMENT***

APPENDIX E: **OBSERVATIONS OF SEAFLOOR LIFE AT THE OCEAN RESEARCH CORRIDOR SITE**

APPENDIX F: **CULTURAL IMPACT ASSESSMENT STUDY**

APPENDIX G: **CONSULTATION AND PUBLIC PARTICIPATION**

APPENDIX A: PROJECT AGREEMENT FOR INTERNATIONAL COLLABORATION ON CO_2 OCEAN SEQUESTRATION

This Project Agreement is entered into among the Federal Energy Technology Center (FETC) of the Department of Energy of the United States of America, the New Energy and Industrial Technology Development Corporation (NEDO) of Japan, and the Research Council of Norway (NRC) (collectively the "Parties").

WHEREAS, in 1995 member countries of the International Energy Agency and the Organization for Economic Cooperation and Development created the Climate Technology Initiative (CTI);

WHEREAS, the CTI seeks to support the objectives of the United Nations Framework Convention on Climate Change by increasing the use of existing climate-friendly technologies and developing new and improved climate-friendly technologies through the promotion of international cooperation in research, development, deployment and information dissemination;

WHEREAS, an objective of CTI's Task Force 7 is to enhance international collaboration in research and development in greenhouse gas capture and disposal, including research on ocean sequestration of CO_2; and

WHEREAS, the CTI's Task Force 7 invites the Parties to explore on an international collaborative basis the technical feasibility and environmental impact of CO_2 ocean sequestration, in order to advance current knowledge of the behavior of discharged CO_2 in the ocean;

NOW THEREFORE, the Parties agree as follows:

Article 1
Objective of the Project

The objective of the international collaboration project on CO_2 ocean sequestration (the "Project") is to determine the technical feasibility of, and improve understanding of the environmental impacts of, CO_2 ocean sequestration in order to minimize the impacts associated with the eventual use of this technique to reduce greenhouse gas concentrations in the atmosphere.

Article 2
Scope of Work

To advance current knowledge of the behavior of discharged CO2 in the ocean, joint research shall be undertaken which mainly focuses on dissolution-type CO_2 discharge experiments conducted at an ocean site. In this joint research, a CO_2 injection system will be constructed and operated to observe near-field phenomena such as droplet plume dynamics and subsequent peeling and intrusion of enriched water. This joint research shall be conducted within the estimated cost of the Project as described in Article 9.

Article 3
Work Program

The program of work for the Project (hereinafter the "Work Program") shall be as follows:

1. Selection of the most suitable site for ocean field experiments.
2. Determination of the discharge depth, rate, timing and duration of experiments.
3. Design of facilities for CO_2 storage, transport and discharge.
4. Selection of the items to be measured and monitored in experiments.
5. Preparation and testing of equipment for measurement and monitoring.
6. Construction of CO_2 storage, transport and discharge facilities.
7. Carrying out of ocean field experiments.
8. Analysis of data acquired during experiments.
9. Collation of overall results obtained in the field experiments.
10. Formulation of a proposal for the next phase of the Project.
11. Other activities as may be mutually agreed by the Parties in writing.

All Parties shall cooperate with one another to promote the Work Program.

Article 4
Addition and Withdrawal of Project Participants

(1) Upon approval of the Steering Committee (described in Article 6), participation in the Project shall be open to other organizations which sign or accede to this Project Agreement, accept the rights and obligations of a Party, and make an appropriate contribution to defray the cost of the Project.

(2) In the event a Party wishes to withdraw from the Project for budgetary or other reasons, it may do so at the end of a fiscal year (as defined in Article 8) upon sixty (60) days' written notice to the other Parties.

Article 5
Implementing Research Organizations

(1) Each Party may implement Project activities through an appropriate domestic research organization (hereinafter "Implementing Research Organization"). Alternatively, a Party may undertake Project activities itself.

(2) The Parties' designated Implementing Research Organizations are as follows:

For FETC:
Massachusetts Institute of Technology (United States of America)

For NEDO:
Research Institute of Innovative Technology for the Earth (Japan)

For NRC:
Norwegian Institute for Water Research (Norway)

(3) The Parties shall support their respective Implementing Research Organizations by providing annual funding to be used for implementing the Project, subject to Article 9.

(4) In order to establish work responsibility, details regarding treatment of intellectual property, and necessary policy and procedure for the Project, the Implementing Research Organizations shall conclude an annual joint research agreement for each fiscal year of the Project.

Article 6
Steering Committee

(1) A committee consisting of one representative of each Party (hereinafter "Steering Committee") shall be established to manage the overall direction and scope of the Project and to consider and approve the participation of other organizations in the Project.

(2) The Steering Committee shall be responsible for resolving any misunderstandings or problems related to this Project Agreement or the Project based on the principles of mutual benefit, equality, cooperation and trust.

(3) The Steering Committee shall hold its first meeting within one (1) month of the execution of this Project Agreement to establish duties, policies and procedures for implementing the Project. Following its first meeting, the Steering Committee shall meet approximately once a year at a place mutually agreed by all members.

Article 7
Technical Committee

(1) The Parties shall establish a Technical Committee consisting of up to three (3) representatives appointed by each Implementing Research Organization, to formulate the annual Work Program for each year of the Project, to supervise its technical aspects and execution, and to consult about treatment of intellectual property.

(2) The Technical Committee shall also be responsible for managing the budget for implementing the Work Program and coordinating any optional research studies which may be undertaken during the Project.

(3) The Technical Committee shall report to the Steering Committee at least twice a year regarding implementation of the annual Work Program for the Project.

(4) The specific functions of the Technical Committee shall be set forth in the annual joint research agreements among the Implementing Research Organizations.

Article 8
Project Fiscal Year

The Parties agree that the fiscal year of the Project shall extend from April 1st to March 31st of the following year.

Article 9
Cost Contributions

The total estimated cost of the Project is Three Million Eight Hundred Thousand U.S. Dollars (U.S.$3,800,000). Subject to the availability of appropriated funds and appropriate authorizations by their respective governments, the Parties agree to share the cost of the Project as follows:

Agency	Funding Level (U.S.$)	Percentage of Funding
FETC	$850,000	22.4%
NEDO	$2,600,000	68.4%
NRC	$350,000	9.2%

Article 10
Treatment of Project Results

Basic policy regarding the use and protection of research data and intellectual property resulting from Project activities shall be determined through mutual discussion and agreement of the Parties. Specific details concerning the treatment of project results shall be included in the annual joint research agreements provided for under Article 5.

Article 11
Waiver of Claims for Damages

In the event of any material damage or loss of life due to an accident or any reason other than willful misconduct or gross negligence during the implementation of the Project, no compensation shall be claimed by any Party against any other Party or against the Implementing Research Organizations.

Article 12
Amendment of this Agreement

In the event the Steering Committee determines that it is necessary to amend this Project Agreement, it may be amended by written agreement of the Parties.

Article 13
Mutual Trust and Cooperation

(1) Each Party shall endeavor, in the spirit of mutual trust, to resolve any difficulties or misunderstandings which might arise concerning the Project or this Project Agreement.

(2) Each Party shall conduct the collaboration under this Project Agreement in accordance with the applicable laws and regulations under which each Party operates.

(3) Any questions arising in connection with the interpretation or implementation of this Project Agreement or anything not specified herein shall be promptly discussed through mutual consultation among the Parties.

Article 14
Responsibility for and Use of Information

(1) The Parties support the widest possible dissemination of information generated by Project activities. Such information may be made available for public dissemination at the discretion of the Parties, subject to the need to protect proprietary information in accordance with Article 14(2).

(2) The Parties shall take all necessary measures as they may consider appropriate to protect proprietary information. For the purposes of this Article, proprietary information shall include information of a confidential nature such as trade secrets and know-how (for example, computer programs, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes or treatments) which:

(i) is not generally known or publicly available from other sources;

(ii) has not previously be made available by the owner to others without obligation concerning its confidentiality; and

(iii) is not already in the possession of the recipient without obligation concerning its confidentiality.

It shall be the responsibility of each Party supplying proprietary information to identify the information as such and to ensure that it is marked "Proprietary Information".

(3) Information transmitted by one Party to another Party shall be accurate to the best knowledge and belief of the transmitting Party, but the transmitting Party does not warrant the suitability of the information transmitted for any particular use or application.

Article 15
Effective Date, Extension, and Termination

(1) This Project Agreement shall be effective from the date of its signing by all Parties through March 31, 2002, unless extended or terminated.

(2) By mutual written agreement, the Parties may extend this Project Agreement for additional periods.

(3) The Parties may by mutual written agreement terminate this Project Agreement at any time.

IN WITNESS WHEREOF, each Party has executed this Project Agreement on the date indicated, with each Party to retain one (1) fully executed copy.

Federal Energy Technology Center
Department of Energy
United States of America

Signature:
Name: Harvey M. Ness
Title: Director, Power and Environmental Systems
Date: December 4, 1997

New Energy and Industrial Technology
Development Organization
Japan

Signature:
Name: Hiroshi Mitsukawa
Title: Executive Director
Date: December 4, 1997

Research Council of Norway
Norway

Signature:
Name: Eirik Normann
Title: Assistant Director
Date: December 4, 1997

APPENDIX B: PUBLIC OUTREACH PROGRAM

As the implementing organization, the Pacific International Center for High Technology Research (PICHTR) developed and initiated an extensive public outreach program for the *Ocean Sequestration of Carbon Dioxide Field Experiment*. The outreach program has had several key purposes:

- Expand pre-consultation process to include environmental and community organizations, as well as other local stakeholders in order to provide an opportunity to give input into the experimental design.
- Work with stakeholders to keep them well informed and to listen to their concerns.
- Instill a sense the *Field Experiment* would be conducted with full public knowledge.
- Secure an understanding of the *Field Experiment*'s importance to informed public policy decision-making.

The public outreach program consists of several phases. Those phases, and the objectives of each, are outlined below.

Phase I: Gather Information and Prepare Outreach. Develop a public outreach program for the *Ocean Sequestration of Carbon Dioxide Field Experiment*. Identify key contacts, including: NELHA tenants; citizen and native Hawaiian marine advocates; scientists and extension agents; West Hawaiʻi Fishery Council; private sector representatives; and elected officials.

Phase II: Prepare NELHA Site Proposal. Build understanding of the rationale for conducting the *Field Experiment* at the Natural Energy Laboratory of Hawaiʻi Authority's Ocean Research Corridor. Listen to and address concerns through mailing information packages to key contacts, telephone calls and one-on-one (or small group) meetings with decision-makers, media contacts, and project-related articles and opinions published in local newspapers and magazines. On August 6, 1999, a project presentation was made at a NELHA Tenants Association Meeting. A web site containing descriptive information concerning the *Field Experiment* and links to other relevant web sites was established (www.co2experiment.org). This web site has been updated several times in subsequent phases. The project web site includes an Email address for the public to submit comments. The project team has made great efforts to try and respond to all public inquiries. Email correspondence with the public has continued in subsequent phases.

Phase III: NELHA Site Proposal and Review. Continue building community involvement and initiate formal environmental scoping. Activities included presenting at a University of Hawaiʻi Sea Grant Extension Service's REEFTALK (September 14, 1999), showing a video of this presentation several times in November 1999 on a West Hawaiʻi public access cable channel. The project team also briefed the NELHA Board, held a public scoping meeting for the Environmental Assessment (Section 3.4.4), and informed project leadership about concerns so that appropriate adjustments could be made in the *Field Experiment*'s design.

Phase IV: Prepare EA and (if necessary) apply for permits. Foster public understanding and ensure plans for the *Field Experiment* are adjusted as needed. On March 1, 2000, a presentation was given to the Hawaiian Islands Humpback Whale National Marine Sanctuary Advisory Council. Email correspondence between the project team and local stakeholders continued throughout this and other phases.

Phase V: Final activities prior to conducting *Field Experiment*. The next phase in the extensive public outreach effort is in the time leading up to the actual conducting of the *Field Experiment*. Planned activities include: (i) preparing and circulating a press release prior to initiation of the *Field Experiment* and (ii) continuing background briefings with media contacts at West Hawaii Today, Hawaii Tribune-Herald, Honolulu Star-Bulletin, and the Honolulu Advertiser.

Phase VI: Experiment Phase and Post-Experiment Activity. Provide the public with current and accurate information on the final preparation for and conducting of the *Field Experiment*. Results of the *Field Experiment* would be published in the technical literature available to the public. In addition, if the project web site remains activated for a sufficient time after the completion of the *Field Experiment*, data and results may be posted and thus become available online. It must be realized, however, that for technical reasons there usually is a substantial delay between the collection of raw field data and their availability as calibrated or processed information. An even longer delay should be anticipated in the case of peer-reviewed technical literature. The presence of observers during the execution of the *Field Experiment* would pose logistical and safety problems. While observers that are not directly affiliated with the project could be admitted onboard the research vessels, a strict protocol would have to be enforced to ensure everyone's safety and to avoid interference with ongoing experimental and monitoring activities. Such a protocol would naturally restrict the number of people who could serve as observers.

APPENDIX C: DRAFT EXPERIMENTAL PLAN FOR THE OCEAN SEQUESTRATION OF CO_2 FIELD EXPERIMENT

APPENDIX D: CONCEPTS AND MODELS RELEVANT TO THE FIELD EXPERIMENT

An understanding of the potential utility and environmental effects of ocean sequestration of CO_2 requires knowledge of natural processes that take place within widely different scales of time and space. One of the ways that scientists investigate such processes and their implications for ocean sequestration is through development of computer models. The models are developed using known physical principles to predict measurable consequences. Such models are supported, modified, and validated by oceanographic investigations that measure the actual causes and results in the real world.

The proposed *Field Experiment* is one example of this kind of investigation, and it is focused on the small scale. The following passages consider three different scales, global, mesoscale, and the small scale proposed for the experiment, and describe the relevance of the proposed *Field Experiment* to each. This is followed by a short description of the specific models that the *Field Experiment* is designed to support.

Global Scale

A basic understanding of the relationship between CO_2 in the ocean and CO_2 in the atmosphere is necessary for appreciating the rationale for ocean sequestration of CO_2. In general, regions of upwelling correspond to a transfer of CO_2 from the ocean into the atmosphere, while the highly alkaline waters of subtropical gyres, cold waters in high latitudes and biologically productive surface waters all absorb CO_2 from the atmosphere (Wong and Hirai 1997, p. 23-24).

The difficulties associated with the measurement of seasonally and locally varying carbon fluxes on the vast expanses of the entire oceanic surface are substantial. At a given time and location, these fluxes are proportional to the difference between p_a, the partial pressure of CO_2 in the atmosphere, and p_m, the partial pressure of free CO_2 in the mixed layer of the ocean. The coefficient of proportionality itself depends on various factors such as wind speed, local CO_2 solubility, etc. The net sink associated with the North Pacific Subtropical Gyre (NPSG), for example, was recently estimated to be 0.2 GtC/yr, over an area of 26.3 x 10^6 km^2 (Winn *et al.* 1994). This value corresponds to a small partial pressure imbalance $p_a - p_m$ of the order of 10 µatm (or ppmv).

While our improved ability to measure detailed carbon fluxes is very important, especially for three-dimensional predictive tools such as Ocean Global Climate Models (OGCMs), some global knowledge already is available (Siegenthaler and Sarmiento 1993). On one hand, it is acknowledged that prior to the middle of the 19^{th} Century, the pre-industrial atmosphere and ocean had been in global equilibrium for many centuries, with large fluxes across the ocean surface (of the order of 74 GtC/yr) balancing each other out. Today, not only have global carbon fluxes across the ocean surface increased (to about 90 GtC/yr), but more importantly, the mixed layer has become a net global carbon sink, of about 2 GtC/yr across an oceanic surface of about 3.7 x 10^8 km^2. The NPSG appears to be an average region, with local values aligned with global estimates.

Notwithstanding uncertainties that remain to be clarified, the net global carbon sink across the ocean surface can be attributed to current anthropogenic CO_2 emissions in the atmosphere (about 6 GtC/yr). In other words, the mixed layer of the ocean already has been absorbing the equivalent of one third of all atmospheric emissions from the burning of fossil fuels.

As CO_2 atmospheric emissions have been projected to rise sharply on a worldwide basis through the 21^{st} Century, certain physical and chemical phenomena that play a crucial role in the carbon budget of the oceanic mixed layer should be succinctly discussed. It will be seen that, as a result of these mechanisms, the oceanic mixed layer represents a veritable bottleneck to the eventual transfer of excess atmospheric carbon to the deep ocean.

The mixed layer of the ocean is typically 60 to 75 m thick and lies between the atmosphere and the deep ocean. The upper reaches of the deep ocean, down to approximate depths of 1,000 m, constitute the main (or permanent) thermocline. Because of the density stratification of the upper deep ocean, transport phenomena such as turbulent eddy diffusion (dispersion) are greatly inhibited. Vertical stability through the thermocline can be 'visualized' by imagining a tiny water blob moving up (down) into less (more) dense ambient water; it would immediately tend to sink (rise) back into its original position because of an imbalance between its weight and buoyancy.

Thus, a first limiting transfer mechanism affecting the mixed layer is the slow downward vertical migration of any excess carbon through the thermocline. Recent estimates of the vertical eddy diffusivity are actually one order of magnitude lower than previously thought (Wong and Matear 1996). As a result, the influence of the deep ocean in limiting the rise of atmospheric and mixed-layer carbon concentrations might not be felt over time scales of decades, when it would be most critical. It is noteworthy to add that this limitation also applies to the downward dispersion of heat. In other words, slow vertical dispersion through the main thermocline might also prevent a timely reduction of any temperature buildup (Global Warming) in the upper layers.

Going back to the flux of CO_2 across the ocean surface, another fundamental mechanism must now be described that limits the transfer of excess atmospheric CO_2 into the mixed layer. It was mentioned in previous sections that in seawater, several carbon species exist and that their relative amounts are controlled by the requirements of chemical equilibrium. Thus, when CO_2 is added to seawater, the amount of dissolved inorganic carbon (DIC) increases accordingly. In spite of the buffering (neutralizing) effect of carbonate ions (CO_3^{2-}) on CO_2, [CO_2] increases sharply with [DIC] and the pH is reduced.

A fundamental result from the chemistry of carbon species in seawater is that with the addition of carbon, the <u>relative</u> increase in [CO_2] greatly exceeds the <u>relative</u> increase in [DIC]. Since [CO_2] is proportional to the free CO_2 partial pressure p_m, one can define the Revelle factor ξ as:

$$\xi = \{(p_m - p_{m0})/p_{m0})\}/\{([DIC]-[DIC]_0)/[DIC]_0)\},$$

where the subscript 0 indicates a state of reference.

Currently, ξ is of the order of 10, and is an increasing function of [DIC]. High values of ξ indicate that the transfer of excess atmospheric carbon into the ocean's mixed layer is rather difficult. Increasing values of ξ with [DIC] mean that this transfer will get even more difficult as more carbon is released into the system. An intuitive explanation of this point can be stated as follows. A small relative increase in [DIC], which measures the storage capacity of the mixed layer, corresponds to a ξ -fold relative increase in p_m. In turn, high values of p_m choke the flux of carbon into the mixed layer, which is controlled by $p_a - p_m$. In general, most CO_2 emitted into the atmosphere stays in the atmosphere, with only a small fraction being transferred into the ocean mixed layer.

The above discussion provides the fundamental tenet underlying the general concept of CO_2 Ocean Sequestration. The ocean mixed layer is a very narrow bottleneck inhibiting the transfer of the excess CO_2 from the atmosphere into the deep ocean. This bottleneck has two components: the import of carbon from the atmosphere into the mixed layer (the Revelle factor effect) is difficult, and the export of carbon to the deep ocean from the mixed layer (from the stratification of the main thermocline) is difficult. CO_2 Ocean Sequestration essentially calls for bypassing the ocean mixed layer. Moreover, the stratification of the upper deep ocean – an impediment to vertical dispersion - would now help confining CO_2 disposed directly into the deep ocean.

If one considers the potential for future large-scale implementation of CO_2 ocean sequestration, the feasibility of the concept and its environmental effects should be evaluated by OGCMs, preferably coupled with a climate model including the atmosphere, biosphere, surface ice, etc.

A dozen or so of these models are being developed and tested by various groups throughout the World. Currently, the prediction time scale for these models is from years to decades and centuries. The space scale is of the order of 100 km at the very least (the smallest grid size ever run on very powerful supercomputers is one degree, or 60 nautical miles). In addition to computer run time limitations, a better understanding of many complex mechanisms needs to be developed, and what occurs at sub-grid scales needs to be integrated as 'input' (in a generalized sense).

For an OGCM evaluation of the CO_2 ocean sequestration concept, the marine macro-scale biogeochemical cycle would be considered. A more commonly used term is "the biological pump" (Wong and Hirai 1997, p. 24-26). The detritus flux of organic matter sinking below the pycnocline accelerates the transfer of carbon to the deep ocean. The primary components of this 'pump' include the silicate and calcium carbonate exoskeletons from phytoplankton as well as the fecal matter from zooplankton that graze upon them.

Nitrogen, phosphorus, oxygen, and other elements all have their own global cycles as well. In the ocean, a fundamental coupling between these elements and carbon occurs via biological activity. The photosynthesis reaction itself is a striking illustration of such coupling. Some very interesting one-dimensional models have been published that show the role of marine biota on the overall compositional structure of the world oceans (Kheshgi and Flannery 1991).

Currently, ongoing OGCM evaluations of the CO_2 ocean sequestration concept try to include the cycling of as many elements as possible. However, the interaction of carbon that would be disposed in the ocean, with elements such as nitrogen for example, would take place indirectly, inasmuch as changes in the concentrations of inorganic carbon species, pH and alkalinity (if the dissolution of calcareous sediments occurs) would affect biological processes. The small scale and short duration of the *Field Experiment* do not lend themselves to a critical evaluation of the interplay between carbon and nitrogen cycles under CO_2 disposal scenarios.

A primary goal of OGCMs is to describe accurately the large-scale ocean currents in all their complexity. In this sense, they should be able to simulate the thermohaline "conveyor," whereby deep water is formed in polar latitudes, and resurfaces elsewhere. Our understanding of this circulation has greatly evolved over the past decade (Wong and Hirai 1997, p. 46; Wong and Matear 1996).

Results from the proposed *Field Experiment* would not contribute directly to the understanding of these processes or to the validation or modification of OGCMs.

