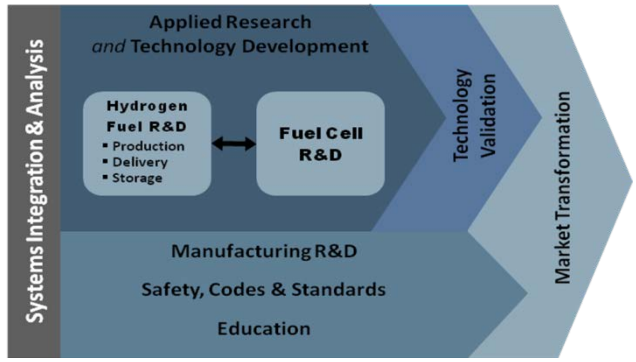
4.0 Systems Analysis



The Fuel Cell Technologies Program (FCT Program) conducts a coordinated, comprehensive effort in modeling and analysis to clarify where hydrogen and fuel cells can be most effective from an economic, environmental, and energy security standpoint, as well as to guide RD&D priorities and set program goals. These activities support the FCT Program's decision-making process by evaluating technologies and pathways and determining technology gaps, risks, and benefits.

The Systems Analysis sub-program works at all levels of the program, including technology analysis for specific sub-programs, policy and infrastructure analysis, and high-level implementation and market analysis. Examples of activities include pathway analysis for hydrogen production, evaluating impacts of technology advancements on fuel cell cost, feasibility studies of combined heat, hydrogen and power production from stationary fuel cells, analyzing impacts of hydrogen quality on fuel cell performance and infrastructure, and complete "well-to-wheels" or life-cycle analysis of pathways to determine reductions in greenhouse gas emissions and petroleum use. Risk analysis is also performed to determine the effects of certain variables on the likelihood of meeting program targets and to help identify risk mitigation strategies. Policy analyses include investigating the effects of different policy options and scenarios, infrastructure and resource analysis, vehicle consumer choice analysis, and market penetration studies. Analysis of employment opportunities and needs, manufacturing capability and growth potential, and overall domestic competitiveness are also a critical part of the sub-program's activities.

To perform these analyses, the sub-program utilizes a diverse portfolio of models, including cost models such as Hydrogen Analysis (H2A), technology performance models such as Autonomie which is an improved version of the previous PSAT (Powertrain Systems Analysis Toolkit) vehicle simulation model, economic models such as NEMS (National Energy Modeling System), MARKAL (Market Allocation model), agent-based models, emissions models such as GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation), and integrated models, such as the Macro-System Model and Hydrogen Demand and Resource Analysis. The FCT Program is dually focused on using established models to address analysis gaps, and on enhancing existing models to broaden analysis capabilities.

4.1 Technical Goal and Objectives

Goal

Provide system-level analysis to support hydrogen and fuel cell technologies development and technology readiness by evaluating technologies and pathways including resource and infrastructure issues, guiding the selection of RD&D projects, and estimating the potential value of RD&D efforts.

Objectives

- By 2012, complete the evaluation of hydrogen for energy storage and as an energy carrier to supplement energy and electrical infrastructure.
- By 2012, complete the evaluation of fueling station costs for early vehicle penetration to determine the cost of fueling pathways for low and moderate fueling demand rates.
- By 2014, complete environmental studies that are necessary for technology readiness.
- By 2018, complete analysis of program performance, cost status, and potential for use of fuel cells for a portfolio of commercial applications.
- By 2019, complete analysis of the potential for hydrogen use in stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling equipment. The analysis will address necessary resources, hydrogen production, transportation infrastructure, performance of stationary fuel cells and vehicles, and the system effects resulting from the growth of fuel cell market shares in the various sectors of the economy.
- Provide milestone-based analysis (including risk analysis, independent reviews, financial evaluations and environmental analysis), to support the FCT Program's needs prior to technology readiness.
- Periodically update the life-cycle energy, petroleum use, greenhouse gas, and criteria emissions analysis for technologies and pathways for FCT Program to include technological advances or changes.

4.2 Technical Approach

The overall approach to implementing a robust Systems Analysis capability is based on the need to support FCT Program decision-making processes and milestones, to provide independent analysis when required to validate decisions and/or ensure objective inputs, and to respond to external review recommendations. Systems analysis generates outputs necessary to support programmatic needs, which include recommendations, reports, independent reviews, validation results, and supporting data. As depicted in Figure 4.2.1, the outputs are supported by fuel cell and hydrogen technologies transformation scenarios for environmental, economic, and other analyses. The analyses are dependent upon tools that the program is developing and/or modifying. Both the analyses and tools are dependent upon the framework that has been developed and are continuously updated. To ensure the analysis effort is focused, objective, and effective, internal and external peer reviews are conducted, annually and biennially (respectively).

The Systems Analysis sub-program continues to address relevant issues including infrastructure development, resource availability, life-cycle benefits, and domestic competitiveness. Examples of key focus areas include:

Model Development and Validation

- Validate analytical models with real-world data and refine models as required.

Technology Analysis and Quantification of Benefits

- Determine the potential for hydrogen as an energy storage medium or energy carrier to optimize the use of intermittent renewable resources such as wind and solar.
- Quantify the benefits of integrating hydrogen fuel production with stationary fuel cell power generation.
- Evaluate the potential for biogas, landfill gas, and stranded hydrogen streams as renewable fuel for stationary fuel cell power generation.
- Assess the Life Cycle Analysis (LCA) benefits of hydrogen and fuel cells for diverse applications and conduct a rigorous comparison to incumbent and emerging technologies such as gasoline engines and battery electric vehicles.

Infrastructure Analysis

- Work with industry and other stakeholders to assess and identify infrastructure scenarios and options for both long term transportation needs and early market opportunities for hydrogen and fuel cells.

Market and Policy Analysis

- Assess opportunities for diverse applications of fuel cells; including the potential for job growth, workforce development needs, manufacturing capacity, and the effects of a federal fuel cell acquisition program on fuel cell costs and market sustainability.

Studies and Analysis

Planned studies and analysis are separated into the following categories: understanding the initial phases of the fuel cell and hydrogen technologies early market penetrations; understanding the long-term potential and issues of fuel cell and hydrogen technologies; environmental analysis; and cross-cutting analytical studies that require quick response.

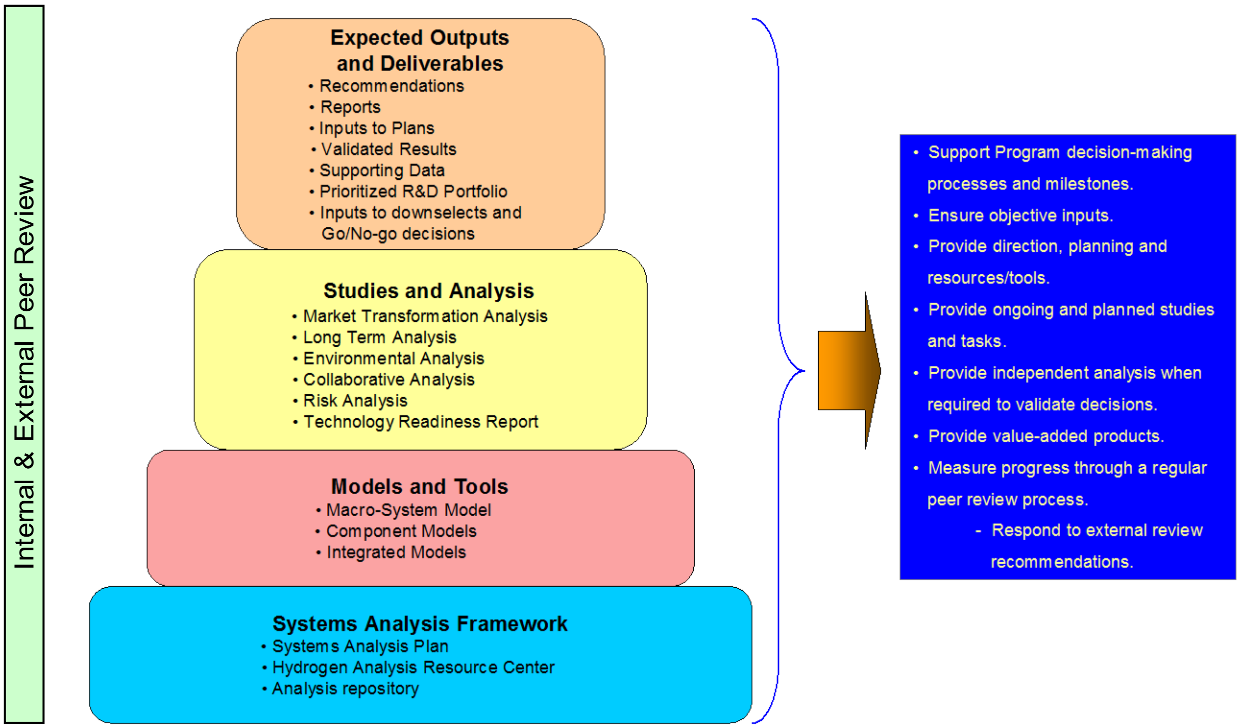


Figure 4.2.1 Systems analysis approach overview

Hydrogen Threshold Cost

In 2010, the Program developed a new hydrogen competitive threshold cost to replace the previous hydrogen cost goal. The hydrogen competitive threshold cost, which is independent of the production and delivery pathway, was adjusted from \$2 – \$3 per gallon of gasoline equivalent (gge) (untaxed) to <\$4 per gge (untaxed). The new hydrogen threshold cost is based on the Energy Information Administration’s 2009 forecast of gasoline cost in 2020 and the fuel economy and incremental vehicle cost of hydrogen fuel cell vehicles relative to hybrid electric vehicle technologies in 2020.