Mesoscale

Phenomena that are just too small or perhaps too short-term to be yet modeled by OGCMs, but that develop in a matter of weeks or months and span dimensions of orders 10 to 100 km, are also important for the understanding of ocean sequestration. The Kona coast of the Big Island is an interesting example where mesoscale eddies often develop in the lee of the island. These eddies can even be generated in pairs: along the North Kona coast a cyclonic (counterclockwise) eddy, and along the South Kona coast, an anticyclonic (or clockwise) eddy (Flament, *et al.* 1997). Ke hole Point lies at the boundary of the formation zones of these eddies, and therefore may be subjected to the action of a cyclonic eddy, or of an anticyclonic eddy. In the former case, coastal waters experience a North running (Kohala) current, with the core area of upwelled water well offshore (order of tens of kilometers).

Wyrtki *et al.* (1967) identified and characterized a cold-core cyclonic eddy off the North Kona coast well before the advent of satellite imagery. They performed oceanographic measurements down to 300 m in the course of two successive research cruises, in May and July of 1965. The eddy seemed to have formed within two months before the first cruise, and intensified between the May and July observations (inasmuch as the same eddy did persist for two months!). Its size was about 100 km. Data on the deformation of isotherms showed that the eddy was concentrated in the upper 300 m in the earlier, less intense stage (May observations), but affected deeper water in July. Observations were not available for water deeper than 300 m, however.

Current measurements collected at Ke hole Point in August 1999 showed the presence of shear (horizontal current reversal) about 500 m below the surface while satellite data showed a strong mesoscale cyclonic eddy offshore (Sundfjord and Golmen 2000). These results suggest that the dynamic effects of mesoscale eddies along the Kona coast are mostly confined in waters shallower than 300 to 500 m.

The proposed *Field Experiment* is not designed to evaluate such oceanographic processes or the behavior of CO_2 releases at these temporal and spatial scales. Though the currents to be expected on the seabed at the *Field Experiment* site may be influenced indirectly by such eddies and other mesoscale processes, the proposed releases of CO_2 will not be large or persistent enough to be tracked long enough or far enough away from the release point to permit a credible study of the interactions between the released CO_2 and these natural processes.

The *Field Experiment*

The size and duration of the controlled CO_2 releases planned during the *Ocean Sequestration of CO_2 Field Experiment* place the project at the low end of small-scale (local) dynamics. Time scales of hours to days, and spatial scales of tens of meters to a few kilometers characterize the regime of interest for the *Field Experiment*. The scientists involved with the project hope to investigate the near-field behavior of a CO_2 release to get a better understanding of the complex interactions between dissolving liquid CO_2 droplets and deep seawater. The natural processes that would control the behavior of the released CO_2 include tides, internal waves, localized solid boundary effects, and other processes.

The models developed to study the small-scale evolution of CO_2 that would be released in deep waters (buoyant rise, dissolution, dispersion, etc.) use computers just as powerful as the OGCMs, but deal with small-scale physics and grid sizes of the order of meters. Incidentally, more powerful computers would only increase the simulation times that can be calculated, or permit smaller grid sizes – great benefits *per se*, but would offer no insight on basic input sub-models (hydrate effects, droplet dissolution rates, droplet terminal velocities, etc.). In turn, it is not possible to replicate the complex stratified seawater column in a laboratory at the necessary sizes, especially because of high-pressure requirements.

Several groups have been developing specific models of the behavior of CO_2 when it would be released into deep seawater. There currently are two methods of approach: one based on laboratory experiments conducted on the basis of similarity laws, and another that involves the numerical solution of complex equations with powerful computers. In all cases, the *Field Experiment* would provide valuable data that would help dispel modeling uncertainties.

A group led by Dr. Adams at the Massachusetts Institute of Technology has spearheaded plume studies based on similarity analysis. Laboratory experiments conducted on fluids other than CO_2 that do not necessitate very high pressures and unrealistic tank sizes have provided results on plume behavior that have been interpreted in terms of non-dimensional numbers (these numbers combine different physical properties of the fluids). This establishes a basis for extrapolation to the case of liquid CO_2. This type of analysis has the potential to identify very subtle qualitative phenomena, such as the existence of multiple intrusion layers resulting from the peeling of dense seawater out of the core of a rising plume, or the possible separation of the cloud of droplets from the dense carbon-rich seawater in a cross flow (current). It is not obvious whether existing computer-based models have sufficiently high spatial resolutions to predict such qualitative features. The inherent weakness of these laboratory experiments, however, is that CO_2 and high-pressure seawater cannot directly be used.

One computer-based model that has been available and developed for more than three years is the three-dimensional (3-D) code of Dr. Alendal's group, at the Nansen Environmental and Remote Sensing Center (NERSC) in Norway. Seawater and CO_2 droplets are treated as two separate phases in a two-phase Computational Fluid Dynamics (CFD) solver of the basic momentum and continuity equations. Transport equations allow the mapping of temperature, salinity, carbon, and droplet density. The fact that CO_2 exists in the form of droplets (dispersed phase) is accounted for by the introduction of the "droplet density" parameter. The CO_2 and seawater phases interact through drag (as the buoyant droplets rise through the water column) and mass transfer (as carbon dissolves into seawater). From the results calculated by the CFD model's transport equations, pH can be determined from another set of equations describing carbon chemistry in seawater. The CO_2 injection nozzle is modeled in one numerical cell as a source term.

Other computer-based models developed to describe the behavior of liquid CO_2 injected in deep seawater share the same basic approach. One such 3-D model was conceived by Dr. Sato of the University of Tokyo. Typical reasons for differences between computer-based model results are the size and resolution of numerical grids (i.e., how closely spaced "calculation points" are) and the choice of the relationships describing the interaction between CO_2 and seawater (dissolution rates and droplet slip velocity), including hydrate formation and droplet shape.

Dr. Chen of Japan's Research Institute of Innovative Technology for the Earth (RITE) also developed a two-dimensional (2-D) computer model. The loss of one dimension (width) in the constitutive equations of the CFD code can be seen as a weakness of this approach, although the other two dimensions (height and length) are in a sense more fundamental. This means that "flat" maps of the physical quantities of interest (e.g., pH) are obtained instead of fully three-dimensional results that would be visually more representative of reality. In a 2-D approach, the much smaller numerical grid leads to shorter computer run times, which facilitates the inclusion of additional (and complicating) features such as current shear, or allows a finer numerical-grid spacing. All things being equal, a two-dimensional algorithm could be viewed as globally conservative since it does not allow any spreading of the injected matter along the missing third dimension (in other words, concentrations should be higher).

Recent work by these scientists and others indicates that the input relationships describing CO_2 droplet dissolution and droplet slip velocity are mostly responsible for differences between different predictions.

APPENDIX E: OBSERVATIONS OF SEAFLOOR LIFE AT THE OCEAN RESEARCH CORRIDOR SITE

The following table describes the observations made from the video tapes collected by the Hawaiʻi Undersea Research Laboratory (HURL) submersible *Pisces IV* when examining the seafloor at the Ocean Research Corridor site in October 2000.

Hawai‘i Undersea Research Laboratory
Video Log Records for Dives P4-006, P4-007, P4-008, P4-009, and P4-010
Collected October 2000

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-006-d1-1	0	v	None		none	0	0		
P4-006-d1-2	0	v	None		none	0	625	19 42.193	156 03.895
P4-006-d1-3	5	v	crab;pagurid?		pagurid?	1	625	19 42.193	156 03.895
P4-006-d1-4	10	v	crab;pagurid?		pagurid?	1	625-645		
P4-006-d1-5	10	v	fish;macrourid?		macrourid?	1	625-645		
P4-006-d1-6+	10	v	fish;myctophid		myctophid	2	645		
P4-006-d1-7+	15	v	fish;myctophid		myctophid	2	680		
P4-006-d1-8	15	a	Fish		eel	1	680-770		
P4-006-d1-9	20	v	None		none	0	680-770		
P4-006-d1-10	25	v	None		none	0	770		
P4-006-d1-11	30	v	fish;macrourid?		macrourid?	1	800	19 42.170	156 04.171
P4-006-d1-12	35	v	Fish		fish	1	800-815		
P4-006-d1-13	35	a/v	Squid		squid	1	800-815		
P4-006-d1-14	35	v	fish;macrourid?		macrourid?	1	800-815		
P4-006-d1-15	35	v	fish;eel		eel	1	800-815		
P4-006-d1-16	35	v	Shrimp		shrimp	1	800-815		
P4-006-d1-17	40	v	Shrimp		shrimp	1	815		
P4-006-d1-18	40	v	holothurian;synallactid		Paelopatides retifer?	1	805-815		
P4-006-d1-19	40	v	crab;pagurid		pagurid	1	805-815		
P4-006-d1-20+	40	v	shrimp;nematocarcinid?		Nematocarcinus tenuirostris	1	805-815		
P4-006-d1-21+	40	v	fish;congrid?		congrid?	1	805-815		
P4-006-d1-22	40	v	Fish		fish	1	805-815		
P4-006-d1-23+	45	v	fish;eel		eel	1	805		
P4-006-d1-24	45	v	fish;congrid?		congrid?	1	800		
P4-006-d1-25	50	v	None		none		800	19 42.298	156 04.216
P4-006-d1-26	55	v	None		none		800	19 42.298	156 04.216
P4-006-d1-27	100	v	None		none		800	19 42.298	156 04.216

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-006-d2-1	0	v	None		none		800	19 42.298	156 04.216
P4-006-d2-2	5	v	None		none		800	19 42.298	156 04.216
P4-006-d2-3	10	v	None		none		800	19 42.298	156 04.216
P4-006-d2-4	15	v	None		none		800	19 42.298	156 04.216
P4-007-d7-8	35	v	none		none	0	800		
P4-007-d7-9	40	v	none		none	0	800		
P4-007-d7-10	45	v	none		none	0	800		
P4-007-d7-11	50	v	none		none	0	800		
P4-007-d7-12	55	v	none		none	0	800		
P4-007-d7-13	100	v	none		none	0	800		
P4-007-d8-1	0	v	fish		fish small	1	780-800		
P4-007-d8-2	0	v	cnidarian;anemone		anemone large orange	1	780-800		
P4-007-d8-3	5	v	cnidarian;anemone		anemone large orange	1	780		
P4-007-d8-4	10	a	holothurian		holothurian	1	740-750		
P4-007-d8-5	15	v	cnidarian;anemone		anemone large orange	1	700-740		
P4-007-d8-6	20	v	fish;macrourid		macrourid	1	680-700		
P4-007-d8-7	20	v	cnidarian;anemone		anemone large orange	1	680-700		
P4-007-d8-8	25	v	none		none	0	680	19 43.095	156 04.468
P4-007-d8-9	30	v	cnidarian;anemone		anemone large orange	1	680	19 43.095	156 04.468
P4-007-d8-10	35	v	none		none	0	680	19 43.095	156 04.468
P4-007-d8-11	40	v	none		none	0	680	19 43.095	156 04.468
P4-008-d1-1	0	v	none		none	0	505	19 42.998	156 04.241
P4-008-d1-2	5	v	none		none	0	505-695		
P4-008-d1-3	10	v	none		none	0	505-695		
P4-008-d1-4	15	v	none		none	0	505-695		
P4-008-d1-5	20	v	none		none	0	505-695		
P4-008-d1-6	25	v	none		none	0	695-740		
P4-008-d1-7	25	v	fish		fish	1	740		
P4-008-d1-8	30	a	fish		fish	1	740-800		
P4-008-d1-9	35	v	shrimp		shrimp	1	800	19 42.987	156 04.588
P4-008-d1-10+++	35	v	seastar;goniasterid		Ceramaster bowersi?	1	800	19 42.987	156 04.588

APPENDIX E

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-008-d1-11	40	a	shrimp;pandalid?		Heterocarpus laevigatus?	1	800	19 42.987	156 04.588
P4-008-d1-12	40	v	fish;eel		eel	1	800	19 42.987	156 04.588
P4-008-d1-13	45	v	none		none	0	800	19 42.987	156 04.588
P4-008-d1-14	50	v	fish;eel		eel	1	800		
P4-008-d1-15	55	v	none		none	0	800		
P4-008-d1-16	100	v	none		none	0	800		
P4-008-d2-1	0	v	none		none	0	800		
P4-008-d2-2+++	5	v	cnidarian;scyphozoan		scyphozoan	1	800		
P4-008-d2-3	10	v	none		none	0	800		
P4-008-d2-4	15	v	none		none	0	800		
P4-008-d2-5	20	v	none		none	0	800		
P4-008-d2-6	25	v	none		none	0	800		
P4-008-d2-7	30	v	none		none	0	800		
P4-008-d2-8	35	v	none		none	0	800		
P4-008-d2-9	40	v	none		none	0	800		
P4-008-d2-10	45	v	none		none	0	800		
P4-008-d2-11	50	v	none		none	0	800		
P4-008-d2-12	55	a	fish;scorpaenid?		Ectroposebastes imus?	1	800		
P4-008-d2-13	100	v	none		none	0	800		
P4-008-d3-1	0	v	none		none	0	800		
P4-008-d3-2	5	v	fish		fish small	1	800		
P4-008-d3-3	5	v	shrimp		shrimp	1	800		
P4-008-d3-4	10	v	none		none	0	800		
P4-008-d3-5++++	15	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800		
P4-008-d3-6	15	a	fish		fish	1	800		
P4-008-d3-7	15	a	holothurian;synallactid		Paelopatides retifer	1	800		
P4-008-d3-8	20	v	shrimp		shrimp	1	800		
P4-008-d3-9	25	v	none		none	0	800		
P4-008-d3-10	30	v	none		none	0	800	19 42.955	156 04.559
P4-008-d3-11	35	v	none		none	0	800		
P4-008-d3-12	40	v	fish;eel		eel	1	800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-008-d3-13	40	v	fish		fish small	1	800		
P4-008-d3-14	45	a	cnidarian;anemone		anemone large orange	1	800-840		
P4-008-d3-15++	45	v	fish;macrourid		Hymenocephalus sp	1	850	19 43.016	156 04.647
P4-008-d3-16	45	v	shrimp		shrimp	1	850	19 43.016	156 04.647
P4-008-d3-17	50	v	fish		fish small	1	850		
P4-008-d3-18+	55	v	fish;squalid?		squalid?	1	850		
P4-008-d3-19	55	v	cnidarian;ceriantharian?		cerianthid black?	1	850		
P4-008-d3-20	55	v	fish;macrourid		Nezumia propinqua?	1	850		
P4-008-d3-21	55	v	cnidarian;anemone		large orange anemone	1	850		
P4-008-d3-22	55	v	shrimp		shrimp	1	850		
P4-008-d3-23	100	v	cnidarian;ceriantharian?		cerianthid black?	1	850		
P4-008-d3-24	100	v	cnidarian;anemone		anemone large orange	1	850		
P4-008-d3-25	100	v	shrimp		shrimp	1	850		
P4-008-d4-1	0	v	fish;eel		eel white-tailed	1	850		
P4-008-d4-2	0	v	fish		fish small	2	850		
P4-008-d4-3	0	v	shrimp		shrimp	1	850		
P4-008-d4-4	0	v	cnidarian		cnidarian long-stalked	1	850		
P4-008-d4-5	0	v	fish;myctophid?		myctophid?	1	850	19 42.738	156 04.539
P4-008-d4-6	5	v	none		none	1	850	19 42.738	156 04.539
P4-008-d4-7+	10	v	holothurian?		holothurian?	1	815-850		
P4-008-d4-8	10	v	shrimp		shrimp	1	815-850		
P4-008-d4-9	10	v	fish		fish small	1	815-850		
P4-008-d4-10	10	v	fish;eel		eel	1	815-850		
P4-008-d4-11	10	v	fish;myctophid?		myctophid?	1	815-850		
P4-008-d4-12+	15	v	cnidarian;anemone		hormathiid sp 2?	1	815		
P4-008-d4-13+	15	v	cnidarian;ceriantharian?		cerianthid black?	1	805-815		
P4-008-d4-14+	15	v	cnidarian;anemone		anemone large orange	1	800	19 42.774	156 04.484
P4-009-d1-1	0	v	fish	eel	eel	1	610	19 42.859	156 04.309
P4-009-d1-2	0	v	cnidarian	anemone	anemone large orange	1	610	19 42.859	156 04.309
P4-009-d1-3	5	v	fish	eel	eel	1	610-750		
P4-009-d1-4	10	a	holothurian	synallactid	Paelopatides retifer	1	610-750		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d1-5	10	a	cnidarian	anemone	hormathiid sp 2?	1	610-750		
P4-009-d1-6	10	v	fish	eel	eel	1	610-750		
P4-009-d1-7	10	v	fish	myctophid?	myctophid?	1	610-750		
P4-009-d1-8	15	v	fish	fish	fish	1	610-750		
P4-009-d1-9	15	v	cnidarian	anemone	anemone large orange	1	610-750		
P4-009-d1-10	15	v	fish	fish	fish small	1	610-750		
P4-009-d1-11	15	v	fish	nettastomid	nettastomid	1	750		
P4-009-d1-12	15	v	fish	myctophid?	myctophid?	1	750-765		
P4-009-d1-13	15	v	fish	macrourid	macrourid	1	750-765		
P4-009-d1-14	15	a	shrimp	shrimp	shrimp	1	750-765		
P4-009-d1-15	20	v	fish	eel	eel	1	750-765		
P4-009-d1-16	20	v	fish	squalid?	squalid?	1	765		
P4-009-d1-17	20	v	cnidarian	ceriantharian?	cerianthid black?	1	765		
P4-009-d1-18	20	v	fish	fish	fish small	1	765		
P4-009-d1-19	20	v	fish	macrourid	macrourid	1	765		
P4-009-d1-20++	25	v	fish	macrourid	macrourid	1	795	19 43.160	156 04.617
P4-009-d1-21	25	v	fish	myctophid?	myctophid?	1	795-805		
P4-009-d1-22	25	v	seastar	goniasterid	Ceramasters bowersi?	1	795-805		
P4-009-d1-23	25	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-24	30	v	fish	eel	eel	1	795-805		
P4-009-d1-25	30	v	shrimp	shrimp	shrimp	2	795-805		
P4-009-d1-26	30	v	cnidarian	ceriantharian?	cerianthid black?	1	795-805		
P4-009-d1-27	30	v	cnidarian	anemone	hormathiid sp 2?	1	795-805		
P4-009-d1-28	30	v	fish	fish	fish small	2	795-805		
P4-009-d1-29	35	v	cnidarian	anemone	hormathiid sp 2?	1	795-805		
P4-009-d1-30	35	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-31	35	v	seastar	goniasterid	Ceramasters bowersi?	1	795-805		
P4-009-d1-32	35	v	fish	fish	fish large red	1	795-805		
P4-009-d1-33	35	v	fish	plesiobatid	Plesiobatis daviesi	1	795-805		
P4-009-d1-34	35	v	fish	fish	fish small	1	795-805		
P4-009-d1-35	35	v	cnidarian	anemone	anemone large	1	795-805		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d1-36	40	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-37	40	v	fish	macrourid	macrourid	1	795-805		
P4-009-d1-38	40	v	fish	eel	eel	1	795-805		
P4-009-d1-39	40	v	fish	fish	fish small	1	795-805		
P4-009-d1-40++	45	v	fish	macrourid	macrourid	1	795-805		
P4-009-d1-41	45	v	shrimp	shrimp	shrimp	1	795-805		
P4-009-d1-42	45	v	cnidarian	anemone	anemone large orange	1	795-805		
P4-009-d1-43	45	v	fish	squalid?	squalid?	1	805		
P4-009-d1-44	50	v	shrimp	shrimp	shrimp	1	800	19 42.896	156 04.547
P4-009-d1-45	50	v	fish	eel	eel	1	795-800		
P4-009-d1-46	50	v	fish	macrourid	Hymenocephalus sp	1	795-800		
P4-009-d1-47	50	v	cnidarian	anemone	anemone large orange	1	795-800		
P4-009-d1-48	55	v	shrimp	shrimp	shrimp	1	795		
P4-009-d1-49	55	a	fish	plesiobatid	Plesiobatis daviesi	1	800	19 42.979	156 04.578
P4-009-d1-50+++	55	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d1-51+++	55	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d1-52	55	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d1-53	55	v	fish	shark	shark large	1	800	19 42.979	156 04.578
P4-009-d1-54+++	100	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d1-55+++	100	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-1	0	v	amphipod?	amphipod?	amphipod?	3	800	19 42.979	156 04.578
P4-009-d2-2	0	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d2-3	0	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-4	0	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d2-5	0	v	fish	macrourid	macrourid	1	800	19 42.979	156 04.578
P4-009-d2-6	0	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d2-7	5	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d2-8	5	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d2-9	5	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-10	10	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d2-11++	10	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d2-12	10	v	fish	myctophid?	myctophid?	1	800		
P4-009-d2-13	15	v	fish	macrourid	Hymenocephalus sp	1	802		
P4-009-d2-14	15	v	fish	macrourid	macrourid	1	800		
P4-009-d2-15	15	a	shrimp	pandalid	Heterocarpus laevigatus	1	800		
P4-009-d2-16++++	20	v	holothurian	synallactid	Paelopatides retifer	1	800		
P4-009-d2-17	25	v	fish	myctophid?	myctophid?	1	800-805		
P4-009-d2-18++++	25	v	fish	scorpaenid	Ectreposebastes imus	1	805		
P4-009-d2-19	25	v	crab	crab	crab	1	805		
P4-009-d2-20+++	30	v	crab	crab	crab	1	805		
P4-009-d2-21	30	a	shrimp	nematocarcinid	Nematocarcinus tenuirostris	1	805		
P4-009-d2-22	35	v	none	none	none	0	805		
P4-009-d2-23	40	v	none	none	none	0	805		
P4-009-d2-24	45	v	fish	macrourid	Hymenocephalus sp	1	805		
P4-009-d2-25	45	v	fish	fish	fish small	1	805		
P4-009-d2-26	45	a	fish	plesiobatid	Plesiobatis daviesi	1	793-805		
P4-009-d2-27	45	v	cnidarian	anemone	anemone large orange	1	793-805		
P4-009-d2-28	50	v	fish	eel	eel	1	793		
P4-009-d2-29	55	v	none	none	none	0	793-800		
P4-009-d3-1	0	v/a	mollusk	cephalopod	squid unknown	1	800		
P4-009-d3-2	0	v	shrimp	shrimp	shrimp	1	800		
P4-009-d3-3	5	v	none	none	none	0	800	19 42.979	156 04.578
P4-009-d3-4	10	v	none	none	none	0	795-800		
P4-009-d3-5	15	v	none	none	none	0	795		
P4-009-d3-6	15	v/a	fish	plesiobatid	Plesiobatis daviesi	1	795		
P4-009-d3-7++	20	v	fish	fish	fish small	1	795		
P4-009-d3-8	25	v	none	none	none	0	795		
P4-009-d3-9	30	v	none	none	none	0	795		
P4-009-d3-10	35	v	none	none	none	0	785-795		
P4-009-d3-11	40	v	none	none	none	0	785		
P4-009-d3-12	45	v	none	none	none	0	785		
P4-009-d3-13	50	v	shrimp	shrimp	shrimp	1	785-800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d3-14+++	50	v	fish	plesiobatid	Plesiobatis daviesi	1	800		
P4-009-d3-15	55	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d3-16	55	v	fish	plesiobatid	Plesiobatis daviesi	1	800	19 42.979	156 04.578
P4-009-d3-17	100	v	none	none	none	0	800	19 42.979	156 04.578
P4-009-d4-1	0	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-2	5	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-3	10	v	fish	congrid?	Bathycongrus guttulatus?	1	800	19 42.979	156 04.578
P4-009-d4-4	10	v	seastar	goniasterid	Ceramasters bowersi?	1	800	19 42.979	156 04.578
P4-009-d4-5	10	v	shrimp	pandalid	Heterocarpus laevigatus	1	800	19 42.979	156 04.578
P4-009-d4-6	10	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-7	15	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-8	20	v	crustacean	crustacean	crustacean	1	800	19 42.979	156 04.578
P4-009-d4-9	25	v	fish	fish	fish small	1	795-800		
P4-009-d4-10	25	v	fish	macrourid	macrourid	1	795-800		
P4-009-d4-11	25	v	cnidarian	anemone	hormathiid sp 2?	1	795		
P4-009-d4-12	25	v	shrimp	shrimp	shrimp	1	795		
P4-009-d4-13	30	v	fish	eel	eel	1	795-800		
P4-009-d4-14	30	v	cnidarian	anemone	hormathiid sp 2?	1	800		
P4-009-d4-15	30	v	fish	macrourid	Hymenocephalus sp	1	800		
P4-009-d4-16	30	v	cnidarian	ceriantharian?	cerianthid black?	1	800		
P4-009-d4-17	30	v	fish	myctophid?	myctophid?	1	800	19 43.106	156 04.632
P4-009-d4-18	35	v	fish	myctophid?	myctophid?	1	795		
P4-009-d4-19	40	v	fish	eel	eel	1	795-798		
P4-009-d4-20	40	v	cnidarian	ceriantharian?	cerianthid black?	1	795-798		
P4-009-d4-21	40	v	shrimp	shrimp	shrimp	1	795-798		
P4-009-d4-22	40	v	fish	fish	fish small	1	795-798		
P4-009-d4-23	45	v	shrimp	shrimp	shrimp	1	798		
P4-009-d4-24	50	v	seastar	seastar	seastar	1	760-798		
P4-009-d4-25	50	v	fish	fish	fish small	1	760-798		
P4-009-d4-26	50	v	fish	eel	eel	2	760-798		
P4-009-d4-27	50	v	shrimp	shrimp	shrimp	1	760		