The methodology used ensures that consumers’ operating cost (in \$/mile) in a hydrogen fuel cell vehicle will be equal to or less than the competitive gasoline hybrid electric vehicle in 2020. The new hydrogen threshold cost is expressed as a range, which reflects the variability in future fuel efficiency improvement factors, competitive gasoline cost, and vehicle costs. The threshold cost guides the Department’s execution of its hydrogen and fuel cell research and development responsibilities. The threshold cost includes the cost of delivery but excludes taxes, and it is expressed in 2007 dollars.

Market Transformation Analysis

Analysis is focused on assessing the early market introduction of fuel cells for backup, emergency, and remote power generation and specialty vehicles. Analysis also determines the potential for reducing fuel cell cost through economies of scale and the application of lessons learned. Potential technology pathways are modeled and analyzed to determine application requirements (targets), cost, risk, environmental consequence, and societal impact. From these analyses, key cost and technology barriers/gaps are identified, which further define and update the key RD&D needs and plans within each sub-program. In addition, future analyses will be undertaken to update energy, environmental impact, and financial impact/risk projections. This wide range of analyses is required to provide the necessary information about the fuel cell costs, infrastructure, resource requirements and availability, fuel quality, cost and profitability, and life-cycle emissions.

FCT Program-sponsored analyses include assessments of the impacts of government purchases and incentives on fuel cell cost reduction, as well as progress in capitalizing on the economies of scale for manufacturing and potential market penetration. These analyses yield reports and critical information, similar to the Oak Ridge National Laboratory 2011 report *Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities*[1], critical to guiding sub-program target development.

Long-term Analysis

Long-term analysis involves the same focus areas that are addressed by market transformation and social-economic analyses. These analyses, however, entail the investigation of stationary fuel cells for combined heat and power and impact a larger economic sector than the early adopter applications. Long-term analysis requires an understanding of both the availability and the constraints of the hydrogen feedstocks required to fuel stationary and transportation fuel cell applications. Likewise, the importance of centrally produced hydrogen and the potential integration of hydrogen delivery with the natural gas infrastructure merit ongoing analysis.

Future market penetration will continue to have a positive social-economic impact on the creation of domestic jobs. FCT Program's job modeling tool enables examinations of the analysis of the national job growth and regional impacts of specific fuel cell manufacturing installations. This analytical tool assesses job growth and provides job estimates by application sector, such as material handling and distributed power.

Environmental Analysis

This work focuses on completing all environmental analyses necessary before technology readiness. Initial studies involve understanding the potential effects of hydrogen and its infrastructure on the environment. The studied effects include both primary (releases of hydrogen to the atmosphere, construction of pipelines and their associated ecological impacts, materials used for fuel cells, hydrogen storage and other components of the hydrogen systems), as well as secondary effects (i.e., changes in urban criteria pollutants and greenhouse gas (GHG) emissions). Environmental data

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[1] Greene D., Oak Ridge National Laboratory, K. Duleep, ICF International, G. Upreti, University of Tennessee, (2011). *Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities* ORNL/TM-2011/101, Oak Ridge National Laboratory, Oak Ridge, TN, May.

produced from sub-program projects are compiled and analyzed to support Go/No-Go decisions and independent reviews.

Analyses assess greenhouse gas emissions and criteria emissions on a life cycle basis for multiple fuel cell applications and fuel pathways on an ongoing basis. The results are intended to identify benefits for fuel cell applications.

Models and Tools

Systems analysis models include component models (simulate individual portions of hydrogen and fuel cell scenarios), integrated models (economic and environmental factors), and the macro-system model (MSM) that links other models and facilitates consistency and communication between them. Modeling tools provide the basis for analyzing alternatives in terms of their cost, performance, benefit, and risk impacts on the macro system. Analysis is done across key activity boundaries such as using stationary fuel cells to supply heat and power for buildings and to generate hydrogen for specialty and light duty vehicle fuel supply.

To ensure model integrity and analysis consistency, the models are updated and validated with data and information from sub-program projects, independent reviews, and technology validation.

Macro-System Model

The macro-system model (MSM) is a structure that links other existing and emerging models to perform cross-cutting analysis of engineering issues. A number of models exist to analyze components and subsystems of the long-term applications of hydrogen; however, the MSM integrates many of them via a common architecture and calculates overall results (i.e., treating the overarching hydrogen fuel infrastructure as a system). The primary objective of the MSM is to support programmatic decisions regarding investment levels and to focus funding. The MSM also facilitates consistency between models due to its use of common terms and techniques to facilitate information transfer.

Component Models

These models are engineering models used individually to generate technology-specific information and perform techno-economic analyses. Examples of these models are the Fuel Cell Power (FC Power), H2A Production and the Hydrogen Delivery Scenario Analysis (HDSAM v2.2) models. The FC Power and H2A Production models are standardized tools for economic calculations of various stationary fuel cell configurations and hydrogen production technologies. These models are publicly available and enable analysis for a number of different production technologies and pathways. The publicly available HDSAM model has been developed for both delivery component cost and specific delivery scenario cost estimation.

Vehicle costs and performance required for FCT Program analysis are estimated with the Argonne National Laboratory (ANL) Model Autonomie.