APPENDIX E

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d4-28	50	a	holothurian	synallactid	Paelopatides retifer	1	740-760		
P4-009-d4-29+	50	v	cnidarian	anemone	hormathiid sp 2?	1	740		
P4-009-d4-30++	55	v	cnidarian	ceriantharian?	cerianthid black?	1	730-740		
P4-009-d4-31	55	v	cnidarian	anemone	anemone red	1	730-740		
P4-009-d4-32+	55	v	cnidarian	anemone	anemone large orange	2	730-740		
P4-009-d4-33++	55	v	fish	eel	eel small	1	730		
P4-009-d4-34	55	v	fish	fish	fish small black	1	720	19 43.026	156 04.483
P4-009-d4-35	100	v	none	none	none	1	720	19 43.026	156 04.483
P4-009-d5-1	0	v	cnidarian	anemone	anemone large orange	1	690-720		
P4-009-d5-2	0	v	cnidarian	ceriantharian?	cerianthid black?	1	690-720		
P4-009-d5-3	0	v	cnidarian	anemone	hormathiid sp 2?	1	690-720		
P4-009-d5-4	0	v	fish	eel	eel	1	690		
P4-009-d5-5	0	v	shrimp	shrimp	shrimp	1	680-690		
P4-009-d5-6	5	v	cnidarian	ceriantharian?	cerianthid black?	1	680		
P4-009-d5-7+	5	v	cnidarian	anemone	anemone large orange	1	680		
P4-009-d5-8+++	5	v	fish	squalid	Etmopterus sp?	1	680	19 43.060	156 04.456
P4-009-d5-9	10	v	cnidarian	anemone	anemone large orange	1	660-680		
P4-009-d5-10	10	v	fish	eel	eel	1	660-680		
P4-009-d5-11	10	v	fish	fish	fish small	1	660-680		
P4-009-d5-12+	10	v/a	crinoid	crinoid	stalked crinoid	1	660		
P4-009-d5-13	10	v	shrimp	shrimp	shrimp	1	660		
P4-009-d5-14	15	v	shrimp	shrimp	shrimp	1	660	19 43.058	156 04.419
P4-009-d5-15	20	v	none	none	none	0	660	19 43.058	156 04.419
P4-009-d5-16	25	v	seastar	goniasterid	Ceramasters bowersi?	1	660		
P4-009-d5-17	25	v	cnidarian	anemone	anemone large orange	1	660		
P4-009-d5-18	25	v	fish	myctophid?	myctophid?	1	660		
P4-009-d5-19	25	a	shrimp	shrimp	shrimp	1	660		
P4-009-d5-20	25	a	fish	eel	eel	1	660		
P4-009-d5-21+++	25	v	fish	ophidiid	Pycnocraspedum armatum	1	660		
P4-009-d5-22+++	25	v	cnidarian	anemone	hormathiid sp 2?	1	660		
P4-009-d5-23	25	v	cnidarian	ceriantharian?	cerianthid black?	1	660		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d5-24	30	v	fish	scorpaenid	Ectreposebastes imus	1	650		
P4-009-d5-25	30	v	shrimp	shrimp	shrimp	1	660		
P4-009-d5-26	30	v	fish	fish	small fish	1	660	19 43.020	156 04.412
P4-009-d5-27	35	v	fish	ophidiid	Pycnocraspedum armatum	1	660	19 43.020	156 04.412
P4-009-d5-28	35	v	fish	plesiobatid	Plesiobatis daviesi	1	660	19 43.020	156 04.412
P4-009-d5-29++	40	v	fish	myctophid?	myctophid?	1	690		
P4-009-d5-30	45	v	fish	macrourid	Hymenocephalus sp	1	700	19 42.984	156 04.456
P4-009-d5-31	50	v	none	none	none	0	700	19 42.984	156 04.456
P4-009-d5-32	55	v	none	none	none	0	700		
P4-009-d5-33	100	v	none	none	none	0	700		
P4-009-d6-1+	0	a	fish	scombrid?	scombrid big?	1	700-755		
P4-009-d6-2	0	a	fish	plesiobatid	Plesiobatis daviesi	1	755		
P4-009-d6-3	5	v	none	none	none	0	755		
P4-009-d6-4	10	v	fish	fish	fish small	1	735-755		
P4-009-d6-5+++	10	v	fish	plesiobatid	Plesiobatis daviesi	1	735		
P4-009-d6-6	10	v	cnidarian	cnidarian	cnidarian brown	1	740		
P4-009-d6-7	15	v	fish	eel	eel	1	750		
P4-009-d6-8	15	v	fish	macrourid	Hymenocephalus sp	1	750-755		
P4-009-d6-9	15	v	shrimp	shrimp	shrimp	2	750-755		
P4-009-d6-10	15	v	cnidarian	ceriantharian?	cerianthid black?	1	750-755		
P4-009-d6-11	15	v	cnidarian	anemone	hormathiid sp 2?	1	750-755		
P4-009-d6-12	15	v	fish	macrourid	macrourid	1	750-755		
P4-009-d6-13	20	v	fish	macrourid	Hymenocephalus sp	1	760	19 42.860	156 04.485
P4-009-d6-14	25	v	none	none	none	0	780	19 42.858	156 04.484
P4-009-d6-15	30	v	fish	macrourid	Hymenocephalus sp	1	780		
P4-009-d6-16	30	v	shrimp	shrimp	shrimp	1	780		
P4-009-d6-17	30	v	cnidarian	anemone	anemone large orange	1	780		
P4-009-d6-18	30	v	fish	eel	eel	1	780		
P4-009-d6-19	35	v	fish	macrourid	macrourid	1	780-785		
P4-009-d6-20	35	v	shrimp	shrimp	shrimp	2	785		
P4-009-d6-21	35	v	fish	eel	eel	1	785		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-009-d6-22	35	v	cnidarian	anemone	hormathiid sp 2?	1	785		
P4-009-d6-23	35	v	fish	macrourid	Hymenocephalus sp	1	785		
P4-009-d6-24	40	v	fish	eel	eel	1	780		
P4-009-d6-25	40	v	cnidarian	anemone	hormathiid sp 2?	1	780		
P4-009-d6-26	45	v	none	none	none	0	780	19 43.008	156 04.548
P4-009-d6-27	50	v	shrimp	shrimp	shrimp	1	780		
P4-009-d6-28	55	v	shrimp	shrimp	shrimp	1	775		
P4-009-d6-29	55	v	fish	macrourid	macrourid	1	777		
P4-009-d6-30	100	v	none	none	none	0	780	19 42.954	156 04.553
P4-009-d7-1	0	v	cnidarian	anemone	anemone large orange	1	740-780		
P4-009-d7-2	0	v	fish	eel	eel	1	740-780		
P4-009-d7-3	0	v	fish	myctophid?	myctophid?	1	740-780		
P4-009-d7-4	5	v	cnidarian	ceriantharian?	cerianthid black?	1	740		
P4-009-d7-5	5	v	fish	eel	eel	1	700-740		
P4-009-d7-6++	5	v	fish	fish	fish unknown black	1	700-740		
P4-009-d7-7	5	v	cnidarian	anemone	hormathiid sp 2?	1	700-740		
P4-009-d7-8	5	v	seastar	goniasterid	Sphaeriodiscus ammophilis?	1	700		
P4-009-d7-9	5	v	cnidarian	anemone	anemone large orange	1	700		
P4-009-d7-10	10	v	cnidarian	ceriantharian?	cerianthid black?	1	680		
P4-009-d7-11	10	v	tunicate	thaliacean	thaliacean	1	680	19 42.945	156 04.410
P4-009-d7-12++++	15	v	cnidarian	anemone	corallimorpharian	1	680	19 42.934	156 04.409
P4-009-d7-13	15	v	cnidarian	hydrozoan	tubularid	1	680	19 42.934	156 04.409
P4-009-d7-14++++	20	v	cnidarian	hydrozoan	tubularid	1	680	19 42.934	156 04.409
P4-010-d1-1	0	v	cnidarian;anemone		anemone large orange	1	660	19 42.930	156 04.382
P4-010-d1-2	5	v	none		none	0	660-750		
P4-010-d1-3	10	v	fish		fish small	1	660-750		
P4-010-d1-4	15	v	fish;eel		eel	1	660-750		
P4-010-d1-5	15	v	fish		fish small	1	750		
P4-010-d1-6	20	v	fish;eel		eel	1	750-800		
P4-010-d1-7	20	v	fish		fish small	1	800	19 42.992	156 04.582
P4-010-d1-8	25	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800	19 42.992	156 04.582

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d1-9	30	v	fish		fish small	1	800		
P4-010-d1-10	30	v	fish;eel		eel	1	800		
P4-010-d1-11+	30	v	fish		fish unkown	1	800		
P4-010-d1-12+++	35	v	none		none	0	800		
P4-010-d1-13	40	v	none		none	0	800		
P4-010-d1-14	45	v	none		none	0	810		
P4-010-d1-15	50	v	none		none	0	810		
P4-010-d1-16	55	v	none		none	0	810		
P4-010-d1-17	100	v	none		none	0	810		
P4-010-d2-1+	0	v	fish;macrourid		Hymenocephalus sp	1	810-818		
P4-010-d2-2	0	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	818		
P4-010-d2-3	0	v	fish		fish small	1	818		
P4-010-d2-4	5	v	fish;macrourid		Hymenocephalus sp	1	818		
P4-010-d2-5	10	v	none		none	0	818-825		
P4-010-d2-6	15	v	none		none	0	825	19 43.008	156 04.612
P4-010-d2-7	20	v	none		none	0	825	19 43.008	156 04.612
P4-010-d2-8	25	v	fish;macrourid		Hymenocephalus sp	1	825	19 43.008	156 04.612
P4-010-d2-9+++	30	v	cnidarian;scyphozoan		scyphozoan	1	825	19 43.008	156 04.612
P4-010-d2-10	30	v	fish;eel		eel	1	800-825		
P4-010-d2-11	30	v	fish		fish small	1	800-825		
P4-010-d2-12	30	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	800-825		
P4-010-d2-13++	30	v	fish		fish unkown	1	800		
P4-010-d2-14	35	v	fish		fish small	1	800		
P4-010-d2-15	35	v	fish;macrourid		macrourid	1	800		
P4-010-d2-16	40	v	fish;gempylid?		gempylid?	1	800		
P4-010-d2-17	40	v	cnidarian;anemone		hormathiid sp 2?	1	800	19 43.071	156 04.608
P4-010-d2-18	40	v	fish		fish small	1	800	19 43.071	156 04.608
P4-010-d2-19+	45	v	holothurian;synallactid		Paelopatides retifer	1	800	19 43.071	156 04.608
P4-010-d2-20	45	v	cnidarian;ceriantharian?		cerianthid black?	1	785-800		
P4-010-d2-21	45	v	fish		fish small	1	785-800		
P4-010-d2-22	45	v	cnidarian;anemone		hormathiid sp 2?	1	785-800		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d2-23	50	v	fish;ophidiid		ophidiid	1	785	19 43.115	156 04.627
P4-010-d2-24	50	v	fish;macrourid		macrourid	1	785	19 43.115	156 04.627
P4-010-d2-25	50	v	cnidarian;anemone		hormathiid sp 2?	1	785	19 43.115	156 04.627
P4-010-d2-26	55	v	fish		fish small	1	800		
P4-010-d2-27	55	v	shrimp		shrimp	1	800-810		
P4-010-d2-28+	55	v	fish;myctophid?		myctophid?	1	800-810		
P4-010-d2-29	100	v	none		none	0	800-810		
P4-010-d3-1	0	v	cnidarian;anemone		anemone	1	800-810		
P4-010-d3-2	0	v	shrimp		shrimp	1	800-810		
P4-010-d3-3+++	0	v	mollusk;cephalopod		squid unknown	1	810		
P4-010-d3-4	0	v	fish;eel		eel	1	805-810		
P4-010-d3-5	0	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	805-810		
P4-010-d3-6	0	a	fish;scombrid?		scombrid?	1	805-810		
P4-010-d3-7	0	v	cnidarian;anemone		hormathiid sp 2?	1	805		
P4-010-d3-8	5	v	none		none	0	800	19 43.189	156 04.688
P4-010-d3-9	10	v	holothurian;synallactid		Paelopatides retifer	1	795-800		
P4-010-d3-10	10	v	cnidarian;anemone		anemone large orange	1	795-800		
P4-010-d3-11	10	v	fish;eel		eel	1	795-800		
P4-010-d3-12	10	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	795-800		
P4-010-d3-13	10	v	fish		fish small	1	795-800		
P4-010-d3-14	15	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-15	20	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-16+++	25	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-17	30	v	none		none	0	805	19 43.267	156 04.722
P4-010-d3-18	35	v	none		none	0	795-805		
P4-010-d3-19	40	v	fish		fish small	1	795		
P4-010-d3-20	45	v	fish;macrourid		macrourid	1	795		
P4-010-d3-21	50	v	fish;macrourid		Hymenocephalus sp	1	795		
P4-010-d3-22	55	v	none		none	0	795	19 43.282	156 04.681
P4-010-d3-23	100	v	none		none	0	795	19 43.282	156 04.681
P4-010-d4-1	0	v	none		none	0	795	19 43.282	156 04.681

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d4-2	5	v	none		none	0	795	19 43.282	156 04.681
P4-010-d4-3	10	a	fish;plesiobatid		Plesiobatis daviesi	1	795-820		
P4-010-d4-4	15	a	mollusk;cephalopod		squid unknown	1	795-820		
P4-010-d4-5	15	v	cnidarian;anemone		anemone large orange	1	820		
P4-010-d4-6	15	v	fish;macrourid		Nezumia propinqua?	1	820-850		
P4-010-d4-7	20	v	shrimp		shrimp	1	850	19 43.306	156 04.779
P4-010-d4-8	25	v	shrimp		shrimp	1	850	19 43.306	156 04.779
P4-010-d4-9	25	v	cnidarian;anemone		anemone large orange	1	850		
P4-010-d4-10	25	v	fish;macrourid		macrourid	1	825-850		
P4-010-d4-11	25	v	cnidarian;anemone		hormathiid sp 2?	1	825-850		
P4-010-d4-12	25	v	fish;gempylid		gempylid	1	825-850		
P4-010-d4-13	25	v	cnidarian;anemone		hormathiid sp 2?	1	825-850		
P4-010-d4-14	25	v	shrimp;nematocarcinid		Nematocarcinus tenuirostris	1	825	19 43.292	156 04.738
P4-010-d4-15	30	v	fish		fish small	1	800-825		
P4-010-d4-16	30	v	fish;macrourid		macrourid	1	800-825		
P4-010-d4-17	35	v	fish;eel		eel	1	800		
P4-010-d4-18	35	v	cnidarian;scyphozoan		scyphozoan	1	775		
P4-010-d4-19	35	v	cnidarian;anemone		hormathiid sp 2?	1	760		
P4-010-d4-20	40	v	fish;neoscopelid?		Neoscopelus macrolepidotus?	1	750-760		
P4-010-d4-21	40	v	cnidarian;anemone		anemone large orange	1	750	19 43.265	156 04.636
P4-010-d4-22	45	v	cnidarian;anemone		anemone large orange	1	750	19 43.265	156 04.636
P4-010-d4-23	45	v	cnidarian;anemone		hormathiid sp 2?	1	750		
P4-010-d4-24	45	v	fish;macrourid		macrourid	1	750		
P4-010-d4-25	45	v	fish;eel		eel	1	750		
P4-010-d4-26	50	v	cnidarian;anemone		anemone large orange	1	750		
P4-010-d4-27	50	v	cnidarian;gorgonian		Bathypathes conferta?	1	750		
P4-010-d4-28	50	v	sponge?;hexactinellid?		hexactinellid?	1	750		
P4-010-d4-29	50	v	cnidarian;hydrozoan		tubularid	1	750		
P4-010-d4-30	50	v	fish;macrourid		macrourid	1	750		
P4-010-d4-31	50	v	shrimp		shrimp	1	750	19 43.194	156 04.606
P4-010-d4-32	55	v	shrimp		shrimp	1	745-750		

Record #	Int	A/V	Org Type	Org Category	Org Name	Org #	Depth	Latitude	Longitude
P4-010-d4-33	55	v	fish;eel		eel	1	745-750		
P4-010-d4-34	55	v	cnidarian;anemone		anemone large orange	1	745-750		
P4-010-d4-35	100	v	fish;macrourid		macrourid	1	745-750		
P4-010-d5-1	0	v	cnidarian;anemone		anemone large orange	1	745-750		
P4-010-d5-2	0	v	fish;macrourid		Hymenocephalus sp	1	745-750		
P4-010-d5-3	0	v	fish		fish small	1	745		
P4-010-d5-4	0	v	shrimp		shrimp	2	710-745		
P4-010-d5-5	0	v	cnidarian;anemone		hormathiid sp 2?	1	700-710		
P4-010-d5-6	0	v	fish;eel		eel	1	700-710		
P4-010-d5-7	0	v	fish;gempylid		gempylid	1	700	19 43.183	156 04.549
P4-010-d5-8	5	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.183	156 04.549
P4-010-d5-9	5	v	shrimp		shrimp	1	700	19 43.183	156 04.549
P4-010-d5-10	5	v	cnidarian;anemone		hormathiid sp 2?	1	700		
P4-010-d5-11	5	v	cnidarian;anemone		anemone large orange	1	700		
P4-010-d5-12	5	v	fish		fish small	1	700		
P4-010-d5-13	10	v	cnidarian;anemone		hormathiid sp 2?	1	695-700		
P4-010-d5-14	10	v	fish;eel		eel	1	695-700		
P4-010-d5-15	10	v	cnidarian;scyphozoan		scyphozoan	1	695-700		
P4-010-d5-16	10	v	cnidarian;anemone		anemone large orange	2	695-700		
P4-010-d5-17	15	v	fish		fish unkown	1	695-700		
P4-010-d5-18	15	v	cnidarian;anemone		hormathiid sp 2?	1	695-700		
P4-010-d5-19	15	v	cnidarian;anemone		anemone large orange	1	695-700		
P4-010-d5-20	15	v	fish;eel		eel	1	695		
P4-010-d5-21	15	v	fish		fish small	1	700		
P4-010-d5-22	20	v	cnidarian;anemone		hormathiid sp 2?	1	700	19 43.374	156 04.596
P4-010-d5-23	25	v	fish		fish small	1	700	19 43.374	156 04.596
P4-010-d5-24	25	v	sponge?;hexactinellid?		hexactinellid?	1	700	19 43.374	156 04.596
P4-010-d5-25	25	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.374	156 04.596
P4-010-d5-26++	25	v	fish;macrourid		macrourid	1	700	19 43.374	156 04.596
P4-010-d5-27	30	v	fish;macrourid		Hymenocephalus sp	1	700	19 43.374	156 04.596
P4-010-d5-28	35	v	none		none	0	700	19 43.374	156 04.596

Key:

Record #: This field can be used as the index field for PIs who wish to export this file into Microsoft Access. Each record # provides the vehicle (i.e. P4 for Pisces IV), dive # (i.e. 008), tape format, tape number (i.e. d1= digital tape 1), and record number for each organism observed or mentioned on the videotapes. In addition, one or more "+" at the end of the record indicate that the image of the organism is better than average or the organism is of particular interest. Videocaptures were only made of images that were rated ++, +++, or ++++. These records will also have the exact video counter for the image in the notes section (see below).