Integrated Models

Multiple integrated models are engineering models that have been modified to answer overarching fuel cell and hydrogen related questions, including impacts of various policy actions on hydrogen and fuel cell technologies. The models include the following: HyTrans (for transition to fuel cells studies); an Agent-Based Modeling System; Market Allocation (MARKAL) with fuel cell and hydrogen representation; and the Production Infrastructures Options model. Additionally, the GREET model (used for life-cycle energy and emissions analysis) and SERA (Scenario Evaluation and Regionalization Analysis), which is an infrastructure assessment model, are used for programmatic analysis.

Systems Analysis Framework

The systems analysis framework is designed to support all modeling and analysis efforts. It involves establishing a source of consistent data for analytical efforts, determining and prioritizing the analysis tasks, organizing them so that they use consistent techniques and data, and formatting the results so that they can be easily found and used for decision making.

Systems Analysis Plan

A Systems Analysis Plan (SAP) details the overall approach, tasks and processes for the systems analysis efforts of the sub-program. It defines how specific analysis activities relate to the objectives of the overall FCT Program. The SAP contains a catalog of resources, the systems analysis processes, and the analysis results of past studies.

Hydrogen Analysis Resource Center (HyARC)

A technical data management system has been developed to provide a consistent database, a list of assumptions, information standards and tools for analytical activities supporting the sub-program. This analysis resource center provides data for standardized input to analysis activities and helps ensure consistency in the analyses conducted by the sub-program. The database is updated annually and made available to the community of analysts (DOE, national laboratories, universities, private companies, etc.) at http://hydrogen.pnl.gov/cocoon/morf/hydrogen.

Analysis Repository

A repository of technical analysis and evaluation activities has been established. The repository is a web-based database that contains information on analysis and modeling projects and results. It is available at http://www.hydrogen.energy.gov/analysis_repository/ and is updated periodically to ensure that the analytical activities provide direction, focus, and support to the FCT Program's research and development activities.

4.3 Systems Analysis Collaboration

This plan only describes the specific activities performed and funded by the Systems Analysis sub-program of the FCT Program. However, the analytical activities needed to support the entire DOE Hydrogen and Fuel Cells Program are more extensive, and to a large degree, coordinated by and performed in collaboration with the efforts described in this section. These include the following:

- **Analysis activities sponsored by FCT sub-programs:** Sub-programs fund analysis projects which address specific issues relevant to the sub-program and target results to help determine future RD&D focus. The Technology Validation and Production and Delivery sub-programs conduct scenario analysis to improve understanding of the impact of infrastructure development on early market penetration of fuel cells.
- **Hydrogen analysis efforts sponsored by other DOE Offices:** The Office of Fossil Energy and the Office of Nuclear Energy, Science and Technology each perform analysis to support their respective RD&D efforts in the production of hydrogen. These activities are coordinated with Systems Analysis and are reflected in the overall Analysis Portfolio maintained by the Systems Analysis organization for the entire DOE Program.
- **Corporate analyses:** Within EERE, the corporate analysis team performs policy and benefits analysis across the EERE portfolio, but also specifically in support of individual programs – such as the Fuel Cell Technologies Program. The Technology Analyst and Systems Integrator coordinate analyses and studies with this team to ensure the synergy and timeliness of the policy and benefits analysis to support program needs.
- **Coordinated analyses:** Analyses include vehicle life cycle cost, energy use, greenhouse gas emission analysis with Vehicle Technologies and Biomass Programs. An example of this analysis is shown in Figure 4.3.1. Other coordinated analyses include the levelized cost of electricity from a portfolio of technologies including stationary fuel cells with the Office of Electricity, and the Wind and Solar Programs.

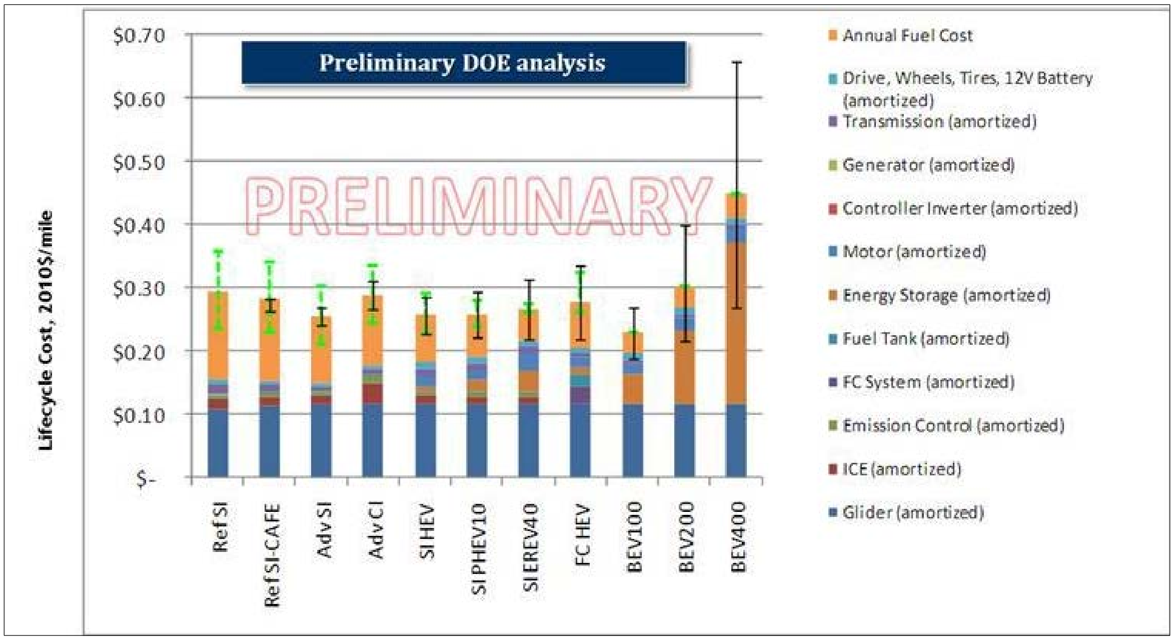


Figure 4.3.1 Lifecycle Costs of Advanced Vehicles

- **External reviews and analyses:** These include such external activities as reviews by the National Academy of Sciences, efforts under the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), and future international work which might be undertaken by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). Although by their nature these are independent of the FCT Program, the Technology Analyst is typically involved in briefing these organizations on program status and needs, participating in working groups which frame the analytical elements, and interpreting the results for use by the program.

4.4 Programmatic Status

Current Activities

Major Systems Analysis activities are listed in Table 4.4.1.

Table 4.4.1 Current Systems Analysis Activities

Task	Subtask	Approach	Organization
Perform Studies and Analysis	Early market analysis	Conduct analysis of infrastructure requirements and cost for the early market emergence of fuel cells for stationary and backup power, material handling equipment, and light duty transportation	Multiple DOE national laboratories, academia, industry and stakeholders
	Production and delivery infrastructure analysis	Analysis of the ability of the fossil, nuclear, and renewable energy infrastructures, as well as the electrical grid, to support hydrogen production facilities	National Renewable Energy Laboratory (NREL): Infrastructure Development Analysis
	Resource analysis	Quantify location, amount, and cost of resources used to produce hydrogen and develop Geographical Information System (GIS) resource maps for use in infrastructure development studies	NREL: GIS studies of renewable resources for hydrogen
	Life-cycle energy and emissions analysis	Conduct life-cycle energy and emissions analysis to compare existing and developing transportation and stationary technologies in terms of emissions and total energy requirements	ANL and NREL: Analysis of life-cycle energy and emissions associated with stationary fuel cells and fuel cell vehicles using the GREET model, with Macro-System Model interface

Table 4.4.1 Current Systems Analysis Activities (continued)			
Task	**Subtask**	**Approach**	**Organization**
Provide Support Functions and Conduct Reviews	Develop Macro-System Model computational infrastructure	Develop a modeling system to link component and integrated hydrogen models	Sandia National Laboratories (SNL): Developing the enterprise modeling system, including a user interface to allow users from across the country to access the MSM
	Maintain and upgrade H2A production and delivery, and FCPower Models	Maintain and upgrade cash flow tool to determine potential economic viability of hydrogen and fuel cell technologies	NREL: Standards and tools for consistent analysis of hydrogen technologies.
	Maintain and upgrade SERA Model	Maintain and upgrade the model that supports analysis of generalized regional energy issues related to hydrogen	NREL: Geographic-specific hydrogen infrastructure model to study hydrogen production and its interface to the electric grid
	Maintain and upgrade HyTrans	Maintain and upgrade the model that analyzes vehicle selections by consumers and those effects on energy cost	Oak Ridge National Laboratory (ORNL): HyTrans hydrogen infrastructure model to study fuel cell vehicle market penetration
	Maintain and update hydrogen capabilities in the MARKAL	Maintain and update hydrogen analysis capabilities of the MARKAL Model to support the impact analysis of hydrogen production on U.S. energy markets	Brookhaven National Laboratory (BNL)
	Maintain and update Production Infrastructure Options Model	Develop model for use in hydrogen production infrastructure options analysis	Directed Technologies, Inc.
	Maintain and Update the HyARC	Keep the modeling information in the web-based HyARC up-to-date and add new data as required by analysts and modelers	Pacific Northwest National Laboratory (PNNL)

4.5 Technical Challenges

The following discussion details the various technical and programmatic barriers that must be overcome to attain the Systems Analysis goal and objectives.

Barriers

A. Future Market Behavior

Understanding the behavior and drivers of the fuel cell, fuel, and vehicle markets are necessary to determine the long-term applications. Other major issues include the hydrogen supply infrastructure, vehicle supply interaction with fuels supply, and the requirements to meet demand. To analyze various hydrogen fuel and vehicle scenarios, models need to be developed to understand these issues and their interactions.

B. Stove-piped/Siloed Analytical Capability

Analytical capabilities and resources have been largely segmented functionally by sub-program (production, storage, fuel cells, etc.) and organizationally by DOE office (EERE, Fossil Energy, Nuclear Energy, and Science) as well as by performers/analysts (laboratories, specialized teams, industry/academia, etc.). Successful systems analysis requires the coordination and integration of analysis resources across all facets of the analytical domain.