Int: For the purpose of providing a rough estimate of the number of observations made of each species during the dive, the tape was analyzed in 5-minute intervals. Interval 0 corresponds to the 0-5 minute interval while interval 115 corresponds to the interval between 1 hr and 15 minutes and 1 hr and 20 minutes. If the PI so chooses, he can use the intervals essentially as sampling units to analyze the data.

A/V: The A/V field identifies the observation as an audio (a) or video (v) record. If v/a is the code, that means that the animal is visible on the video, however, its identification was based on the audio record.

Org Type: This field is for the two most general descriptions of the observed organism. A semicolon is used in this field and other fields as a delimiter to provide flexibility in searchs.

Org Name: This field is for the most detailed description of the organism that we could make (to genus and species when possible).

Org #: This field is for the estimate of the animal's abundance. The values are 0 (none, only used when no organisms of any species are observed in a 5 minute interval), 1 (1-5 organisms observed), 2 (6-10 organisms observed), and 3 (greater than 10 organisms observed). Again, due to time constraints, it was not possible to obtain an exact count for each species.

Depth: This field is for the depth the observation was made. When the precise depth is not known, the value will be a range between the closest recorded depths before and after the observation. All values are in meters water Depth

Latitude: The latitude the observation was made, when known.
Longitude: The longitude the observation was made, when known.

APPENDIX F: CULTURAL IMPACT ASSESSMENT STUDY

Potential Effects of the Proposed CO_2 Ocean Sequestration Field Experiment on Traditional Fishing Sites, Keähole, Kona, Hawai‘i

Prepared for:

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Introduction

The following report presents the results of a study of "Traditional Fishing Sites at Keähole, Kona: an Assessment of Potential Effects of the Proposed CO_2 Ocean Sequestration Field Experiment". The study, based on oral histories, was done by Social Research Pacific, Inc. (SRP), with the assistance of Kumu Pono Associates. It was completed for Pacific International Center for High Technology Research (PICTHR), Honolulu, Hawai‘i, in collaboration with Planning Solutions, Inc., Honolulu, Hawai‘i.

This study was completed to meet Section 106 Consultation requirements of the National Historic Preservation Act (NHPA) (under 36 CFR 800). It directly responds to requests made during the Section 106 review process of the Environmental Assessment (EA)(U.S. Department of Energy, 2000). The interviews, conducted between September 28 and October 24, 2000, were done with Hawaiian *küpuna* primarily on the island of Hawai‘i. The *küpuna* (Hawaiian elders) included those recommended by the State of Hawaiian Office of Hawaiian Affairs (OHA). The study also aimed to satisfy the Hawaii State Historic Preservation Office's (SHPO) request of identifying traditional fishing sites in the vicinity of the project area. This request was met by holding interviews with *küpuna* who have fished in and around the Keähole area, and could identify traditional fishing practices and sites.

This report presents a glimpse of the cultural resources in the area, including the *küpuna* themselves; it is by no means an exhaustive effort looking at native Hawaiian traditions and practices in the Keähole area. Following a brief introduction to the purpose of the study, project area and study approach, the oral histories are presented. The results of the study are presented at the end of this report, and include a review of the six areas identified for assessing cultural impacts.

Purpose of the study

The purpose of this study was to assess the potential effects of the CO_2 Ocean Sequestration Field Experiment on native Hawaiian cultural resources in the area. Cultural resources as pertaining to this project, includes practices, beliefs and traditions associated with an area's significance. The primary objective of the project was to gather information through interviews with individuals knowledgeable about the area and its significance as an ocean resource to native Hawaiians. The project entailed identifying individuals who could provide such information (interviewees), arranging and conducting the oral interviews, and preparation of this report. Interviews completed on the island of Hawai‘i were arranged for by Kepä Maly of Kumu Pono Associates.

Applicable Federal and State Guidelines

Federal and state guidelines for conducting social and cultural impact assessments follow the same principals and similar procedures. At the federal level, Section 106 of NHPA defines the process by which these assessments are to be completed. Given the location and goals of the project, guidelines established under the National Environmental Policy Act of 1969 (NEPA), specifically, section 40 CFR 1508.8, also apply to this study. Hawaii state guidelines help to further define the applicability of these procedures to the local context. A standard approach for evaluating direct and indirect impacts was considered inappropriate for this study since these generally address stationary and/or physical features; the project area is completely water-bound, and information on its significance is based primarily on oral histories. Given the unique nature of this project, as discussed below, state guidelines that also meet the federal criteria are considered acceptable for compliance with Section 106 procedures.

The State of Hawai‘i, under Articles IX and XII of the State Constitution of Hawai‘i (Chapter 343, HRS), requires government agencies to promote and preserve cultural beliefs, practices, and resources of native Hawaiians and other ethnic groups. As such, preparers of environmental impact assessments and statements need to study the impacts of a proposed action on cultural practices and features associated with a project area. The “Guidelines for Assessing Cultural Impacts”, adopted by the Environmental Council of the State of Hawai‘i, on November 19, 1997, identifies the protocol for conducting cultural assessments. The impacts addressed by this study look at the ocean as a cultural resource to the people of the Keähole area. Though the subject matter of the study is neither common nor usual, the project was completed following the protocol established by the Environmental Council.

The Project Area

The project area is located seaward of Kona International Airport and the Natural Energy Laboratory of Hawaii Authority (NELHA), at Keähole, Hawai‘i. Figure 4-1 shows the exact location and boundaries of the project area. The project area proper has no adjoining land boundaries, however, the nearest coastline spans over several *ahupua‘a* boundaries.

The Study Approach

An ethnohistorical approach was taken, with the primary emphasis placed on oral interviews with individuals who could share knowledge about traditional uses of the project area. Since the project area is located in the ocean, and since a major objective of the study was to identify traditional fishing sites (as requested by the SHPO), efforts were made to interview *küpuna* who had been fishermen in these waters. All of the *küpuna*, except for Eddie Ka‘ana‘ana who is from the village of Miloli‘i, have been fishing in the area since they were children. It should be noted that while the project area does not consist of any land area per se, the traditional Hawaiian system of *ahupua‘a* includes the ocean waters which front the landmass. Land resources are discussed only briefly in this report.

Both formal and informal interviews were conducted; these took place between September 28 and October 24, 2000. The goal of the formal interview was to:

1. identify traditional uses of the project area and its surrounding vicinities;
2. identify traditional fishing sites in the vicinity of the project area;
3. identify cultural features (other than ocean-bound) in the area;
4. identify stories, legends and beliefs that may describe traditional uses of the area; and
5. obtain information on if and how the proposed project may impact or effect traditional practices in the area.

While the primary method of obtaining information was through the oral interviews, the study also involved the following tasks:

1. Review of literature to identify known historical areas of significance
2. Identification and location of sources/individuals to interview
3. Conducting interviews on Hawai‘i (and O‘ahu)
4. Translation and transcription of interviews
5. Preparation of draft report

Oral Histories: Interviews with *Küpuna* and others

A total of five *küpuna*, four of whom are current residents of the Kona-Keähole area, were interviewed for this study. In addition, eight other individuals from the island of Hawai‘i shared their knowledge and information about traditional uses of the project area and its surrounding vicinities. Appendix F(1) provides a list of the names of individuals interviewed and/or contacted for this project, and their current residence.

The *küpuna* are all fishermen. All have fished off the waters at Keähole Point, some more regularly than others. They continue to fish in the Keähole area, however, more as a leisure activity than one based on subsistence. Although they differ somewhat in age and the time period during which they became fishermen, their recollections and experiences reveal a great deal of similarities. This is attributed to the consistency in the tradition and practices required for knowing (a) when, (b) where, (c) what and (d) how to fish.

Oral accounts leave little doubt that the cultural practices of native Hawaiians were passed on through the generations, and have continued with each successive generation. Interviews with family members representing more than one generation indicates the degree to which these "traditional ways of doing things" can and does persist. While much of the information shared during the interviews is based on personal accounts, some individuals also shared the lore passed on from their ancestors. Their knowledge of things Hawaiian (a.k.a. traditional) can be assumed to be remnants of how the land and the sea were used during traditional times.

The Interview process

Selection of people to interview was done primarily by locating individuals and families of Hawaiian ancestry, who had lived in the Keähole area and/or had knowledge about the waters off of Keähole Point. OHA was first contacted for recommendations of individuals to interview. As mentioned earlier, interviews with *küpuna* on Hawaii were identified and arranged for by Kepä Maly.

After personal introductions, the interviews proceeded with a summary presentation of the project (including a map of the project area), followed by recollections and narratives of the traditions and uses of the area. The final portion of the interviews entailed questions and answers directed at the interviewer about the project. This allowed the interviewer to elicit responses directed towards whether there would be specific cultural impacts as a result of the project.

In addition to formal interviews, numerous discussions and informal interviews were held with individuals and groups who provided names of Hawaiian *küpuna* and/or knowledgeable community residents. Among these were individuals who have knowledge about the proposed project and shared their views, not necessarily based on personal experience in the area, but on the basis of knowledge and interest in the general cultural traditions and practices of Hawaiians.

Results of the Study

The oral interviews allowed the opportunity to gather information which supplement existing written histories of the project area and its vicinities. The significance of the interviews with the *küpuna* is that these are men who are actively [still] using the waters in and around the project area for their fishing activities. Traditional, and current, fishing sites in the Keähole area are numerous. Many of these sites have been previously documented (see the narratives of J.W.H. Isaac Kihe and John Ka‘elemakule, recently translated by Kumu Pono Associates, in Appendix F(2)).

Responses to known or recorded information (e.g., written accounts, historical literature and archaeological findings) and new information resulting from the interviews are grouped into three areas: deep-sea fishing, near shore fishing and Keähole Point. These areas summarize the types of "traditional uses" that can be recalled or verified from the area, and are not meant to be exhaustive of all possible types of traditional activities. The author fully acknowledges that near shore and land-based cultural resources, e.g., Keähole Point, would not be separated in the context of an *ahupua'a*, in other circumstances. This section is presented by using direct quotes (cited in quotations, with bullets) from the *küpuna*, combined with general descriptions and discussions.

Deep Sea Fishing This is within the immediate vicinity of the proposed project area. All of the *küpuna* recall fishing from Keähole out to the deeper ocean. It is an area where both traditional and modern types of fishing continue to the present day. As some of the narratives tell, traditional methods and knowledge that identified where to fish and what to fish for, hold greater value than modern methods for deep-sea fishing. Using a 1981-82 Loran marker map (provided by Valentine Ako), the fishermen were describing the *'ahi* grounds that extend from Kïholo to Keähole. Among the observations shared by *küpuna* Robert Punihaole, George Kahananui, Valentine Ako, and John Ka'iliwai, were the following:

- "The traditional fishing grounds extended well beyond the 1+ mile marker shown. The main current heads north…these are where the *aku* grounds are…north side of the island. This area was once both *aku* and *ahi* grounds. Hawaiians used to go fishing way out…maybe about 5-6 miles, and would judge their whereabouts by the clouds. If you weren't with an experienced navigator, you'd be dead out there."

- [For] "Deep Sea Fishing today, you gotta go look where they stay…we used to walk with the fish…today you gotta go look where they stay. I used to be able to tell him [*küpuna* Punihaole pointing to his son, Kalei] to go fish for *äholeahole* anywhere. Today I can drive for two hours, but still see no fish. Where the fish all bite, there's no more the numbers you used to see. You would be able to see acres of *'ahi*. There were times outside of Keähole, fish would come in a 'ball' and you could scoop them up with a bucket. You'd catch no water, only the fish. Its not there no more."

The following excerpt from Kona elder, John Ka'elemakule (1854-1935) tells of the importance of deep-sea fishing in the earlier part of this century:

> Let me tell about the customs of fishing in the deep sea, for these are among the things that were practiced by my foster father Kaaikaula, and that he taught to me. Among the important fishing practices of Kekaha, that I was taught in my youth were *aku* fishing, *ahi* fishing, and fishing for *'öpelu* with nets. These were the important fishing customs that I was taught… Fishing for these fish was done at the *ko'a 'öpelu* (*'öpelu* fishing station or grounds), that was not too far out. And beyond that, was the *ko'a* for *aku* and *'ahi* fishing. The *ko'a* for these fish (the *'ahi* and *aku*), was the famous *ko'a lawai'a* (fishing ground) of Kekaha, known by the name, "Haleohi'u…" (in *Ka Hökü o Hawai'i*, November 13, 1928:3; translated by Maly).

<u>Koʻa – traditional fishing grounds or stations</u>

Koʻa are fishing grounds or stations out at sea, and knowledge about them is passed on through generations of fishermen. There were and are several within the boundaries of the project area, that are used currently by fishermen. The following narrative from Kihe (in *Ka Hökü o Hawaiʻi* – translated by Maly), describes the *koʻa* off of Keähole; some of these same *koʻa* were referenced by the *küpuna* during the oral history interviews:

> It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (*ka wili-au*) that flow with the passing current… And there in front of this point, in deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (*muliwai*), and then flow out. It is on that side, that you will find the *koʻa* (fishing stations) for *aku*, *ʻahi*, *kähala*, *ʻöpakapaka* and such. Among these *koʻa* are Päoʻo, ʻÖpae, Kahakai, Kapapu, Kanaha-ha, Kaluahine, Kanukuhale, Kahoʻowaha, Honu, Muliwai (from where one peers upon the dirt of Häʻena, Kohala), and Kaihuakalä, Maui… There are many other *koʻa*, but these that I've mentioned, are the famous *koʻa*. There are many deep *koʻa* all in a line, from the Point of Keähole to the Point of ʻUpolu and the *heiau* of Moʻokini in Kohala (Kihe, October 11-18, 1923).

The following excerpt from the tradition of Ka-Miki (in *Ka Hökü o Hawaiʻi*; 1914-1917 – translated by Maly) tells of the *koʻa* in the Keähole area:

> …In no time the canoe was filled with more than 400 *aku*. An amazing thing is that though Pili's fishermen and all the fishermen of Kekaha were fishing at Kakaʻi, Kanähähä (Haleʻohiʻu), the entire ocean from the *koʻa* of Kapapu (Keähole vicinity) to Kahawai (at Kaʻüpülehu); none of them caught any fish at all…The *aku* school was at the *koʻa* of Päoʻo, also known by the names Ka-nuku-hale and Päoʻo-a-Kanukuhale; the bonito lure fishing grounds which extended from Kaulana to Hoʻonä, fronting Keähole, which is the source of the (supernatural) currents Ke-au-kä…(Kihe & Wise *et al*. in *Ka Hökü o Hawaiʻi*; October 11, 1917)

The *küpuna* discussed how more than one *koʻa* could be used…this knowledge is still applied to deep-sea fishing today:

- "We used about 3 or 4 koʻas to fish in the Keähole area….that whole area was all our fishing grounds and I would not want any desecration in that particular area. We used to fish all the down from Kïholo down to Keähole. This included swordfish, *ʻahi* (*kabachi shimi*)…that type of *ʻahi* didn't have a yellow fin and would grow up to only 90 lbs… *kü kaula* fishing (about 25 to 70 fathoms). The schools would be along the ledge. If you came in, you'd catch *ulua*. When the *ʻahi* bite, you never let ʻem go down again, other wise burn, the meat…"

- "Depending on what type of fishing you're doing, you go out farther or not. *ʻÖpelu* was closer…you go farther out, you get larger fish like *kawakawa* and *ulua*, still

> further off, you get much larger fish. The *ko'a* out there [pointing near the point], is the *ko'a weke;* way inside from 15 to 35 fathom, you can get *weke la'o*."

Along with knowledge about when and where to fish, the *küpuna* shared some of their traditional methods of attracting and replenishing fish. First, the bait they used was always fresh. They never used *pilau* (stink bait or rotten bait) for catching fish. The *küpuna* stressed how important it was to show respect of eating fresh food…the same courtesy was extended to the fish also.

- "In the younger days, old stink bait was never used; stale bait brings on the sharks. And if you feed dirty food to your fish, you'll eat the dirt as well… We never use pilau, or what this generation now calls '*make* dog.' We cared for the ko'a, and would not pollute it…"

Along with using fresh bait, feeding the *ko'a* on a regular basis was also done traditionally…

- "To keep them at home, we'd go feed the *ko'a*. These would extend from near shore at Keähole to Honoköhau, on the south, and from Keähole to Makalawena and Küki'o on the north. The *ko'a 'öpelu* at Honoköhau was not too far away from shore. They feed the main *ko'a*. From the black sand of *Pelekane* (on the boundary of Haleohi'u and Maka'ula), all the way down, all the *ko'a* along there would be fed. We'd go out about 100 yards to up to 2 miles out. The formation of the ground is what determined the path we'd take. We would also *ho'omaha*, let the grounds rest…[we] were careful about what we took."

Near Shore Fishing. Use of the near shore area for fishing continues to the present day. Both modern and traditional fishing methods are used. [Although the near shore fishing resources would not appear to have direct impacts, deeper currents are known to carry to the shoreline areas.] Among the most popular form of near shore canoe fishing (any where from a few hundred yards to a mile off shore) was for *'öpelu*. As told in the following text by John Ka'elemakule (in *Ka Hökü o Hawai'i*; translated by Maly), the Kona area was noted for *'öpelu* fishing:

> …*'Öpelu* fishing was another one of the important practices of these islands in ancient times; it was perhaps the foremost of the practices in the streaked sea (*kai mä'oki'oki*) of Kona. It became the type of fishing that contributed to the livelihood of the fishermen and their families… For *'öpelu* fishing, two men are adequate in going on the canoe to the place of the *ko'a 'öpelu* which has been known since the days of the ancient people. It is at a place where one can look below and see the fish, that he prepares to feed the *'öpelu*. The man at the front of the canoe is the fisherman, the one who is prepared for this manner of fishing, he leads in all things for this kind of fishing.
>
> There in front of the fisherman was set out the bait of the *'öpelu*, that is the *'öpae 'ula* (red shrimp) and sometimes other baits as well. He'd give the man at the back of the canoe the bait, this man would do whatever the fisherman told him to. The man in the back had a stone weight, the black dirt, and the coconut sheath in which the *'öpae 'ula* or other bait would be placed and

folded in. This would be wrapped with cordage and let down into the water about 2 or three fathoms deep, then the man would jerk the cord and the bait would be released… (March 5, 1929:4)

The *küpuna* recall that there were plenty of *‘öpelu* fishermen in Kailua. Among them were George Ka‘iliwai (John Ka‘iliwai’s father), Hattie Hart, and Kolomona Ka‘elemakule. They recall using *limu* and *‘öpae ‘ula* for catching *‘öpelu*:

- “You could see the *‘öpelu* on the surface. Depending on what type of fishing you’re doing, you go out farther or not. *‘Öpelu* was closer in (about 40 feet)…the *ko’a weke*, is way inside from 15 to 35 fathom; you can get *weke la‘o*. I used to fish by myself… At another noted place, just north of Keähole, we caught the *kole nuku heu*. It’s light brown color – about 15-30 feet deep. I don’t know if these fish are still there.”

Eddie Ka‘ana‘ana, once an avid *‘öpelu* fisherman, emphasized the importance of the technique/method used for*‘öpelu* fishing. This included not just knowledge about the area, the *ko’a*, but also knowledge that could be applied when fishing for *‘öpelu* on any of the islands.

Val Ako remembers Kipi Wa‘ahila as the first person to catch Kona crabs.

“…Kipi had a *koa* canoe that he would go out in all the time. He always took plenty dry coconut with him and guava sticks. He would go out there and prepare the nets and everything. He’d come home loaded with Kona crabs, ‘and not the small kind eh’. We had a smart man, Ernest Pua, he asked Kipi how he caught the crabs, and finally Kipi told him. Ernest made the nets and began catching them by larger numbers. Later, there was a Filipino man hanaied by a Hawaiian family in Wai‘anae. He knew that Wai‘anae coast also had Kona crabs, and began fishing for them there. ‘Now they’re wiped out in Wai‘anae too’. Now in Kaua‘i, my fishermen friend, they catch Kona crab, and say that every time they catch Kona crab, they use fish head and smelly things.”

Keähole Point According to *kupuna* Kinoulu Kahananui, Keähole translates as **—** *Ke* (the), *ä-hole* (water banging together, twisting). *Ä-holehole* means “water banging, twisting together”, where two currents blend together...“Very seldom is the area there calm, its usually bubbling, boiling.” The naming of Keähole is not after the fish *äholehole*, but after these unique currents. *Kupuna* Kahananui had previously provided an extensive description of the naming of Keähole to Kepä Maly; this can found in Appendix F(3).

While discussing the nature of the sea and currents at Keähole, and the divisions of the fisheries, the *küpuna* also commented:

- “…We can go down there right now, to Keähole Point, and look and see right in front of your eyes. Very seldom is it calm; most of the time its boiling, boiling…”

- “…Keähole was also the division for various fish. The people of Makalawena fished to the north of Keähole. These were traditional boundaries observed by all fishermen of the island….”

<u>The Currents off Keähole</u>

The following description of Keähole was written by J.W.H. Isaac Kihe (in *Ka Hökü o Hawai'i* – translated by Maly):

> That stone which is situated in front of the Point of Keähole, is called by its name Keähole, and it is for this stone that the point is called Keähole to this day…(Kihe in *Ka Hökü o Hawai'i*; October 11-18, 1923).

The *küpuna* recall that there are special currents off of Keähole Point; where they meet, you can see "boiling". This place is referred to as *Lelewai*, where the water leaps, "boiling" area. (Ho'onä is the calm place and it is to the right of this current).

The importance of Keähole's unique currents is captured in the following excerpt from Kihe (ibid.):

> It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current… (Kihe in *Ka Hökü o Hawai'i*; October 11-18, 1923).

The story of Ka-Miki also tells of the significance of Keähole's currents:

> …the bonito lure fishing grounds which extended from Kaulana to Ho'onä, fronting Keähole, which is the source of the (supernatural) currents *Ke-au-kä*, (The current which strikes), *Ke-au-käna'i* (The current of smooth waters), and *Ke-au-miki* (The current which pulls out to the deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by Mäkälei… (Kihe and Wise *et al*. in *Ka Hökü o Hawai'i*, October 11, 1917; Maly translator).