C. Inconsistent Data, Assumptions and Guidelines

Analysis results are strongly influenced by the data sets employed, as well as the assumptions and guidelines established to frame the analytical tasks. These elements have been largely uncontrolled in the past, with individual analysts and organizations making their own value decisions. Although this approach does not necessarily make the results wrong, it does make it more difficult to put the results and ensuing recommendations in context with other analyses and the overall objectives of the FCT Program. Establishing a Program-endorsed consistent set of data, assumptions, and guidelines is challenging because of the large number of stakeholders involved and the breadth of technologies and system requirements.

D. Insufficient Suite of Models and Tools

The program currently has a group of models to use for analysis; however, the models are not sufficient to answer all analytical needs. A macro-system model is necessary to address the overarching hydrogen infrastructure as a system. Improvement of component models is necessary to make them more useable and consistent. Model validation is required to ensure credible analytical results are produced from the suite of modeling tools

E. Unplanned Studies and Analysis

Every year, many analysis questions are raised that require analysis external to, and, in some cases, instead of the plans made for that year. Many analysis questions need responses in brief periods of time, particularly when they are driven by priority requests or needs (DOE senior management, Congress, OMB [Office of Management and Budget], HTAC, etc.). An approach for accommodating both unforeseen, real time assessment requirements as well as planned FCT Program analysis is necessary.

4.6 Technical Task Descriptions

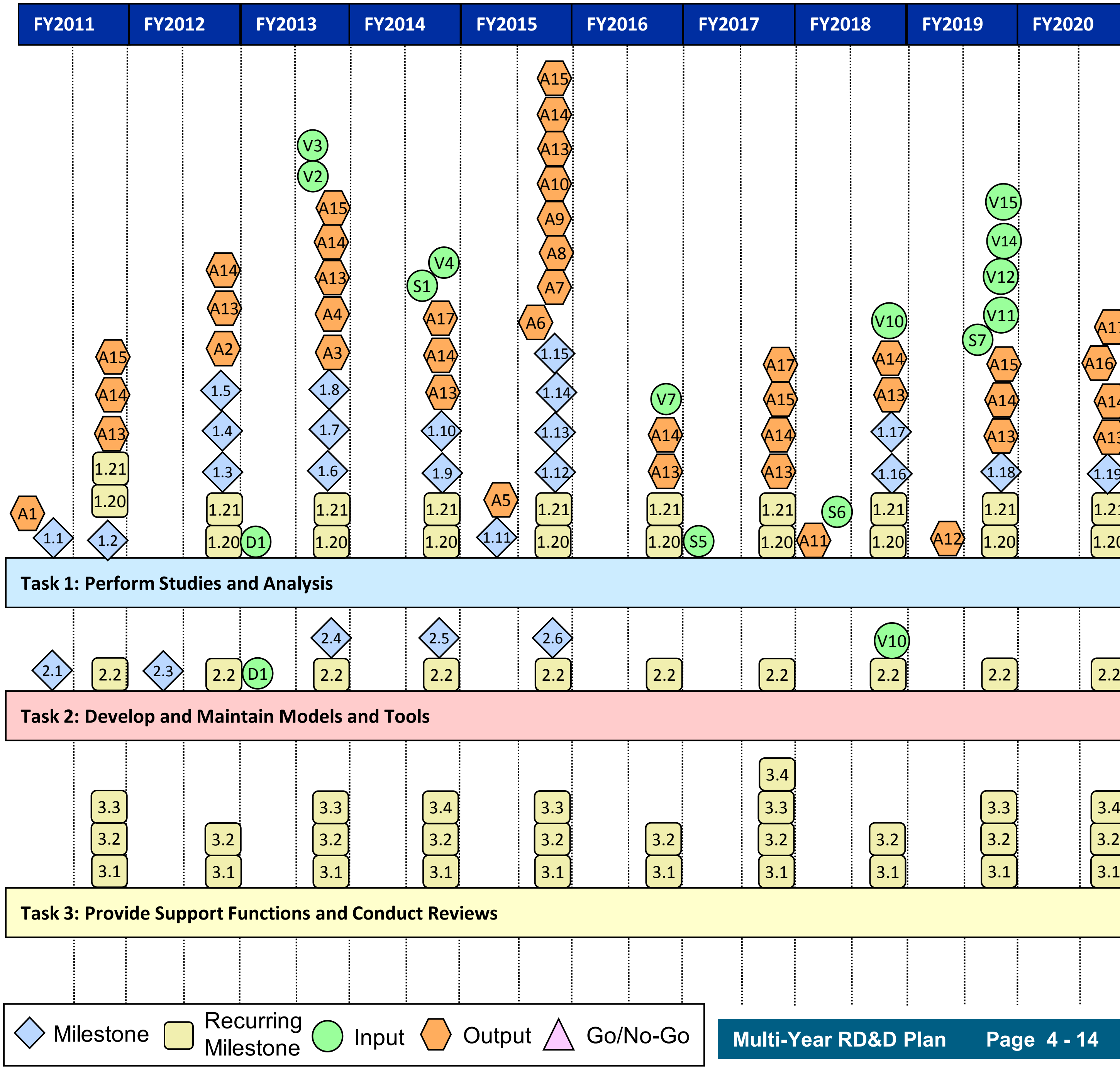
The technical task descriptions are presented in Table 4.6.1.