The *küpuna* also spoke of stories they were told about the old fishpond [*Pä'aiea*], which was buried under the flow of 1801.

- "The canoes actually came into the fishpond, inland from the current, and then went back out. It was easier coming in and going back out then to go around because of the current. They used *Pä'aiea* fishpond, to get back to land".

According to the *küpuna*, currents were also very significant in determining which place to fish. The location of *'öpelu* could be determined by the current/undercurrent. Currents also have tremendous influence on the nutrients for the fish, and on the availability of fish.

- "The current off Keähole Point, the white current (appears to be approximately 100 yards offshore), is where *'öpakapaka*, *'ula'ula*, and *kümü* are found. It's already very deep out there… There's also a 'dead spot' near Kawaihae…an area they all got to know, and stayed away from (an area where there is no fish)."

- "It's like a good [the nutrient value] *ko'a*, the fish bite all the time. If the current's not right, you can sit there 2 to 3 hours and nothing will happen. When the current starts to move however, you're only given about 1-1/2 hrs. to fish and its plenty good at that time."
- *"Kona kai mä'oki'oki* (the streaked sea of Kona) is so named because of the current lines [from Kekaha, the *küpuna* point out to where these black current lines appear off of Keähole]. These black lines reflect the formation of the ground. When you see an upwelling in the current, that's when the nutrients are coming up for feed."
- "Observing of currents could be done both by watching the waves from markers on shore and from out at sea."

Once out at sea, the currents had an influence over how and when the fishermen could come back to shore. The following description of "Ho'onä indicates that it offered a place of refuge when the waters became too rough:

- "Ho'onä was the place where the water would stay calm… About ¾ to a mile out in the sea, is where the waters mix and be so rough. We had a song for Kona that we used to sing when fishing out there. When it came too rough, we would go in to Ho'onä for shelter because we couldn't come back in towards Kailua. We could be stuck there for about 4-5 hours and the captain said that we should get back before dark fall [when the lights go out…during the war period]. Ho'onä is a quiet area, so it was used as a waiting grounds before trying to go back into the landing."

Along with deep sea and near shore fishing practices, the following types of subsistence activities related to fishing, took place off and near the shores of Keähole in traditional times:

1. Shellfish collecting (Kona crabs, *'öpihi*, *wana*)
2. Limu gathering
3. Gathering salt from salt pans

Some of these practices, such as gathering salt and *limu*, continue today. Practices that have been abandoned are due to a variety of reasons, including lesser availability of and/or access to resources. Although *Pä'aiea* fishpond no longer exists, it is referenced as a source for subsistence activities in traditional times.

<u>Archaeological and Historical Features in the Keähole area</u>

Although the project area will not have a visible physical impact on the land, the Keähole area is also known for several archaeological and historical features; these are briefly mentioned here. These include the *Mämalahoa* (the old government road) and the *ala loa* (now referred to as *ala Kahakai)* trails. Val Ako, who was born in 1926, remembers that there were various trails leading from Keähole to Hualälai. He remembers, "there were boulders, stepping stones all the way up Hualälai Mountain…they're all gone…they were all blue rock". Though no remnants appear to exist of the fishpond of *Paaiea*, stories about it have passed down through the generations. An extensive description of *Paaiea* fishpond is found in Appendix F(2) (see *Ka Loko o Paaiea*). As indicated in the following narrative by

Kihe (in *Ka Hökü o Hawai'i* – translated by Maly), among the cultural features in the area were:

> It was at Ho'onä that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one the canoe landings of the place. Today, it is where the light house of America is situated. Pelekäne is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *pähoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today. (J.W.H.I. Kihe in *Ka Hökü o Hawai'i*; compiled from the narratives written February 5-26, 1914 and May 1-15, 1924).

Previous oral interviews with area residents also tell of a possible *Könane* board (ancient Hawaiian checkerboard), located in fairly deep water off the shoreline, and burial sites in the area (see Dye and Prasad 2000). These features have not yet been confirmed by archaeological studies.

<u>Documentary Information</u>

Although a comprehensive review of written accounts of the project area was beyond the scope of this study, among written sources that tell of the traditional significance of this area, are the translations completed by Kumu Pono Associates (1998). These include the writings of J.W.H. Isaac Kihe and John Ka'elemakule, native authors writing in Hawaiian newspapers between 1907 and 1929. Portions of their narratives have been cited in the body of this report; the complete narratives are found in Appendix F(2).

Oral histories, other than those completed by Maly, include "A Social History of Kona: Vol. 1 and II". This report presents the results of an oral history project done with residents from the Kona area, by the Ethnic Studies Program at the University of Hawaii (1981). Its emphasis is on the general experiences of these individuals and includes accounts of non-Hawaiian residents. A review of this report helped gain background information on individual's recollections of the history of this area. While little information was provided on issues relating to shoreline access or historical sites, individuals of Hawaiian ancestry in particular, elaborated on land use in the area in the earlier part of the 20th century. Fishing was a "chief livelihood" at the turn of the century, and "the shores were lined with coconut which the Hawaiians used for food and a variety of other means" (1981:A6). Also, ethnic breakdowns indicate changes that were taking place in the Hawaiian community, who numbered only 20 by 1932. In comparing this figure with informants' [from the current study] recollections about settlement in the area, the numbers do not appear to adequately represent the rather large Hawaiian community in the Kona area. Otherwise, the 1981 interviews do indicate the importance of fishing for Kona-area residents.

In addition to oral histories from individual sources, documentation exists on traditional fishing rights in the area; these were established during Kamehameha III's rule. The *konohiki* fishing rights granted use of the area extending from the beach to the outer edge of the reef, or one geographic mile seaward. Kamehameha III also recognized traditional deep sea fishing grounds (*ko'a*), in waters up to 1,800 feet (MacKenzie 1991 in U.S. Department of Energy, 2000).

Summary: Assessing the Potential Effects to Cultural Resources in the Project Area

Based on information gathered from interviews with Hawaiian *küpuna* and members of the Hawai‘i community, the project area is highly significant as a traditional (and current fishing) site for native Hawaiians. It is also, largely by association, connected to a larger repertoire of traditions and practices associated with the lands of the area. The interviews provided both new information and enhanced information known from previous written accounts.

Potential Effects to Traditional Fishing Sites

Given the experimental nature of the proposed project, the potential effects of CO_2 sequestration on traditional cultural resources (e.g., fishing sites) are difficult to determine at this stage. Even if the project was not experimental in nature, the dynamic conditions of the sea (movement of water, weather conditions, nutrient quality, etc. at any point in time) itself create an unpredictable context in which to make adequate analyses. For the same reasons, it is equally difficult to comment on short or long-term effects of the proposed project on [culturally] valued ocean resources.

However, what is known is the area’s value as a cultural resource. Both traditionally and currently, oral histories tell of the significance of the waters off Keähole Point. Any activity that compromises or changes the nature of this resource, can be seen as having a negative impact. These compromises/changes can include: accessibility to the resource, availability of the resource, and temporary or permanent changes to the quality of the resource.

While an adequate evaluation of potential effects to cultural resources cannot be made in this study, the interviews indicate that overall, there is strong sentiment against the proposed project. These areas concerns/issues raised can be grouped into four major categories:

1) the absence of knowledge or lack of knowledge about the proposed project;
2) the possible negative impacts the experiment may have on the fisheries and waters in the area;
3) a lack of understanding about the area; and
4) the current impacts on the fisheries.

It should be noted that none of the *küpuna* interviewed were aware of the project prior to this study, and that, the information they shared about the traditional practices and beliefs of the area preceded any discussions about the proposed experiment. The latter was done to achieve the goal of identifying native Hawaiian traditions and beliefs associated with the project area without bias; presentation of the proposed experiment was not an objective of this study.

Absence of knowledge or lack of knowledge about the proposed project

With the exception of a few members of the community who have been following the proposed project and are interested in its progress, others interviewed, specifically the *küpuna*, expressed that there has been a complete lack of communication with the community about the project. A recurring question raised by interviewees was what is the material [in reference to CO_2] and from where is it being brought in. They feel that a meeting and presentation of the project should be made by the designers of the project. [Although recommendations are not within the scope of the current study, it is felt that information shared on a first-hand basis would be highly welcomed by the *küpuna*. All of them expressed their willingness to hear and learn more about the proposed experiment.]

Possible negative impacts the experiment may have on the fisheries and waters in the area

Since the area is a highly valued fishing grounds, the implications and possible deleterious effects of the proposed project on the fisheries, are in question. There is fear and doubt, some of it due to past experiences with projects done in the area. Cited was the example of the *taape*, a fish from Tahiti that was apparently introduced to Hawaiian waters in an effort to help replenish local stocks. Since its introduction, the numbers of *taape* has quickly risen, possibly due to its predatory nature on indigenous fishes.

There is great concern about the impact on the fisheries in the area; the “unknowns” associated with the experiment worry these *küpuna* fishermen. In the absence of knowledge about the proposed project, the idea of an “experiment” increases doubts and questions about its possible effects. The two questions most often repeated were:

1. why is the experiment being proposed for this area specifically Kona, and for the island of Hawaii in general?
2. what assurance is there that the experiment won’t backfire? (Comparisons were made to the problems resulting from introduction of the *taape*).

A lack of understanding about the area

There is specific information about the project area that better describes sites and features which make the waters off of Keähole Point a special fishing grounds. This information known and described by the *küpuna* (fishermen), is not shown on the map prepared for the Environmental Assessment (U.S. Department of Energy, 2000) of the project area. [If a presentation of the project is made to the *küpuna*, this information on traditional areas and practices, can be collected and illustrated].

Another concern was the lack of application of the concept of *ahupua‘a* to the project area. Traditional and cultural customs and practices involve addressing the entire *ahupua‘a*. The project area adjoins a landmass which covers several *ahupua‘a* (as with Kona International Airport and NELHA). Since these waters are considered within this traditional designation, the broader context of an *ahupua‘a* may need to addressed.

Current impacts on the fisheries

An area of major concern to *küpuna*, fishermen and residents in the Kona area is the impacts of existing activities (not related to the proposed project) on the fisheries in this area. This is based on (a) an actual supply [reduction] of resources, and (b) limited or restricted physical access to shoreline areas known previously as prime fishing grounds. The reduction in the supply of fish resources is associated with general competition from other fishermen (both subsistence and commercial), changes in fishing techniques (use of drift nets), change in the quality (nutrients) of the waters, and the activities of NELHA. Although these changes are related to other events, in general, people see NELHA's use of the area has having seriously changed the availability of ocean resources in the Keähole area.

An example of changes attributed directly to the presence of NELHA is cited by *küpuna* Ako. According to him, a black sand beach beyond Keähole lighthouse that was a very good fishing ground, was completely destroyed during NELHA's attempts to raise algae. Also, there was easier and greater access to salt ponds in the area; some of these have completely disappeared or are no longer good areas for collecting salt. While these issues may not be directly related to the proposed project, the events are etched in the minds of these *küpuna* and residents.

In addition to the concerns and issues raised by Hawaiian *küpuna* relating directly to the proposed CO_2 experiment, issues and interests of Hawaii based organizations that address impacts on cultural resources, may also need to be considered. Among these are Public Access Shoreline Hawaii (PASH), and the *Kohanaiki Ohana;* both groups are concerned with traditional and cultural rights of Hawaiians in the Kona area (c.f. Native Hawaiian Bar Association, 1997; Office of Planning, 1998). PASH in particular is concerned with (a) limited access to the shoreline within the vicinity of Kona International Airport, (b) access to prime fishing grounds, and impacts to aquifers and sea beds, and (c) boundaries compromised and/or seen as inseparable from NELHA.

<u>Application of the Environmental Council Guidelines for Cultural Impact Assessments:</u>

Efforts were taken to meet the Environmental Council's guidelines for conducting cultural impact assessments. An evaluation of the council's six-point protocol is offered below. As noted in the introduction and preceding section of this report, a standard approach for identifying direct and indirect (potential) impacts was not considered appropriate for this study since the project area is completely water-bound, and information that tell of the area's significance are connected almost exclusively to oral accounts. There are no stationary or physical features per se.

1) Efforts were made to contact individuals and organizations that have expertise concerning the types of cultural resources, practices and beliefs found within the vicinity of Keähole (these include the *ahupua'a* of Makalawena, Mahai'ula, Haleohi'u, Kalaoa, 'O'oma and Kohanaiki), and the island of Hawai'i.

2) Efforts were made to select individuals who specifically had knowledge of the proposed project area; this included contacts made with six *küpuna* from the island of Hawai'i. (Interviews were completed with five).

3) Formal oral interviews were conducted with seven informants with historical knowledge about the area. In addition, seven informal interviews and discussions were held with individuals who may have had some knowledge about the area, and/or could recommend bearers of cultural information.

4) Documentary research, particularly on the location of cultural and historical uses of the area, was conducted on O'ahu and Hawai'i.

5) Cultural resources (land-based) in the project area are briefly referenced in this report, and are not seen as a major component of the current study's purpose.

6) The summary above is considered an appropriate conclusion since it was not the goal of this study to conduct a comprehensive Cultural Impact Assessment but rather to identify cultural resources (practices, beliefs and traditions) in the project area.

The preceding presentation and discussion have also fulfilled the SHPO's request (in response to the Section 106 review process) of identifying traditional fishing sites in the vicinity of the project area. This includes narratives by the *küpuna,* and references from a limited number of written sources on traditional fishing grounds/stations (*ko'a*) and the currents off of Keähole Point, and the general vicinity of the project area.

Conclusion

The study found that the point of Keähole and the deeper waters surrounding it are prime fishing grounds. It is very likely, that all islands have such "special places". [According to *küpuna* Eddie Ka'ana'ana, rich *'öpelu* grounds are found on nearly all of the Hawaiian Islands]. And while this may not be the only grounds for highly valued fish such as *aku, 'ahi* and *'öpelu,* on the island of Hawai'i, it has continued to be the preferred fishing grounds from traditional to modern times for these and other fish.

The most significant cultural/traditional feature is the *ko'a* – fishing grounds/stations at sea, that lie within the boundaries of the project area. Although the frequency of their use may differ between generations and fishing objectives, knowledge about them and their significance has carried into the present times. The most significant cultural practice is fishing – through time this has ranged from being subsistence-based to a highly valued sport. It is also a common commercial activity in the project area. The most significant aspect of the cultural lore, as it pertains to the physical uniqueness of the project area, is knowledge about the currents. Lastly, the *küpuna* themselves are a highly valued cultural resource.

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Appendix F(1)

Individuals Contacted and Interviewed

Name	Position/Title	Residence
Valentine K. Ako	*Kupuna* (born and raised in Kona)	Kaua'i
Robert Ka'iwa Punihaole Sr.	*Kupuna*	Kekaha
George Kinoulu Kahananui Sr.	*Kupuna*	Kekaha
John Hills Ka'iliwai	*Kupuna*	Kona
Frances Keanaaina	*Kupuna*	Kona
Kepä Maly	Oral Historian	Hilo
Eddie Ka'ana'ana	*Kupuna* (born in Miloli'i)	Oahu
Mauna Roy*	*Kupuna*	Kona
Mikihala Roy	Director, Kulana Huli Honua	Kona
Hanohano Punihaole	Educator	Kekaha
Kalei Punihaole	Commercial fisherman	Kekaha
Isaac Harp	Hawaiian Fisherman and Cultural practitioner	Maui
Elizabeth Ako	family member	Kaua'i
Edna Punihaole	family member	Kekaha
Annie Coelho	family member	Kekaha
Hannah Springer**	Native resident of Kekaha Kukui'ohiwai	
Angel Pilago**	Hawaiian advocate/practitioner	

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* An in-person interview was not possible during the study period.
** Attempts to contact and interview these individuals were not successful.

Appendix F(2)

THE FISHERIES AND LANDS OF KEKAHA: AN OVERVIEW OF TRADITIONS RECORDED BY NATIVE RESIDENTS

(compiled by Kepä Maly[38])

The following narratives are excerpted from several native traditions and historical description of the lands, fisheries and practices of native residents of the Kekaha region, North Kona, Hawai‘i (with emphasis on the lands and fisheries of Kalaoa and vicinity). The original texts were written by native writers (residents of Kekaha), and published in the Hawaiian language newspaper, *Ka Hökü o Hawai‘i*. The translations were prepared by Kepä Maly as a part of ethnographic studies and oral history interviews which he has conducted since 1991.

About the Native Authors

In the period from ca. 1907 to 1929, J.W.H. Isaac Kihe (who also wrote under the penname "Ka-‘ohu-ha‘aheo-i-nä-kuahiwi-‘ekolu") and John Ka‘elemakule, who independently and in partnership with Reverend Steven Desha Sr. and John Wise[39], wrote detailed historical accounts in Hawaiian language newspapers. Their rich narratives provide readers with important documentation regarding the importance of the Kekaha fisheries, and provide important site-specific documentation pertaining to *ko‘a* (fishing stations – both in the sea and markers on land), as well as documentation regarding traditional beliefs, customs, and practices associated with these features and resources.

While providing important documentation, the following narratives are in no way complete, and additional documentation has been, and may still be recorded in oral history interviews with elder native Hawaiian residents of Kekaha.

"Ka‘ao Ho‘oniua Pu‘uwai no Ka-Miki"
(The Heart Stirring Story of Ka-Miki)

…Ka-Miki had his companions Uhalalë and Uhalalï board the canoe, and told them not to sit on the seat lest they fall from the canoe (October 4, 1917). With one push, Ka-Miki had the canoe beyond the shoreward waves, with two dips of the paddle, they passed Kaiwi Point (at Keahuolu). Upon reaching Ahuloa Ka-Miki opened the *hökeo pä hï aku* (bonito lure container) in which the supernatural lure Kaiakeakua was kept. Ka-Miki then commanded that Uhalalë and Uhalalï paddle the canoe. Though these two paddled with all their might, the canoe only moved a little. Ka-Miki then chanted out to his shark *‘aumakua Niho‘eleki — mele ‘aumakua, mele lawai‘a*:

I Tahiti ka pö e Niho‘eleki	Niho‘eleki is from ancient Kahiki,
I hana ka pö e Niho‘eleki	Niho‘eleki is founded in antiquity
Lawalawa ka pö e Niho‘eleki	Niho‘eleki is bound in antiquity
Mäkaukau ka wa‘a la e Niho‘eleki	Niho‘eleki has made the canoe ready
O ke kä o ka wa‘a ‘ia e Niho‘eleki	The canoe bailer is Niho‘eleki's
O nä hoe a Ka-Miki	The paddlers are Ka-Miki's

[38] *Kumu Pono Associates* – 554 Keonaona St. – Hilo, Hawai‘i 96720 – (808) 981-0196 – kepa@interpac.net

[39] Kihe and Wise were highly regarded for the knowledge of native traditions, and were primary translators of the "Fornander Collection of Hawaiian Antiquities and Folklore" (1916-1919).

O Uhalalï a me Uhalalë	They are Uhalalï and Uhalalë
O ka pä hi aku o Kaiakeakua	The *aku* lure is Kaiakeakua
Akua nä hana a ke Aku i këia lä	It is a gods work of securing the *aku* on this day
He ʻïlio nahumaka ʻai kepakepa	[Fish] Like a fattened dog to be chewed to pieces
ʻAi humuhumu, ʻai kukukü	Consumed voraciously – noisily
Kuʻi ka pihe, he pihe aku	The din of voices spread, carried about
O ke aku mua kau	It is the first caught *aku*
ʻÖʻili kähi, pälua, päkolu	Which appears once, twice, three times greater than the rest
O ke aku hoʻolili la	The *aku* which ripples across the ocean surface
O ke aku kaʻawili	The aku which twists in the water
O ke kumu o ke aku la	It is the lead *aku*
o Kumukea-Kähuli-Kalani	Kumukea-Kähuli-Kalani…[40]

When Ka-Miki finished his chant, the *aku* began to strike at the canoe, and Ka-Miki told Uhalalë *mä* to take the first caught and place it in a gourd container. After this the *aku* rose like biting dogs, tearing at the water, and Ka-Miki moved like a swift wind. In no time the canoe was filled with more than 400 *aku*. An amazing thing is that though Pili's fishermen and all the fishermen of Kekaha were fishing at Kakaʻi, Kanähähä (Haleʻohiʻu), the entire ocean from the *koʻa* of Kapapu (Keähole vicinity) to Kahawai (at Kaʻüpülehu); none of them caught any fish at all.

The *aku* school was at the *koʻa* of Päoʻo, also known by the names Ka-nuku-hale and Päoʻo-a-Kanukuhale; the bonito lure fishing grounds which extended from Kaulana to Hoʻonä, fronting Keähole, which is the source of the (supernatural) currents *Ke-au-kä*, (The current which strikes), *Ke-au-känaʻi* (The current of smooth waters), and *Ke-au-miki* (The current which pulls out to the deep sea). These are the currents of that land where fish are cherished like the *lei hala* (pandanus *lei*) worn close to the breast, the fish cherished by Mäkälei. Ka-Miki then turned the canoe and landed at *Nä Hono ʻElua* (the two bays) also called *Nä Honoköhau* (Honoköhau), Ka-Miki divided the fish between the family of the chiefess Paehala and people of those lands (October 11, 1917).

Ka-ala-püʻali and Kanähähä, the twins of Mäʻihi challenged the rule of Pili in Kona. Having proven himself before Pili and his court, Ka-Miki was allowed to answer the challenge. Ka-Miki first fought Ke-ala-püʻali and defeated him. Kanähähä then challenged Ka-Miki to a battle in the sea. The two contestants departed in Pili's canoes from Niumalu and when they reached the deep sea, they leapt into the ocean. Ka-Miki commanded that the canoes return to Niumalu once the fight began. Kanähähä then leapt to grab Ka-Miki, but Ka-Miki told Kanähähä, "You will not catch Ka-Miki, descendant of Ka-uluhe and Nihoʻeleki the shark god from Kahiki-kü. Instead Kanähähä, you will be bound on the coral below and become food for the crabs."

Calling upon the shark-god form, *Nihoʻeleki*, Ka-Miki grabbed Kanähähä and pulled him under, twisting and pushing him into the coral. When Kanähähä stopped moving, Ka-Miki rose to the surface and the two were carried by the current *Ke-au-miki*. Ka-Miki watched the

[40] When the Priest P ʻao came to Hawaiʻi, brought with him the schools of *aku* and ʻ *pelu* fish (cf. Kamakau; *K ʻ koʻa* –December 29, 1866). In this account, Kumukea-K huli-Kalani was the name of lead *aku* that came to Hawaiʻi with P ʻao.

shore of Kekaha-wai-ʻole, they passed Hoʻonä, Awalua, Kaʻelehuluhulu, and the sands of Kapuʻualiʻi… Ka-Miki then turned around and secured Kanähähä in the ocean, where he became a *koʻa* (deep sea fishing station) at Haleʻohiʻu for *ʻahi* and *aku* lure fishermen of Kekaha-wai-ʻole. Ka-Miki then swam to the shore of Awalua which served as a *mäkähä* (sluice gate) for the fish pond of Paʻaiea (November 29, 1917).

Ka Loko o-Paaiea (The fishpond of Paʻaiea)

…Paʻaiea was a great fishpond, something like the ponds of Wainänäliʻi and Kïholo, in ancient times. At that time the high chiefs lived on the land, and these ponds were filled with fat *awa, ʻanae, ähole*, and all kinds of fish that swam inside. It is this pond that was filled by the lava flows and turned into *pähoehoe*, that is written of here. At that time, at Hoʻonä. There was a *Konohiki* (overseer), Kepaʻalani, who was in charge of the houses (*hale papaʻa*) in which the valuables of the King [Kamehameha I] were kept. He was in charge of the King's food supplies, the fish, the *hälau* (long houses) in which the fishing canoes were kept, the fishing nets and all things. It was from there that the King's fishermen and the retainers were provisioned. The houses of the pond guardians and *Konohiki* were situated at Kaʻelehuluhulu and Hoʻonä.

In the correct and true story of this pond, we see that its boundaries extended from Kaʻelehuluhulu on the north, and on the south, to the place called Wawaloli[41] (in the vicinity of ʻOʻoma). The pond was more than three miles long and one and a half miles wide, and today, within these boundaries, one can still see many water holes.

While traveling in the form of an old woman, Pele visited the Kekaha region of Kona, bedecked in garlands of the *koʻokoʻolau* (*Bidens* spp.). Upon reaching Paʻaiea at Hoʻonä, Pele inquired if she might perhaps have an *ʻamaʻama*, young *äholehole*, or a few *ʻöpae* (shrimp) to take home with her. Kepaʻalani, refused, "they are *kapu*, for the King." Pele then stood and walked along the *kuapä* (ocean side wall) of Paʻaiea till she reached Kaʻelehuluhulu.

There, some fishermen had returned from aku fishing, and were carrying their canoes up onto the shore.

Pele had now taken the form of a beautiful young woman, and she approached one of the houses at Kaʻelehuluhulu, where she was greeted. Because it was seen that she was a stranger to the place, one of the natives commented on this, and asked "Where is this journey that has brought you here, taking you?" Pele confirmed that she was indeed a visitor, and that she had come down to the place of the chief, to fetch some *paʻakai* (salt) with which to season their fish. Pele told them, "When I came down here, I went before the *Konohiki*, and was told that the fish, the *palu* (fish relish), the young mullet, the *ähole*, and the *ʻöpae* were all *kapu* (restricted). They were only for the King. Thus, I have arrived here before you."

When the natives of the village heard Pele's story, the woman who dwelt in the house that Pele was at, told her "Here, the fish is cooked, it has been steamed (*häkuʻi*), let's eat. Then

[41] Maguire's account of Paʻaiea (1929:14-17), indicates that the pond extended as far as Ke hole. This description fits in with the extent of the 1801 lava flows of Hual lai. It will be noted that the pond would have extended beyond Ke hole if canoes traveling on it were to pass inland of the point (see also Kamakau 1961:184-186).

when you've finished eating, you may continue your journey." Pele joined the *kama'äina* of the place, and when she dipped her finger in the bowl, she took and ate all the fish to see if the people would deny her the food. But when she did this, the *kama'äina* set another bowl before her, not refusing her.

Pele then stood up, ready to leave and she told the people, "This evening set up *lepa* (flags, boundary markers) at the corners of your land. One doesn't know if perhaps tonight, something good or bad might occur." Then Pele departed from the place, and she disappeared from sight. Startled, it was then that the people said among themselves, "This woman that visited our home must have been Pele-Honuamea (Pele of the red earth)..."

…That night, a white flash was seen to travel from Mauna Loa to Hualälai, and in a short time a red glow was seen at Ka-iwi-o-Pele. The people along the coast thought that it was the fire of the bird catchers at Hono-(manu)-'ua'u. The light dimmed and then appeared at (*pu'u*) Kïleo where the shiny hills of black *pähoehoe* may be seen. Pele then went underground and appeared at Keone'eli where she caused deep fissures to open, and the *kahe-ä-wai* (fire rivers) to flow… …Now because Kepa'alani was stingy with the fishes of the pond Pa'aiea, and refused to give any fish to Pele, the fishpond Pa'aiea and the houses of the King were all destroyed by the lava flow. In ancient times, the canoe fleets would enter the pond and travel from Ka'elehuluhulu to Ho'onä, at Ua'u'älohi, and then return to the sea and go to Kailua and the other places of Kona. Those who traveled in this manner would sail gently across the pond pushed

forward by the '*Eka* wind, and thus avoid the strong currents which pushed out from the point of Keähole

It was at Ho'onä that Kepa'alani dwelt, that is where the houses in which the chiefs valuables (*hale papa'a*) were kept. It was also one the canoe landings of the place. Today, it is where the light house of America is situated. Pelekäne (in Pu'ukala) is where the houses of Kamehameha were located, near a stone mound that is partially covered by the *pähoehoe* of Pele. If this fishpond had not been covered by the lava flows, it would surely be a thing of great wealth to the government today. (J.W.H.I. Kihe in *Ka Hökü o Hawai'i*; compiled from the narratives written February 5-26, 1914 and May 1-15, 1924).

Ka Lae o Keähole (The Point of Keähole)

Another of Kihe's short accounts published in this same time period, under the heading "*Na Hoonanea o ka Manawa*," was about the point known as Keähole. Excerpts from this historical piece are included here because Kihe provides readers the names of various *ko'a* (fishing grounds) extending from Keähole to Kohala. Some of these *ko'a* are referenced in various places of this study, but the texts here put them in order of location, south to north.

It is not a large place, this point, Keähole, but here is the thing that makes it famous, the strength of its mixed, or twisting currents (ka wili-au) that flow with the passing current… And there in front of this point, in deep waves where this current swirls, on the side there is a stone, on which the waters rise up with strength as if filling an estuary (muliwai), and then flow out. It is on that side, that you will find the ko'a (fishing stations) for aku, 'ahi, kähala, 'öpakapaka and such. Among these ko'a are Päo'o, 'Öpae, Kahakai, Kapapu, Kanaha-ha, Kaluahine, Kanukuhale, Kahoʻowaha, Honu, Muliwai (from where one peers upon the dirt of Häʻena, Kohala) and Kaihuakalä, Maui… There are many other koʻa, but these that I've mentioned, are the famous koʻa. There are many deep koʻa all in a line, from the Point of Keähole to the Point of Upolu and the heiau of Moʻokini in Kohala.

That stone which is situated in front of the Point of Keähole, is called by its name Keähole, and it is for this stone that the point is called Keähole to this day… (Kihe in *Ka Hökü o Hawaiʻi*; October 11-18, 1923)

"He Moʻolelo no Mäkälei" (*A Tradition of Mäkälei*)

…In the early morning, Mäkälei arrived at the shore, he called is *käohi* into their positions as before, and boarded the canoe himself and they were off to the *koʻa*. The *aku* were swimming all around and Mäkälei had his *käohi* turn the canoe. Then this expert fisherman of Kekaha-wai-ʻole called out in a chant:

E Hina-i-ka-malama-o-Käʻelo	Hail Hina of the season of *Käʻelo*
Kuʻu kupuna wahine kino paʻeʻe	My ancestress of the supernatural body forms
Hoʻoülu mai ka iʻa	Cause the fish to increase
O ke aku aliʻi, aku kahähä, aku oloolo i kaʻelewaʻa	The chief aku, the astonishing *aku*, the *aku* which overflow from the canoe hull
O ke aku wiliwiliau i ke kai kähala	The aku which stir up the ocean of the amberjack,
Kai ʻele, kai uli, kai pöpolohua Käne	The dark ocean, the green blue ocean the purplish-blue ocean of Käne
I mae i ke koʻa, huea mai a lana iluna	Let the fish rise off the *koʻa*
Wehe ʻia nä puka o ka hale o ka iʻa	Open the doors of the house [station] of the fish
Mai muli i Kanukuhale	[Which] begins at Kanukuhale
A hoʻe[a] imua o Päoʻo	And reaches before Päoʻo
I ka wiliwilia o Keähole	There at the currents of Keähole
I Hoʻonä i ka hale o ka iʻa i noho ai	At Hoʻonä the house at which the fish dwell

Upon completing his chant, the *aku* began striking from the beginning of Kanukuhale until they reached the front of Päoʻo. The fish rose like smoke from a burning *imu*, they were like gnashing dogs. Mäkälei then had Poʻo and Kapahi turn the canoe around to return to the shore… (March 20, 1928)

Ko Keoni Kaelemakule Moolelo Ponoi — The True Story of John Kaelemakule (Kakau ponoi ia mai no e ia – Actually written by him[42])

…The fishing customs in our land, as handed down from ancient times, is something that was greatly regarded by our beloved chiefs. Cherished customs, taught to the children by their parents. The practices of farming were taught to those of the land, and the practice of fishing were taught to those of the coast. Those were the important skills in the ancient times of our ancestors…Let me tell about the customs of fishing in the deep sea, for these are

[42] This account was published in serial form in the Hawaiian newspaper *Ka H k o Hawaiʻi*, from May 29, 1928 to March 18, 1930. The translated excerpts in this section include narratives that describe Mahaiʻula and nearby lands in Kekaha with references to families, customs, practices, ceremonial observances, and sites identified in text. The larger narratives also include further detailed accounts of Kaʻelemakule's life, and business ventures. A portion of the narratives pertaining to fishing customs (November 13, 1928 to March 12, 1929), and canoeing practices (March 19 to May 21, 1929) were translated by M. Kawena Pukui, and may be viewed in the Bishop Museum-Hawaiian Ethnological Notes (BPBM Archives).

among the things that were practiced by my foster father Kaaikaula, and that he taught to me. Among the important fishing practices of Kekaha, that I was taught in my youth were *aku* fishing, *ahi* fishing, and fishing for *'öpelu* with nets. These were the important fishing customs that I was taught Fishing for these fish was done at the *ko'a 'öpelu* (*'öpelu* fishing station or grounds), that was not too far out. And beyond that, was the *ko'a* for *aku* and *'ahi* fishing. The *ko'a* for these fish (the *'ahi* and *aku*), was the famous *ko'a lawai'a* (fishing ground) of Kekaha, known by the name, "Haleohiu…" (November 13, 1928:3)

Aku Fishing

Aku fishing was done with a *pä* in ancient times by our fishermen ancestors, at the famous *ko'a* of Hale'ohiu, of the land of Kekaha-wai-ole-o-nä-Kona…From this waterless shore of Kona, it is believed that the first *pä aku* fishing was found, made from the shoulder blade (*iwi hoehoe*) of Keuwea. He was the father of that famous fisherman of Kekaha, called Ka'eha. His story was seen in the "Newspaper, the Star of Hawaii…" [in 1907]. It is said in the legend, that Ka'eha killed his father, at his father's command, and that Keuwea's shoulder and thigh bones were thrown into a *käheka* (tidal pool) of Kekaha. On a following day, Ka'eha went to look at his father's bones and he saw growing up from them, some *päpaua* (mother of pearl bivalves). From the *päpaua* on the right side, Kaeha made the "*pä hi aku kuahuhu*" (the *kuahuhu aku* lure). The *päpaua* that was on the left side, was thrown into the sea, and that is the reason that the *päpaua* spread throughout the islands, and how it came to be used for *aku* lures… (December 11, 1928:3)

…It is perhaps appropriate for me to mention some of the famous *aku* fishermen of the days of my youth, those who I fished with at my home of Kekaha-wai-'ole-o-nä-Kona where I was reared. The fishermen whom I mention, their names are on the list of the foremost *aku* fishermen of those days. Nahale was one of the head fishermen at that time. He dwelt in his home at Makalawena, in the land of Kekaha. He was famous for his distant traveling, finding of the *aku*, and *aku* lure fishing. He was very strong and could lift the *aku* onto the canoe… Hoino was another famous *aku* lure fisherman of those days. He was a resident of Mahai'ula, and he would fish for *aku* with lures at Hale'ohiu, the famous *ko'a* (deep sea fishing station) of Kekaha. When I was young, before I became an *aku* fisherman, I was one of his canoe men… Pahupiula, was a part Caucasian fisherman, and he is the third of the fishermen that I remember here on this page. He was very smart in fishing for *aku* with lures, and very fast at getting the *aku* off of the lure and into the canoe. He was from the village of Makalawena… (January 15, 1929:3)

…When I left Kekaha, Pahupiula and the other head fishermen had died, and new head fishermen arose. Makanani was one of the lead fishermen later. But, not only him, there was also Kamaka, who was among the foremost fishermen of the famous *ko'a*, Hale'ohiu. These men held that position later and their fame was made known, because of their strength, alertness, and readiness in lifting the *aku* fish to the canoe, and their quickness in freeing the fish from the *pä*.

The well known head fishermen of Kekaha, those who practiced and became the foremost *aku* fishermen were Nahale, Hoino, Pahupiula, Ka'elemakule, Makanani, and Kamaka. All of them were fishermen of the first class… (February 5, 1929:2)

Ahi fishing was also an important practice. …The bait that was for *ahi* fishing at the *koa* of

Haleohiu, as well as at other *koa*, was the whole *'öpelu*. Also the sliced *'öpelu* mixed with *aku*. Sometimes, when there was none of this type of bait, the *weke 'ula*, *weke lä'ö*, and even the tail meat of the '*ahi* were used. Some fishermen also used the *po'ou*, *moi*, and *akule* as bait… (February 26, 1929:4)

'Öpelu Fishing

'Öpelu fishing was another one of the important practices of these islands in ancient times; it was perhaps the foremost of the practices in the streaked sea (*kai mä'ok'ioki*) of Kona. It became the type of fishing that contributed to the livelihood of the fishermen and their families… For *'öpelu* fishing, two men are adequate in going on the canoe to the place of the *ko'a 'öpelu* which has been known since the days of the ancient people. It is at a place where one can look below and see the fish, that he prepares to feed the *'öpelu*. The man at the front of the canoe is the fisherman, the one who is prepared for this manner of fishing, he leads in all things for this kind of fishing.

There in front of the fisherman was set out the bait of the *'öpelu*, that is the *'öpae 'ula* (red shrimp) and sometimes other baits as well. He'd give the man at the back of the canoe the bait, this man would do what ever the fisherman told him to. The man in the back had a stone weight, the black dirt, and the coconut sheath in which the *'öpae 'ula* or other bait would be placed and folded in. This would be wrapped with cordage and let down into the water about 2 or three fathoms deep, then the man would jerk the cord and the bait would be released. The water would be blackened by the dirt, and this would help the fisherman see the *'öpelu* eating in the water…When many *'öpelu* were seen, he would have the man feed the fish again and lower the net into the water. While the *'öpelu* were eating, the net was drawn up, and as the fish tried to swim down, they were caught in the net…

While I was a youth living at my beloved land of Mahai'ula, I fished for *'öpelu*. I went with my foster father, Kaaikaula, to fish for *'öpelu* at the *ko'a 'öpelu* (*'öpelu* fishing ground) called "Kaloahale," it was directly seaward of the black sand shore of Awalua… (March 5, 1929:4)

Appendix F(3)

Interview with George Kinoulu "Kino" Kahananui Sr.

(from Excerpts Oral History Kekaha (Honoköhau to Ka'üpülehu) Vicinity, North Kona, Hawai'i, – December 11th 1999, by Kepä Maly, released July 27, 2000)

Describing how Keähole was named, and the ancient fishpond of Pä'aiea:

KM: …*Ua lohe 'oe i këia mau mo'olelo, e like me Keähole. Pehea ka mana'o Keähole*?

…So you heard these kinds of stories, like that of Keähole. What does Keähole mean?

KK: *Ke-ähole no këia au o ke kai*.

Keähole is called that because of the current.

KM: *A, no këlä mau au o ke kai*?

Oh, for the currents of the sea?

KK: *Nä au*. *Mai Kohala a Kona mai a ho'oku'i.*

The currents. From Kohala and from kona, and the strike one another.

KM: *Äholehole*? [Mixing, twisting?]

KK: *Äholehole*. [Mixing, twisting?]

KM: Choppy, *nö ho'i*?

KK: Choppy.

KM: *A 'oia ke kumu. Ua like me au i 'ölelo mua ai, 'o tütü Kihe, ua käkau 'oia i kekähi mo'olelo o Ke-au-kä, Ke-au-miki, Ke-au-käna'i, 'oia nä 'au a wili.*

So that is the reason for the name. It's like the currents spoken of before by tütü Kihe, he wrote a tradition about *Ke-au-kä, Ke-au-miki, Ke-au-käna'i*, the intertwining currents. [see Kihe in this study]

KK: *A wili*. [Twisting.]

KM: *Ma këlä wahi*? [at that place?]

KK: *'Ae pololei. Ho'opüpü no wau i këlä, o pololei.*

Yes, that's correct. By what I draw together (understand), that's right.

KM: *'Ae*. [Yes.]

KK: *Nei 'oe e 'imi i ka mo'olelo o këlä au, këlä ke au pololei. A no laila, ka po'e kahiko, maopopo i ka mo'olelo o Keähole, wehewehe 'ana läkou ma këlä. A'ole ho'i o këia wehewehe, 'he i'a këlä." Pololei he i'a. He inoa i kapa 'ia këia i'a, he äholehole. A'ohe na'e* [chuckles] *no këia. No ke au*!

Like you, you've searched out the old traditions of those currents, those are the proper names. Thus the people of old understood the history of

Keähole, and they've explained it in that way. It is not like it's stated now, 'a fish.' While it's true there is a fish by that name, *äholehole*. It's not because of that. It's for the currents.

KM: *No këia wahi, a'ole no nä i'a*? [So for this place, it's not the fish?]

KK: *A'ale na'e*! [Absolutely not!]

KM: *E pili 'ana ke au*? [So it's about the currents?]

KK: *Ke au*. [The currents.]

KM: *'Oia ke kumu o këlä inoa, hea ia o*…? [So that is the source of that name?]

KK: *Keähole. No ka mea, o Keähole 'oi'oi ia i waho*.

Keähole. Because Keähole, it juts out.

KM: *'Ae*. [Yes.]

KK: *A 'oia ke kumu*. [pointing to location on Register Map 2035] *A këlä wahi ma loko pili…ma ka pili pali, a'ole loa. O këia wahi wale nö*.

That's the reason. (pointing to location on Register Map 2035) That the place in there, close to the cliff, not far out. It's only that place.

KM: *'Ae. Oia ka huina o ke*…? [Yes. So that's the meeting place of the…?]

KK: *Ka huina o këia au. Ka huina o këia mau au, e ho'okui läkou*.

The meeting place of the currents. That's the these currents meet, they strike at one another.

KM: *Ua lohe paha 'oe mamua…? And këia au, he mea ikaika loa. Ua lohe paha 'oe mamua, he loko paha ko këia 'äina, a ua uhi 'ia i ka 'a'ä, i ka pele*?

Did you perhaps hear before…? And these currents are very strong. Did you perhaps hear that there used to be a fishpond on this land, and that it was covered over by the stones, the lava flow?

KK: *Lohe wau i këlä, pololei*. [Right, I heard that.]

KM: *Ua lohe 'oe*. [So you did hear it.]

KK: *Mai Kaloko a ne'e a hö'ea i Ka'üpülehu*.

From Kaloko, all the way to Ka'üpülehu.

KM: *'Ae*. [Yes.]

KK: *He loko nui*! [It was a great fishpond!]

KM: *Ua käkau kekähi po'e küpuna i ka* nineteenth century…

It was written by some elders in the nineteenth century…

KK: *Ka mo'olelo*. [The tradition.]

KM: Yeah. *Mamua nui ka ikaika o ke au o këia wahi o Keähole*.

Yeah. That before, there were very strong currents at this place Keähole.

KK: Uh-hmm.

KM: *A a'ale hiki iä läkou ke holo pono, holo mua. So ua ho'okomo ka wa'a…*

And they could not travel forward in their canoes. So the canoes would enter…

KK: *I loko*. [Inside.]

KM: *'Ae, i loko o këia loko i'a. Ua lohe paha 'oe*?

Yes, in the fishpond. Did you perhaps here about that?

KK: *A'ole wau i lohe*. [I didn't hear about it.]

KM: Hmm.

KK: *Ka mea au i lohe mai ku'u kükü, 'oia o Kamaka, Palakiko, näna i wehewehe mai këia mo'olelo.*

What I heard from my elder, that is Kamaka, Palakiko, it was he who shared this story with me.

KM: *'Ae.* [Yes.]

KK: *I ku'u nui 'ana, hele hui launa me kükü Palakiko Kamaka. Näna i wehewehe mai këia mau mo'olelo a pau. He manawa no hele au e maha'oi, hele e nänä, pololei paha…*

While I was growing up, I often went with kükü Palakiko Kamaka. He explained all of these stories to me. There were times when I would go, and be inquisitive, I'd go and look, see if what had been said was true.

KM: *'Ae, hoihoi 'oe*. [Yes, you were curious.]

KK: *Pololei ka mo'olelo*. [Well, the story was true.]

KM: *'Ae*. [yes.]

KK: *Ha'i mai 'oia, ka manawa mamua, mai Ka'üpülehu, këia 'ao'ao, a hiki ke 'ao'ao pono o he loko nui. He loko nui*.

He said, before times, from Ka'üpülehu, this side (on the north), to this side right here (pointing to area below his home at Kalaoa), there was a large pond. A great fishpond.

KM: *'Ae. 'Oia ka mo'olelo*? [Yes. So that was the story?]

KK: *'Oia ka mo'olelo. Ho'okähi kuahiwi ai iä Hu'ehu'e, ma ka lalo, o Puhi-a-Pele.*

[That is the story. There is a mountain below Hu'ehu'e, Puhi-a-Pele.]