Table 4.6.1 Current Systems Analysis Activities		
Task	**Description**	**Barriers**
1	**Perform Studies and Analysis** • Analyze issues related to infrastructure for fuel and resource supply, including the effects on vehicle options customers have and how they make those decisions, non-vehicular hydrogen use, feedstock quality issues for fuel cells, cost/profitability analysis, and life-cycle energy and emissions analysis • Analyze early market opportunities for fuel cell applications including auxiliary power units (APUs), specialty vehicles, and stationary and backup power generation • Analyze the long-term impact of hydrogen fuel and vehicles, including the necessary infrastructure development, vehicle options, resource analysis, fuel quality analysis, cost/profitability analysis, and life-cycle energy and emissions analysis • Analyze environmental impact assessments • Perform risk analysis across FCT sub-programs • Conduct collaborative analyses with other DOE offices, and other government organizations, and international organizations	A, B, D, E
2	**Develop and Maintain Models and Tools** • Maintain and update H2A, HDSAM, FCPower model, and the Macro-System Model • Provide the following component models: geographic models; H2A production models; HDSAM; and FCPower model • Maintain the following integrated models: infrastructure models; hydrogen capabilities in MARKAL; the Hydrogen Infrastructure Options model; GREET; and SERA	A, B, C, D
3	**Provide Support Functions and Conduct Reviews** • Maintain and update the Hydrogen Analysis Resource Center through a configuration-managed change process • Maintain and update the Analysis Repository • Provide other support to the program and other organizations • Conduct workshops and conferences to focus and highlight program and hydrogen-related analysis activities • Utilize reviews and a working group to continuously improve Systems Analysis	B, C

4.7 Milestones

The following chart shows the interrelationship of milestones, tasks, supporting inputs from other FCT sub-programs, and technology/analytical outputs from the Systems Analysis function from FY 2011 through FY 2020. The inputs/outputs are also summarized in Appendix B.

Systems Analysis Milestone Chart



Task 1: Perform Studies and Analysis	
1.1	Complete an analysis of the hydrogen infrastructure and technical target progress for hydrogen fuel and vehicles. (2Q, 2011)
1.2	Update well-to-wheels analysis and quantify reductions in petroleum use, greenhouse-gas emissions, and criteria pollutant emissions. (Q4, 2011)
1.3	Complete analysis of the impact of biogas quality on stationary fuel cell cost and performance. (4Q, 2012)
1.4	Complete evaluation of fueling station costs for early vehicle penetration to determine the cost of fueling pathways for low and moderate fueling demand rates. (4Q, 2012)
1.5	Complete evaluation of hydrogen for energy storage and as an energy carrier to supplement energy and electrical infrastructure. (4Q, 2012)
1.6	Complete analysis of biogas availability for stationary power generation and hydrogen production. (4Q, 2013)
1.7	Complete analysis of job impact for fuel cell growth in material handling equipment sector through 2020. (4Q, 2013)
1.8	Determine economies of scale required for government ramp down of funding for RD&D. (4Q, 2013)
1.9	Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness. (4Q, 2014)
1.10	Complete analysis of job impact for fuel cell growth in distributed power generation sector through 2020. (4Q, 2014)
1.11	Complete analysis of the impact of hydrogen quality on the hydrogen production cost and the fuel cell performance for the long range technologies and technology readiness. (2Q, 2015)
1.12	Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (4Q, 2015)
1.13	Complete environmental analysis of the technology environmental impacts for hydrogen and fuel cell scenarios and technology readiness. (4Q, 2015)
1.14	Complete analysis of the job impact from fuel cell growth in stationary power generation sector through 2020. (4Q, 2015)
1.15	Complete analysis of program milestones and technology readiness goals - including risk analysis, independent reviews, financial evaluations, and environmental analysis - to identify technology and risk mitigation strategies. (4Q, 2015)
1.16	Complete analysis of program performance, cost status, and potential use of fuel cells for a portfolio of commercial applications. (4Q, 2018)

1.17	Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
1.18	Complete life cycle analysis of vehicle costs for fuel cell electric vehicles compared to other vehicle platforms. (4Q, 2019)
1.19	Complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling equipment including resources, infrastructure and system effects resulting from the growth in hydrogen market shares in various economic sectors. (4Q, 2020)
1.20	Complete review of fuel cell and hydrogen markets. (4Q, 2011 through 4Q, 2020)
1.21	Complete review of commercial products and patents resulting from government funding for fuel cell and hydrogen technology R&D. (4Q, 2011 through 4Q, 2020)