KM: *Puhi-a-Pele. 'Oia ke kumu o këia pele*?

Puhi-a-Pele. And that was the source of the lava flow?

KK: *'Ae*. [Yes.]…

APPENDIX G: CONSULTATION AND PUBLIC PARTICIPATION

AGENCY CONSULTATION CORRESPONDENCE

The Agencies contacted during development of this Environmental Assessment are outlined in Table G-1, and the correspondence that documented the contacts and the responses is reproduced at the end of this Appendix.

Table G-1 Agencies Contacted

No.	Agency Contacted	Date	Author/ Contact	Date of Agency Response	Author
1	Office of Environmental Quality Control	01/25/00	DOE		
	Office of Environmental Quality Control	04/17/00	PICHTR		
2	DLNR, Land Division	04/17/00	PICHTR	06/07/00	Uchida
3	DLNR, Div. Of Boating & Ocean Recreation	04/19/00	PICHTR	06/06/00	Bearman
4	State Dept. of Health; Env. Management Division	04/19/00	PICHTR	06/13/00	Arizumi
5	U.S. Coast Guard	04/19/00	PICHTR	05/08/00	McClelland
6	U.S. Army Corps of Engineers	04/19/00	NELHA	05/02/00	Young
7	DLNR State Historic Preservation Division	04/28/00	DOE	05/18/00	Johns
	DLNR State Historic Preservation Division	05/24/00	PICHTR	06/01/00	Johns
8	U.S. Fish & Wildlife Service	04/28/00	DOE	06/08/00	Henson
			DOE	09/22/00	Henson
9	National Marine Fisheries Service	04/28/00	DOE		
	National Marine Fisheries Service	08/07/00	DOE	09/13/00	Lent
			DOE	09/15/00	Dupree
	National Marine Fisheries Service	01/12/01	DOE		
10	Office of Hawaiian Affairs (H. Springer)	07/07/99	PICHTR	07/13/99	Springer
	Office of Hawaiian Affairs (C. Kippen)	06/08/00	PICHTR	08/28/00	Kippen
	Office of Hawaiian Affairs (L. Hao)	08/30/00	PSI	10/10/00	Kippen
11	Hui M lama	07/14/00	PICHTR		

Copies of the correspondence with agencies consulted in the formulation of the EA are reproduced at the end of this appendix. As a result of these consultations, actions were taken to respond to the agency concerns and have been incorporated into the Final Environmental Assessment.

PUBLIC REVIEW OF THE DRAFT ENVIRONMENTAL ASSESSMENT

A draft Environmental Assessment (EA) for the *Ocean Sequestration of CO_2 Field Experiment* was released for public participation on August 8, 2000, with a comment period extending through September 8, 2000. The policy and standard practice of the U.S. Department of Energy (DOE) is to consider all comments that are submitted in the comment period during preparation of a final EA, with all comments received following close of the comment period considered to the extent practicable. That standard was used in preparing this final Environmental Assessment.

The draft EA was provided for public review at three libraries in the Hawaiian Islands - at the Kailua-Kona Public Library and at the Hilo Public Library on the Island of Hawai‘i, and at the Hawai‘i State Library in Honolulu on the Island of O‘ahu. The draft EA was also available for review at the DOE – National Energy Technology Laboratory's public reading room in Pittsburgh, PA, and was provided to all individuals who requested a copy. The first page of the draft EA specified the time period for receipt of comments and included contact information for cognizant DOE personnel.

Availability of the draft EA was announced through three newspapers published in the Hawaiian Islands, through two internet web sites, and through an announcement of an agency of the Hawaiian Islands' state government. Newspaper announcements citing availability of the draft EA were published in the West Hawaii Today and Hawaii Tribune-Herald newspapers on the Island of Hawai‘i and in The Honolulu Advertiser on the Island of O‘ahu, beginning August 8, 2000, for a period of three days. Collectively, about 85% of the population of the Hawaiian Islands resides on these two islands. The newspaper announcements specified the closing date of September 8 for submitting responses to DOE and provided the information necessary for interested members of the public to submit telephone (voice-to-voice or toll-free recorded message), mail, fax, or Email comments and feedback to the cognizant DOE individual, the NEPA Compliance Officer for the proposed action.

Availability of the draft EA was also announced by the National Energy Technology Laboratory (NETL), which is the Department of Energy office proposing the action, on its internet site at http://www.netl.doe.gov, and by a proposed participant in the experiment, the Pacific International Center for High Technology Research, on a web site designed for dissemination of information about the proposed project at http://www.co2experiment.org. In addition, availability of the draft EA was announced in the August 8, 2000, issue of the semi-monthly *Environmental Notice*, a publication prepared and distributed by the State of Hawai‘i's Office of Environmental Quality Control for facilitating reviews of the environmental impacts of projects proposed in Hawaii and for inviting public comments on Environmental Assessments and Environmental Impact Statements.

All interested persons were requested to submit comments on the draft EA via telephone, mail, fax, Email, or toll-free number to NETL's NEPA Compliance Officer. Through the close of the comment period on September 8, 2000, a total of 129 responses were received from 120 separate individuals. Responses were submitted by Email, fax, telephone, and letter, with the preponderance of responses submitted by Email. Tables G-2 and G-3 display information on the methods used by respondents to provide comments and on the non-Hawai‘i origins of the 129 replies received in accordance with provided instructions, when such locations could clearly be determined from responses:

Table G-2 Methods of Submitting Responses Received by Closing Date

Type	Number
Email	115
Fax	9
Telephone	3
Letter	2
TOTAL	**129**

Table G-3 Responses Clearly Originating from Outside Hawai‘i

Location	Number
California	10
Texas	2
Georgia	2
New York	1
Washington	1
Florida	1
Ohio	1
New Jersey	1
Oregon	1
Colorado	1
Missouri	1
Canada – Nova Scotia	1
Puerto Rico	1
TOTAL	24

In addition, replies continued to be received following the closing date of September 8, 2000, and some replies were directed to individuals other than the designated NEPA Compliance Officer. Comments continued to be received as late as October 10, 2000; only a request for a copy of the draft EA was received following that date. Comments received from all respondents were considered during the process of preparing this final EA. In most cases, the general themes of comments received after September 8 were similar to those received during the identified comment period.

For the category of late or misdirected responses, a total of 101 additional replies were received from an additional 84 individuals. Thus, through the October 10 date when the most recent comments were received, a total of 230 replies from 204 individuals were submitted in response to the draft EA or to the announcement of its availability. Information from all responses regarding methods used by respondents to provide feedback on the draft EA and the locations of respondents clearly residing outside the Hawaiian Islands are presented in Tables G-4 and G-5 below.

Table G-4 Methods of Submitting Responses Received through October 10, 2000

Type	Number
Email	210
fax	10
Telephone	3
Letter	7
TOTAL	230

Table G-5 Responses Clearly Originating from Outside Hawai‘i (all responses)

Location	Number
California	16
Texas	2
Georgia	2
New York	1
Washington	1
Florida	1
Ohio	1
New Jersey	1
Oregon	1
Colorado	1
Missouri	1
Maine	1
Iowa	1
Alaska	1
Arizona	1
Canada – Nova Scotia	1
Puerto Rico	1
TOTAL	34

Among the 230 responses, a total of 112 individuals forwarded endorsements of comments submitted by other respondents. One individual provided a petition of opposition containing signatures of 60 individuals residing in New York, California, Hawai‘i, Washington, Florida, Oregon, Maryland, Kansas, Ohio, Illinois, Louisiana, Utah, British Columbia, Alberta, Ontario, or Australia.

Responses to the draft EA and to the announcements regarding the proposed action varied widely, but all comments could generally be grouped under one of the following categories:

- requests for additional information,
- brief statements of opposition to (or descriptive characterizations of) the proposed project or project participants,
- concerns about the potential implications of large-scale implementation of the concept proposed for research,
- comments expressing concern about the science underlying the proposed experiment, and
- expressions of concern specific to the potential consequences of (or need for) conducting the proposed experiment at the proposed test site

The types of information requested by respondents included copies of the draft EA, notification of the final DOE decision, copies of the final EA, and other analyses regarding the concept of sequestering CO_2 in the ocean. Where such information was available (e.g., through web sites or the draft EA), the requests were quickly fulfilled. In some cases, requests were submitted for information that was either non-existent (e.g., requests for a specific type of report on the ocean sequestration concept) or that would be available through the final EA. These requests were acknowledged. About 8 of the individuals who provided feedback either provided responses that only requested additional information or expressed no concerns about (or opposition to) the proposed action.

From the 204 individuals who provided responses to the draft EA or to announcements about the proposed action, about 124 provided statements of opposition with no individually identified concerns specific to the proposed action. Statements of opposition to the proposed action were acknowledged if they were received by the closing date for comments, but all statements of opposition were noted and recorded. For preparation of this final EA, no specific changes were made to the text of the Assessment in response to general comments of opposition.

From the approximately 80 respondents who identified individual concerns regarding the proposed action, their concerns focused on (1) the potential problems associated with large-scale implementation of the approach to carbon sequestration that is proposed to be tested under the proposed action, (2) the adequacy of information regarding the scientific foundation for the experiment, or (3) the potential environmental interactions and effects associated with conducting the proposed experiment at the proposed site.

Large-scale implementation of ocean sequestration is neither contemplated under or as part of the proposed action nor an anticipated follow-on activity subsequent to the completing the proposed action. The proposed action is, as explained in Section 3.2.1 (DOE's Purpose) and Section 3.3 (Need for the Action) of the draft EA and this final EA, an action to develop scientific information from which to validate scientific principles and computer models associated with the concept of carbon dioxide sequestration in the deep ocean. To further demonstrate the status of this ocean sequestration experiment as one of a variety of concepts being evaluated by DOE, the final EA includes an expanded discussion of the current scientific investigations on the wide variety of potential approaches to carbon sequestration that are being researched by DOE. This expanded discussion places the proposed action for the ocean sequestration experiment in context, as only one of several concepts being investigated at a relatively small scale, for the purpose of developing information that could be used, if needed, at some unknown future time for decision-making on avenues to be further pursued if sequestration of carbon becomes necessary to alleviate problems of global climate change.

Finally, for those respondents who identified concerns potentially associated with the proposed action, their individually stated concerns could be grouped and categorized under a limited number of topic areas. Those categories of concern are indicated in the Table G-6 below. The number assigned to each topic of concern is provided only for tabulation and reference purposes, and does not ascribe any particular priority to the concerns of the respondents. All concerns have high priority for consideration. Table G-6 lists topics of concern collectively identified from all responses, and it includes concerns that were received following the close of the comment period, through the October 10 date on which the most recent topics were received.

Table G-6 Topics of Concern

Sequence Number	Topic of Concern
1	Potential effects of the experiment on specific fish species
2	Potential effects of the experiment on marine mammals
3	Potential effects of the experiment on marine organisms
4	Potential effects of the experiment on (and its relationship to) coral resources
5	Potential effects of the experiment on (and its relationship to) the Humpback Whale National Marine Sanctuary
6	Potential consequences of ship activity on fish species and pollution
7	Potential consequences of noise generated by ships
8	Potential effects on commercial and individual water activities
9	Potential consequences of released carbon dioxide on mineral deposition, oxygen levels, water clarity, and water chemistry
10	Potential effects and areal extent of the effects of the experiment on seawater acidity and carbon-enriched water

Sequence Number	Topic of Concern
11	Potential long-term effects of the experiment
12	Potential for reasonably foreseeable future carbon dioxide releases and cumulative effects of related activities on the area
13	Potential for accidents or sudden release of injected carbon dioxide to the atmosphere
14	Potential effects and relationship of the experiment to other on-going or completed research or mariculture activities in the area
15	Potential effects of ocean currents and ocean transport of materials from deeper to shallower waters
16	Potential effects of the experiment on ocean transport of nutrients
17	Level of characterization and definition of the existing sea water environment in the project area
18	Incomplete definition of the experimental testing, monitoring, and data analysis and reporting plans; and lack of involvement by marine environment technical expertise in developing experimental plans
19	Potential for disproportionate adverse effects on low-income or minority populations
20	Potential effects of the experiment on Native Hawaiian rights, customs, culture, and interests
21	Degree of consistency of the experimental activities with activities authorized for performance in the project area
22	Degree of compliance of the experimental activities with requirements of existing laws and their implementing regulations, such as the Ocean Dumping Act, Clean Water Act, Endangered Species Act, Coastal Zone Management Act, and Magnuson-Stevens Fishery Conservation and Management Act
23	Need for the proposed action and potential for the experiment to address the need
24	Quality of models used for prediction of potential effects of the experiment
25	Criteria used for site analysis and investigation of potential alternatives
26	Overall consequences of the experiment on the ecosystem of the area

In most cases, the topics of concern are consistent with topics that were identified and analyzed in the draft EA. Respondents who commented on these topic areas, however, generally emphasized either their desire for more detailed experimental or environmental consequence analysis information or their beliefs that significant adverse effects would occur. In some cases, information was provided to support the need for additional analysis of environmental consequences. Many of the concerns, such as a concern regarding the potential for impacts on fish species, were identified by more than one commenter.

The specific concerns identified during the public review process were analyzed and addressed at the appropriate locations in this final EA. In most cases, the stated concerns resulted in incorporation of additional or clarifying information.

AGENCY CONSULTATION LETTERS

DRAFT

EXPERIMENTAL PLAN
FOR THE
OCEAN SEQUESTRATION OF CO_2 FIELD EXPERIMENT

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1.0 INTRODUCTION

1.1 BACKGROUND

Through controlled release of fixed amounts of liquid CO_2 totaling 40-60 metric tons (44-66 English, or short, tons), the *Field Experiment* would develop information on (1) physical and chemical changes induced in seawater by the release of liquid CO_2 and (2) effects of release rates and nozzle designs on the physical dynamics of a CO_2 cloud of droplets. In addition, sampling of biota and a study of naturally occurring bacteria populations in the immediate vicinity of the discharge nozzle would be conducted, and the results would be compared with background information for preliminary investigations of biological effects caused by CO_2 injection. Data collected during the *Field Experiment* would allow scientists to test and refine the theoretical models they use to predict the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters).

The *Field Experiment* would consist of a series of tests. Each test would be used to observe and evaluate the behavior of a specific nozzle design while operating under varying CO_2 discharge rates or physical conditions. The equipment needed to conduct the tests would be mounted on, and deployed from, vessels chartered for that purpose. One vessel would carry the equipment used to release the liquid CO_2. A discharge platform would be carried on the deck of the ship until it is in position for deployment. A test nozzle would be fitted to the end of an outlet pipe on the platform, and the platform's inlet pipe would be connected, using a short length of flexible hose, to one end of coiled tubing through which liquid CO_2 would be pumped from the vessel. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet. The vessel used to deploy the discharge platform and flexible tubing would have good positioning capabilities. That is, the vessel would contain the navigational and mechanical equipment needed to remain in a fixed position without using an anchor. Other vessel(s) would transport remotely operated vehicles (ROVs) and/or submersibles that would be used to collect data during the *Field Experiment*. Instrumentation used for data collection would include ocean current meters, pH meters, video cameras, and other oceanographic tools. Moored systems would be deployed to obtain continuous records of oceanographic variables at fixed locations, while the ROV system would be used to follow the discharge plume down current.

1.2 PURPOSE OF THIS DOCUMENT

This document details the experimental plan that would be followed in conducting the experiment. It <u>complements</u> the information that is contained in the Environmental Assessment that the Department of Energy is preparing for the project. It includes:

- A list of the experimental objectives.
- An overview of the kinds of measurement platforms and instruments that will be used.
- A detailed description of the experimental activities.
- A summary of the actions that would be taken to modify or suspend the planned activities in the event that real-time monitoring of the results indicates that the CO_2 is behaving in unanticipated ways that have the potential to significantly affect the surrounding environment.

2.0 EXPERIMENTAL OBJECTIVES

The overall objective of the *Ocean Sequestration of CO_2 Field Experiment* is to provide data needed to verify scientific principles and to test, validate, and refine existing computer and laboratory models concerning the behavior of liquid CO_2 released into the ocean at moderate depths (2,300-4,900 feet; about 700-1,500 meters). More specific objectives of the *Field Experiment* are to:

- Investigate CO_2 droplet cloud dynamics;
- Examine pH in the plume and on its margins;
- Clarify effects that hydrates might have on droplet dissolution;
- Trace the evolution of CO_2-enriched seawater resulting from CO_2 dissolution;
- Assess potential impacts on bacterial biomass, production, and growth efficiency associated with induced changes in seawater pH in the vicinity of the release; and
- Examine the effect of a range of CO_2 injection velocities and injector configurations (*e.g.*, orifice size) on the performance of the system and on physio-chemical effects.

3.0 MEASUREMENT PLATFORMS & INSTRUMENTS

3.1 OVERVIEW

Figure 3-1 shows the various platforms to be used for experimental measurements. Those platforms, the kinds of instruments that would be mounted on each, and the sorts of measurements that would be made by each are briefly described below.

Several different measurement and sampling platforms will be used. These include:

- A remotely operated vehicle (ROV), referred to as an RTV (remotely operated television), will observe the behavior of droplets near the nozzle. A separate ROV or manned submersible will at other times conduct surveys of the water column and collect samples from the water column and the bottom within about 100 meters of the discharge platform.
- Small instrument packages will be deployed from the research vessels on fixed moorings and the discharge platform and will collect data from those locations.
- The research vessels will lower instruments to take conductivity-temperature-depth (CTD) measurements at varying distances from the discharge nozzle.

Instruments mounted on (or deployed from) these platforms will be used to collect a wide range of data. Collectively, the scientific team will be sampling the following:

- pH (using probes mounted on the RTV and ROV or submersible, CTD instruments cast from the research vessels, and instruments moored temporarily on the bottom).
- Carbon chemistry (including pH; measured in samples collected by the ROV or submersible and CTD bottles brought onboard ship).
- Microbiology (bacterial production, respiration and community structure; measured in samples collected by the ROV or submersible and CTD bottles brought onboard ship).
- Noise (measured with a moored hydrophone).
- Hydrography (temperature, salinity and density measured using CTDs and instruments mounted on the ROV or submersible).
- Ambient current speed and direction using an Acoustic Doppler Current Profiler (ADCP) deployed from a research vessel and an Acoustic Doppler Velocity meter (ADV) mounted on the ROV or submersible.
- Benthic biology (from samples collected by the ROV or submersible).
- Tracer dye concentration measured with a fluorometer that will be connected to the ROV or submersible or moored in situ downstream from the CO_2 release.
- Video observations using cameras mounted on both the RTV and ROV or submersible.

3.2 DETAILED DESCRIPTION OF INSTRUMENTATION

Table 3-1 summarizes the instruments and measurements associated with each of the platforms that would be used to conduct the experiment.

Table 3-1 Summary of Instrumentation By Platform

Platform	***Instruments/*** Measurements
RTV (Japanese ROV)	***Video Camera/Recorder.*** Observations of CO_2 droplets. Real-time data would be transmitted from the RTV to the research vessel via cable. Data would be recorded for future analysis. ***pH Meters.*** pH meters with real-time data transmission to the research vessel via the cable umbilical line. ***Video Camera/Recorder.*** Observations of biota in water column and on the seafloor to observe reaction. Because reactions are expected to be small and occur over a period of time, most analysis of these data would be done after the experiment is completed.
ROV or Submersible	***pH Meters.*** pH meters with real-time data transmission to the research vessel. ***Geological Samplers***. Sampling devices will collect sediment and rock samples from the bottom for later laboratory analysis related to benthic biology and microbiology. Microbiological data will allow estimates of bacterial production, respiration, and community structure. ***Video Camera/Recorder.*** Observations of CO_2 droplets. Real-time data would be transmitted from the ROV to the research vessel via cable or be observed and recorded on a submersible. Data would be recorded for future analysis. ***Video Camera/Recorder.*** Observations of benthos to observe reactions of fauna. Because reactions are expected to be small and occur over a period of time, most analysis of these data would be done after the experiment is completed. ***Fluorometer.*** A fluorometer attached to the ROV or submersible would be used to measure fluorescent dye concentrations in the discharge. This would enhance the ability to track the plume. ***Conductivity, Temperature, Depth Sensor.*** CTD sensors would be included in the sensor package on the ROV or submersible to characterize the seawater bodies through which the mobile survey system travels. ***Acoustic Doppler Velocity Meter.*** This instrument would measure relative current speed while mounted on the mobile survey system. ***Water Column Samples.*** Samples would be collected using the CTD collection bottle for on board analysis of carbon chemistry and microbiological processes.
Fixed Moorings	***Moored Hydrophone.*** This instrument would measure noise levels near the discharge platform. Data would be transmitted to the research vessels periodically through a low-speed acoustic modem. ***pH Meters.*** pH levels – data are stored for analysis after the mooring is recovered. ***Acoustic Doppler Current Profiler (ADCP)***. The ADCP would provide real-time data concerning current velocity and direction by depth throughout the water column through an acoustic modem to the research vessels.
Research Vessel	***Conductivity, Temperature, Depth Sensors.*** CTD sensors would be deployed from the research vessel and on fixed moorings to characterize the seawater bodies throughout the water column below the ship. Water samples would also be collected for onboard analysis.

Figure 3-1 Platforms and Measurement Devices.

4.0 DESCRIPTION OF EXPERIMENTAL ACTIVITIES

4.1 GENERAL

Table 4-1 summarizes the most important characteristics of the planned tests. It must be stressed that the tasks and durations that are shown are tentative. As is true of all experimental activities, the work plan must remain flexible to allow the investigators to respond to such things as weather patterns, sea states, instrument and shipboard equipment malfunctions, unexpected findings, etc. The following section describes the manner in which the experiment would be conducted.

4.1.1 PLANNED EQUIPMENT

The equipment needed to conduct the *Field Experiment* would be mounted on, and deployed from, ocean-going vessels chartered for the purpose. There would be a vessel used to deploy the CO_2 release system and one or two vessels used to monitor the results of the release. These are described in more detail in the following sections.