Task 2: Develop and Maintain Models and Tools	
2.1	Complete the 2nd version of the Macro-System Model to include the analytical capabilities to evaluate the electrical infrastructure. (2Q, 2011)
2.2	Annual model update and validation. (4Q, 2011 through 4Q, 2020)
2.3	Complete development of job estimation model. (2Q, 2012)
2.4	Complete validation of job estimation model for material handling equipment sector. (4Q, 2013)
2.5	Complete validation of job estimation model for distributed fuel cell power generation. (4Q, 2014)
2.6	Complete validation of job estimation model for stationary fuel cell power generation. (4Q, 2015)

Task 3: Provide Support Functions and Conduct Reviews	
3.1	Annual update of Analysis Portfolio. (4Q, 2011 through 4Q, 2020)
3.2	Annual update of Hydrogen Analysis Resource Center. (4Q, 2011 through 4Q, 2020)
3.3	Complete review of status and outlook of non-automotive fuel cell industry. (biennially from 4Q, 2011 through 4Q, 2019)
3.4	Review Hydrogen Threshold Cost status. (4Q, 2014; 4Q, 2017; 4Q, 2020)

Outputs

A1 Output to Systems Integration: Report on the status of the technologies and infrastructure to meet the demands for the hydrogen fuel and vehicles. (1Q, 2011)

A2 Output to Fuel Cells: Cost of competing vehicle powertrain. (4Q, 2012)

A3 Output to Delivery and Storage: Preliminary well-to-wheel power plant efficiency analysis for advanced material systems. (4Q, 2013)

A4 Output to Delivery: Analysis for costs for optimal hydrogen pressure contributions at each point in the system from production to dispensing at point of use. (4Q, 2013)

A5 Output to Program: Update on hydrogen delivery and refueling data for well to power plant efficiency analysis for advanced material systems. (2Q, 2015)

A6 Output to Storage: Report on the status of composite tank costs. (3Q, 2015)

A7 Output to Program: Update on onboard automotive fuel cell system power, input pressure, and vehicle refill time. (4Q, 2015)

A8 Output to Systems Integration: Report on the results of the infrastructure analysis for the long term technologies and requirements for technology readiness. (4Q, 2015)

A9 Output to Storage: Update on onboard automotive fuel cell system power, input pressure, degree of hybridization and vehicle refill time. (4Q, 2015)

A10 Output to Systems Integration: Report on the environmental analysis of the Hydrogen and Fuel Cells Program. (4Q, 2015)

A11 Output to Storage: Report on the projected performance of materials-based systems for onboard hydrogen storage. (1Q, 2018)

A12 Output to Storage: Report on the status of advanced materials system costs. (2Q, 2019)

A13 Output to Education and Program: Annual market reports on status of fuel cell and hydrogen industry. (4Q, 2011 – 2020)

A14 Output to Program: Annual report on the status of commercial products and patents resulting from government funded R&D. (4Q, 2011 – 2020)

A15 Output to Education and Program: Report on the status of government policies on non-automotive fuel cell industry. (4Q, 2011; 4Q, 2013; 4Q, 2015; 4Q, 2017; 4Q, 2019)

A16 Output to Storage: Report on the projected performance of hydrogen storage systems for non-automotive applications. (3Q, 2020)

A17 Output to Program: Revised hydrogen threshold cost based on fuel and automotive technology advances, if required. (4Q 2014; 4Q, 2017; 4Q, 2020)

Inputs

D1 Input from Delivery: Delivery pathways that can meet an as-dispensed hydrogen cost of <$4/gge ($1/100ft3) for emerging fuel cell powered early markets. (1Q, 2013)

S1 Input from Storage: Update status of composite tank costs. (3Q, 2014)

S5 Input from Storage: Projected performance of materials-based systems for onboard hydrogen storage. (1Q, 2017)

S6 Input from Storage: Update status of advanced materials system costs. (2Q, 2018)

S7 Input from Storage: Projected performance of hydrogen storage systems for non-automotive applications. (3Q, 2019)

V2 Input from Technology Validation: Validate achievement of a refueling time of 3 minutes or less for 5 kg of hydrogen at 5,000 psi using advanced communication technology. (3Q, 2012)

V3 Input from Technology Validation: Publish/post composite data products for material handling and backup power, including safety event data. (3Q, 2012)

V4 Input from Technology Validation: Validate stationary fuel cell system that co-produces hydrogen and electricity and report on durability and efficiency. (4Q, 2014)

V7 Input from Technology Validation: Validate novel hydrogen compression technology durability and efficiency. (4Q, 2016)

V10 Input from Technology Validation: Validate distributed production of hydrogen from electrolysis at a projected cost of $3.90/kg with an added delivery cost of <$4/gge. (4Q, 2018)

V11 Input from Technology Validation: Validate station compression technology provided by the delivery team. (4Q, 2019)

V12 Input from Technology Validation: Validate light duty fuel cell vehicle durability. (4Q, 2019)

V14 Input from Technology Validation: Validate liquefaction technology provided by the delivery team. (4Q, 2019)

V15 Input from Technology Validation: Validate pipeline technology provided by the delivery team. (4Q, 2019)