4.1.1.1 Carbon Dioxide Delivery Vessel

One vessel would carry the equipment used to release the liquid CO_2. This vessel would have good positioning capabilities, which means that it would have navigational and mechanical equipment needed to remain in a fixed position without use of an anchor. The equipment mounted on the vessel would consist of the following:

- A standard refrigerated CO_2 storage tank system of the type widely used by food and beverage companies and hospitals. The deck-mounted tank would keep the CO_2 at a pressure of 20 to 22 bar and -4°F (-20°C).
- A pump, metering system, and high-pressure hose capable of delivering the liquid CO_2 from the storage tank into coiled tubing, through which the CO_2 would be transported to the discharge platform and nozzle on the seafloor.
- A reel holding approximately 3,940 feet (1,200 meters) of 1.5- to 2-inch (3.81 to 5.08 centimeter) outside-diameter coiled tubing, a control cabin with hydraulic power pack, and a deck-mounted container housing controls for the other equipment.

A discharge platform would be carried on the deck of the ship. When the vessel is in position for deployment, a test nozzle would be fitted to the end of the outlet pipe, and the inlet pipe would be connected to the end of the coiled tubing. The platform would then be lowered to the bottom at an estimated water depth of 2,600 feet (800 meters). The platform would be about six or seven feet wide by thirteen feet long and would weigh approximately 11,000 pounds. The discharge platform would consist of the following:

- A flat, steel structure that would provide sufficient tension to the tubing during deployment to minimize drifting due to currents.
- A vertical steel pipe connected to the CO_2 supply tubing by a short, flexible hose secured by chains. The connection would also include a swivel joint to minimize torsion forces in the tubing.
- A trumpet-shaped guide to prevent kinking in the CO_2 supply line.
- Four pointed, steel legs to minimize horizontal movements on the hard seabed, which can have a slope of as much as 30 degrees.

Table 4-1 Preliminary *Field Experiment* Matrix

Duration of Each Test Release (approximate)	Two Hours.
CO_2 Flow Rates	1.6 and 15.8 gallons per minute (0.1 and 1.0 kg/s)
Number of Nozzle Designs Tested	2 to 3
Ambient Conditions	Conduct tests at range of current speeds, if possible
Number of Tests	12 to 20
Total Amount of CO_2 Released	Approximately 10,500 to 15,500 gallons (40 to 60 metric tons)
Source: Pacific International Center for High Technology Research (PICHTR)	

- A discharge pipe to which the test nozzle would be attached; the discharge pipe would extend outward and upward from the side of the platform.
- Anti-backflow devices, such as a check valve, to prevent seawater from entering the pipe and causing hydrate blockages.

The platform may also be equipped with electric heaters to 'melt' any hydrates that form, transponders, tracer dye injectors, and other small pieces of scientific equipment.

4.1.1.2 Other Support Vessels and Equipment

Other vessels would be used to support the *Field Experiment*. These would include one or two mother ships to deploy the remotely operated vehicle (ROV) or submersible and the remotely operated television (RTV) systems that would be used to collect data during experimental tests. In addition, a small boat would probably be chartered to carry scientists and samples between the research vessels and the shore. As discussed elsewhere, small chemical and physical sensors, as well as ROV transponders, would be placed temporarily on the seafloor during the *Field Experiment*.

4.1.2 PROPOSED TEST SEQUENCE: GENERAL

The *Field Experiment* would consist of a series of test sequences. Each test is designed to observe and evaluate the behavior of a specific nozzle design while operating under a defined release rate and known physical conditions. It is expected that at least two different nozzle designs would be tested, and an effort would be made to conduct the releases over a range of current speeds. Altogether, approximately 10,500 to 15,500 gallons (40 to 60 metric tons) of CO_2 would be released over the course of the tests.

Tests would only be conducted when weather and sea conditions allow vessels to maintain their positions within a designated area. The relatively high frequency of moderate seas and calm winds in the lee of the Big Island makes it particularly well suited for the *Field Experiment*.[1] Based on equipment requirements, the preferred surface current for conducting tests would be 2 knots (about 1 meter per second) or less.

[1] A 3.28-foot (1 meter) wave height with periods from 4 seconds upward is deemed representative of the conditions that would be experienced during deployment and testing.

The vessel deploying the platform would maintain station while the coiled tubing is extended for a single experimental test series. In general, this means that the vessel would be stationary above the platform for periods ranging from 8 hours to 3 days.

4.1.2.1 Deployment

Before the discharge platform is lowered from the ship, one of the specially designed nozzles would be attached to the end of the CO_2 discharge pipe. Each nozzle would likely consist of a vertical riser (pipe) about 8 inches (20 centimeters) in diameter that ends in a blind flange with 10 to 60 small holes for release ports.

When prepared for deployment, the platform and attached coiled tubing would be slowly lowered into the water. The weight of the platform would result in a virtually vertical descent of the assembly.

While deploying the platform, the ship would maintain station within a radius of approximately 80 feet (25 meters) over the platform's intended resting-place on the bottom. After the platform reaches the bottom, additional tubing would be deployed until approximately 650 to 1,000 feet (200 to 300 meters) of tubing would be laid on the seafloor. Laying out this additional tubing would provide an unobstructed space immediately above the discharge platform so that survey systems, such as the RTV, ROV, and submersible, would have a clear view of the CO_2 plume. The separation is also needed to prevent possible entanglements between the ROV cables and CTD cables that connect these survey systems to the research vessel and the CO_2 supply pipeline.

The platform would likely be raised from the seafloor at least once during the course of the experiment to change the discharge nozzle, to perform maintenance on the nozzle and/or discharge platform instrumentation, or to correct any operational problems. No more than 5 deployments of the discharge platform are anticipated; this is half the maximum of 10 that were used in the *Draft EA* for environmental impact prediction.

4.1.2.2 Carbon Dioxide Release

Following proper placement of the discharge platform on the bottom, the CO_2 release through the nozzle being tested would begin. The design of each nozzle would generate a unique assemblage of CO_2 droplets at each release rate. As indicated in Table 4-1, the CO_2 would be released from the nozzle at maximum flow rates of 15.8 gallons per minute (1.0 kilograms per second).

Following each release, two distinct regimes of CO_2 behavior are expected. The first regime would consist of rising droplets of liquid CO_2, with droplets possibly covered with films of hydrated CO_2. The release rate and the design of the nozzle would largely control both the size and shape of the droplets and the extent of hydrate formation.

The second regime would result as the buoyant, rising droplets dissolve in seawater. The droplets would gradually dissolve because the natural concentration of inorganic carbon in ambient seawater is orders of magnitude below the solubility limit for liquid CO_2. At the release rates planned for the *Field Experiment*, the vertical rise of the liquid CO_2 droplets would cease within 1,000 feet (~300 meters) from the nozzle. The dynamics of the ascending droplets would be complex, with some seawater being entrained upward by the momentum of the rising droplets. CO_2-enriched water along the edges of the rising plume would sink as dissolved concentrations of carbon increase. This relatively dense, carbon-rich seawater would stop sinking when sufficient mixing with lighter ambient seawater would bring the mixture to a neutrally buoyant equilibrium. Then, the carbon-rich water would drift with the current while being diluted further by turbulence. Examination of this complex, near-field behavior is the primary objective of the *Field Experiment.*

4.1.2.3 Monitoring Methods

During each test, staff on the vessel deploying the platform would: operate and monitor the CO_2 pump system and nozzle flow rate; maintain the vessel's position; and interface with project administrators and the ships from which the ROVs or submersible would operate.

The crew and staff of the vessel or vessels deploying the survey systems would: make ocean measurements; control and monitor the system locations; provide feedback concerning the behavior of the release and the condition of the discharge platform; visually monitor the behavior of megafauna near the test release; and conduct related tests and measurements. Sampling bottles would be deployed and retrieved from the research vessels to collect water and sediment for chemical and biological (bacterial) analysis. Conductivity, temperature, and depth (CTD) measurements from the research vessel would supplement the data obtained from small sensors moored temporarily on the bottom and from the ROVs or submersible.

The CO_2 droplets would be visible and tracked directly using the video equipment mounted on the RTV and the ROV or submersible. Dissolved carbon in the carbon-rich water plume would not be visible and would need to be monitored indirectly. Since CO_2 would increase acidity (lower pH) of the seawater as it dissolves, the plume would be distinguished from normal seawater by measuring the pH. This would be done continuously using instruments mounted on the RTV and ROV or submersible. These vehicles would follow a zigzag course through the droplet cloud and plume of carbon-enriched seawater. Scientists would use real-time measurements of pH to help determine the lateral and vertical edges of the plume for purposes of guiding the ROV or submersible on its survey path. Non-toxic tracers, such as fluorescent dyes, would also probably be released with the CO_2 to facilitate monitoring.

The instruments described in Table 3-1 would be used to monitor ambient conditions and perturbations resulting from the experiment itself**.** Instruments on the RTV and ROV or submersible (e.g., a solid state pH sensor, a more traditional SeaBird glass electrode pH probe, fluorometer, Acoustic Doppler Velocity meter, and video camera) would monitor the plume continuously during releases at distances up to about 100 meters from the release point. Beyond this distance, the scientists believe that the plume would be difficult or impossible to follow consistently. These measurements would be available in real time and would be used to help guide the survey path followed. These surveys will focus in the near field, where the pH would be lowest. The moored instruments would be approximately 200 meters from the discharge.[2] Because of this distance and the fact that they are fixed in space, while the plume will meander, these fixed instruments may or may not be in the center of the plume and record the highest concentration of plume constituents.

Data collected during each test would be used to produce detailed maps of the parameters under scientific investigation (*e.g.*, pH, temperature, and salinity) and of the ocean current fields. The mobile video systems and video lamps would provide flow images of the CO_2 droplet evolution over time. The ADV would obtain point measurements of fluid velocities for use in evaluating turbulence within the discharge plume. Small transponders on the seafloor would be used to track the underwater position of the mobile systems.

Data obtained on CO_2 droplet cloud dynamics, effects of hydrate films on droplet dissolution, and three-dimensional mapping of the dispersing, CO_2-enriched seawater would be used to assess the physical and chemical effects of CO_2 sequestration in ocean water.

To assess potential impacts of CO_2 sequestration on environmental health, variations in bacterial biomass, productivity, and growth efficiency would be determined and compared to conditions in the ambient water column. Measurement of nutrients (dissolved and particulate organic carbon and

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[2] The moored instruments need to be well separated from the discharge platform to insure that the ROV or submersible will not strike them. Because of this, they are most effective at measuring ambient background levels rather than at recording near field perturbations caused by the CO_2 release.

organic nitrogen) would be conducted for corollary analysis. These measurements would identify changes in substrate availability that could alter bacterial activity during injection of CO_2. The analysis of bacterial cycling rates would be combined with an analysis of the variation in bacterial genetic diversity to interpret stresses that might arise from pH changes. This information would provide a better understanding of the effect of water column acidification on the base of marine food chains. These data would also be collected to confirm that the experiment protects overall water quality.

4.1.3 POST TEST/SITE CLEAN-UP

Because of the deployment method planned, the discharge platform, nozzle, and tubing would be removed from the seabed. The small instrument packages and transponders that would be deployed around the test area would also be retrieved.

4.2 DETAILED DEPLOYMENT, RELEASE, AND MONITORING SCENARIO

Figure 4-1 depicts the details of the scheduled activities. The left-hand column lists activities. The bands of colors and other symbols indicate the approximate period during which each activity would take place. Additional information concerning each of these is provided below.

4.2.1 MOORED SENSOR DEPLOYMENT AND RETRIEVAL

The first day that the research vessels are on station would be spent scouting the area that has been selected and deploying the moored sensors. The moorings would consist of concrete or iron anchors connected by acoustic release devices to the instruments. These moored sensors include:

- The Acoustic Doppler Current Profiler (ADCP) that will be used to monitor ambient current speed and direction throughout the experiment.
- Fixed pH sensors that will be located around the experiment site.
- At least one hydrophone that will be used to measure noise from the experiment.
- At least three acoustic transponders. When the transponders receive the proper acoustic codes from the ship, they emit short, distinctive acoustic signals that can be received by instruments on the research vessels and on the RTV/ROV/submersible. Equipment on the latter would allow scientists to fix the positions of the ships and the deployed instrument systems.

The moored sensors would be recovered on the final day of the experiment (tentatively Day 9). This would be done by raising them to the surface and lifting them onto the decks of the research vessels. Once the recovery is complete, the vessels would depart the area for their homeports or their next assignment.

4.2.2 PRE-RELEASE OBSERVATIONS FOR DEPLOYMENT 1: 0.40 CM NOZZLE OPENINGS (EXP 1)

Once the moored sensors are in place, the research vessel carrying the discharge platform would lower the platform to the bottom. When the platform is in place, the RTV would follow. It would be used to confirm that the platform is appropriately positioned and to conduct a visual survey of the area, including the other sensors that were lowered previously and the seafloor where the tubing is

Figure 4-1. Tentative Schedule of Experimental Activities.

deployed. During this same period, the entire set of moored sensors would be exercised to establish that they are working properly. Readings on the moored pH sensors would be crossed-checked against measurements made by instruments on the RTV to insure accuracy. Finally, the CO_2 would be turned on at a very small flow rate and the RTV would observe the rise of individual (or small collections of) droplets. The research vessels would also make CTD casts to collect physio-chemical water quality data. This last activity is identified as "Exp 1" in the figure and may take up to eight hours.

4.2.3 LOW FLOW-RATE TEST FOR DEPLOYMENT 1: 0.40 CENTIMETER NOZZLE OPENINGS (EXP 2)

This test series, which would be made using a nozzle assembly having orifices with a diameter of 0.4 centimeters, would extend over the remainder of Day 2 and all of Day 3. All of the tests during this period would involve flow rates of 0.1 kilogram per second (1.6 gallon per minute). Approximately 5 metric tons of liquid CO_2 would be used. The low flow-rate tests are scheduled first to allow the scientists to check and improve on the experimental protocol as they learn from successive 2-hour releases.

Observations of the initial 2-hour release would be made using instruments on the RTV, which would remain in the water following completion of its baseline observations. It would observe the entire cloud of rising droplets, look for possible reactions on the part of marine biota, and take pH measurements of the carbon-enriched plume. Following completion of the release test, the mother ship would recover the RTV and prepare to launch either the ROV or the manned submersible. During this interim period, when all of the ship-launched sensors are out of the water, the research vessels will try to take vertical profiles of the plume with a CTD; this would give a continuous vertical distribution of pH.

The next set of measurements and releases (conducted over a period of about 8 hours) would be made using sensors on the ROV or manned submersible. These would measure pH, collect water samples for subsequent analysis, collect samples of sediment from the bottom for laboratory analysis, and perform other tests not possible using the RTV. Most of the sampling would be done within the lowest 100 meters of the water column.

The extremely low density of organisms at the depth at which the experiment would be conducted makes it difficult to monitor biological effects on a real-time basis using only video observations of naturally occurring fauna. Because of this, the experimental protocol also calls for the use of test organisms carried in a basket on the outside of the ROV or submersible to monitor for deleterious effects. This would entail the following:

- Baited scavenger traps would be placed on the seafloor in the study area the day before each experiment. Traps deployed in the proposed research area in October 2000 caught amphipods, decapod shrimp and teleost fishes, most of which are sufficiently sensitive to environmental change to be used to monitor for the kinds of water quality changes that would result from the proposed experiment.
- When the ROV or submersible is deployed for a test, it would descend to the bottom and recover two of the traps. It would place one trap upstream from the nozzle as a control and place the other trap in its equipment rack and carry it about while it is carrying out its other monitoring tasks. The trap would be in a position where it could be observed in real-time using a video camera. A pH meter would be placed on the ROV or submersible close to the trap so that it would provide representative measurements of that parameter.
- During the experiment, a biologist would be present for the initial release and the first high-flow release of CO_2. During those dives time would be allocated to observe organisms that the plume encounters during and after the release. A biologist would observe the organisms in the trap on the seafloor as well as other organisms that may be visible in the environment. If the organisms

within the trap are killed by exposure to the CO_2 plume, adjustments would be made as discussed in Section 4.3 of this plan.

This procedure will place the trapped organisms in the most strongly affected waters for an extended time. Because the organisms will receive a greater dose of CO_2 than free organisms in the environment, we expect them to be a sensitive indicator of possible temporary environmental harm. They may also be made more vulnerable to CO_2 exposure by the stress of capture and manipulation.

Subsequent series of tests would be made over the remainder of Experiment 2 as shown in the Figure. Periods of release would be interspersed with periods when all of the observation vehicles (RTV, ROV/manned submersible) are out of the water. These interim periods would also provide time to make CTD casts, to repair equipment that is not operating properly, to adjust operational plans, taking advantage of information and insights that have been obtained during the previous tests, and to rest the ship crews and scientists.

4.2.4 HIGH FLOW-RATE TEST FOR DEPLOYMENT 1: 0.40 CENTIMETER NOZZLE (EXP 3)

This test series (Experiment 3) would be conducted using the same nozzle assembly as the previous test series. It would extend over most of Day 4. All of the tests during this period would involve flow rates of 1.0 kilogram per second (approximately 16 gallon per minute). Nearly 22 metric tons of liquid CO_2 would be used during these test releases.

As with the low-flow discharge tests, observations of the initial 2-hour release would be made using the high-resolution video camera and pH measuring devices on the RTV. Scientists would use the camera to observe the entire cloud of rising droplets and to look for possible reactions on the part of marine biota. They would also take pH measurements of the carbon-enriched plume. Following completion of the release test, the mother ship(s) would recover the RTV and prepare to launch either the ROV or the manned submersible. During this interim period, when all of the ship-launched sensors are out of the water, the research vessels will try to take vertical profiles of the plume with a CTD; this would give a continuous vertical distribution of pH.

Experiment 3 would conclude with two additional 2-hour tests. These would be monitored using the fixed instruments and instruments mounted on the ROV or manned submersible. Other activities would be identical to those carried out during Experiment 2. At the conclusion of the high flow-rate test, the platform would be recovered from the bottom and hoisted onto the deck of its mother ship.

4.2.5 NOZZLE EXCHANGE/CO_2 RESTOCKING

No experiments would be conducted on Day 5. The time would be spent changing the nozzle assembly, maintaining and repairing the equipment, conducting ROV or submersible dives and CTD casts and, if necessary restocking the CO_2. If necessary, the mother ship might make port in Kawaihae Harbor to pick up the additional CO_2 or parts. If this were not necessary, it would maintain position in the general area of the experimental site.

4.2.6 DEPLOYMENT 2: 0.25 CENTIMETER NOZZLE OPENINGS (EXP 4 THROUGH EXP 6)

The same activities would be conducted during the second deployment of the discharge platform as were conducted during the first. The only differences would be that this series of experiments would be conducted using a nozzle assembly with orifices 0.25 centimeters in diameter instead of the 0.40-centimeter orifices used in Deployment 1 and the low release sequence would be shorter. Because the researchers and equipment operators would have the benefit of lessons learned during the first deployment, it is anticipated that the experiments (4 through 6) that would be conducted during the Deployment 2 could be completed in approximately two days (i.e., on Day 6 and Day 7). This is one day less than is planned for the first deployment of the platform. If the activities were completed on time, activities during Day 8 would be limited to the collection of post-test experiment samples and additional CTD casts.

4.3 CONTINGENCY PLANS

The plans for the proposed experiment have been developed using the best available scientific information concerning the probable behavior of the cloud of CO_2 droplets and the plume of carbon-enriched water. The analyses that have been conducted to-date indicate that the release will have a very limited effect on water quality or biota. Real-time collection and display of pH data combined with visual monitoring of biota in the surrounding environment and the test organisms carried outside the ROV or submersible will provide researchers an immediate warning of unanticipated results. Spotters aboard ship will be dedicated to observation of the surface waters above the release site to provide early warning of any approaching threatened or endangered species as well as any unanticipated surfacing and flashing of CO_2.

The experimental activities would be reviewed and, if necessary, modified under the following conditions:

- Scientists observe unusual mortality of the trapped organisms (e.g., amphipods, decapod shrimp and teleost fishes) carried on the outside of the ROV or manned submersible.[3]
- Biologists observe unusual mortality of fish, squid, or other free-swimming organisms in the water column. This decision will be based on the professional judgment of the scientist in charge of the biological component of the experiment.
- Biologists observe unusual mortality of benthic organisms.
- Scientists observe that a stream of CO_2 droplets is reaching the surface.
- pH levels below 6.0 are observed more than 100 meters from the point of release.
- Threatened or endangered species are observed by the submersible in the vicinity of the release point.
- Significant numbers of sensitive species are observed in the impacted area.
- Large aggregations of organisms are observed transiting the area in or near the CO_2 enriched plume.
- Noise levels measured by the hydrophones are substantially higher than expected and real-time visual observations by the project biologists indicate that these noise levels are affecting the behavior of macrofauna near the test platform.
- The spotters on the ship observe substantial aggregations of any threatened or endangered species.

It is impossible to pre-determine the most appropriate response for each of these occurrences. However, if the biologist in charge determines that it is appropriate, and with the concurrence of the chief scientist, the biologist will direct the data collection undertaken by the ROV/RTV/manned submersible during the remainder of the test release during which the effect is observed. If the chief biologist determines that the effects are not significant, the primary experiments will resume. If the biologist determines that the effects may be significant, the experimental protocol (e.g., release rate or duration) would be modified (including the possibility of suspension or termination of the releases) as agreed upon between the chief scientist and the chief biologist.

Laboratory observations suggest that short duration exposure to pH levels within 2 points of ambient do not visibly harm marine life. This experiment provides an opportunity to examine the response of marine life to elevated CO_2 levels and depressed pH in situ. Scavenger traps deployed the day before the experiments will provide organisms that can be directly observed in the plume during the experiment. Observation of these organisms during and after the CO_2 release will provide the first

[3] Baited traps would be placed on the seafloor in the study area the day before the experiment. On the day of the experiment, one trap would be placed in the ROV or submersible's equipment rack where it can be observed in real-time using a video camera. A pH meter would be placed close to the trap.

behavioral and physiological observations of organisms stressed in such a manner. Trapped organisms will experience a more intense and longer duration exposure to the plume than organisms free in the environment.

4.4 CLOSING NOTE

The environmental assessment that was prepared for the proposed project conservatively assumed that as a worst-case, the platform could be deployed up to 10 times over the course of two weeks. As planning has progressed, it has been determined that the scientific objectives could be achieved with substantially fewer deployments of the platform.

The detailed scheduling described above assumes just two deployments. It is possible that equipment failure, the sudden arrival of adverse weather or sea conditions, or other factors could lead researchers to split the tests over as many as three additional deployments (for a total of 5). This would not change the amount of liquid CO_2 that is discharged or substantially alter other aspects of the project.