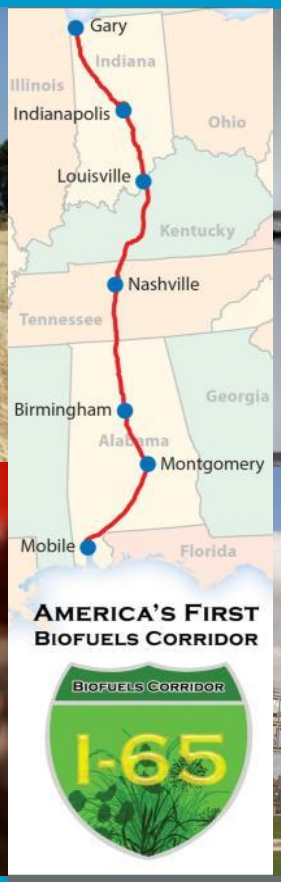
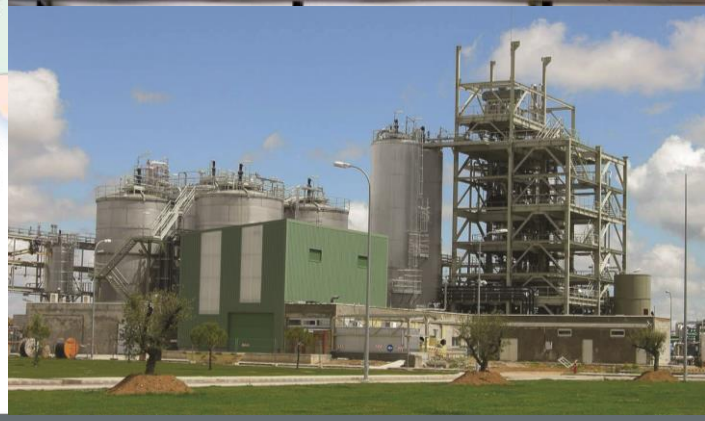




"Wet" Waste-to-Energy

3/18/2015

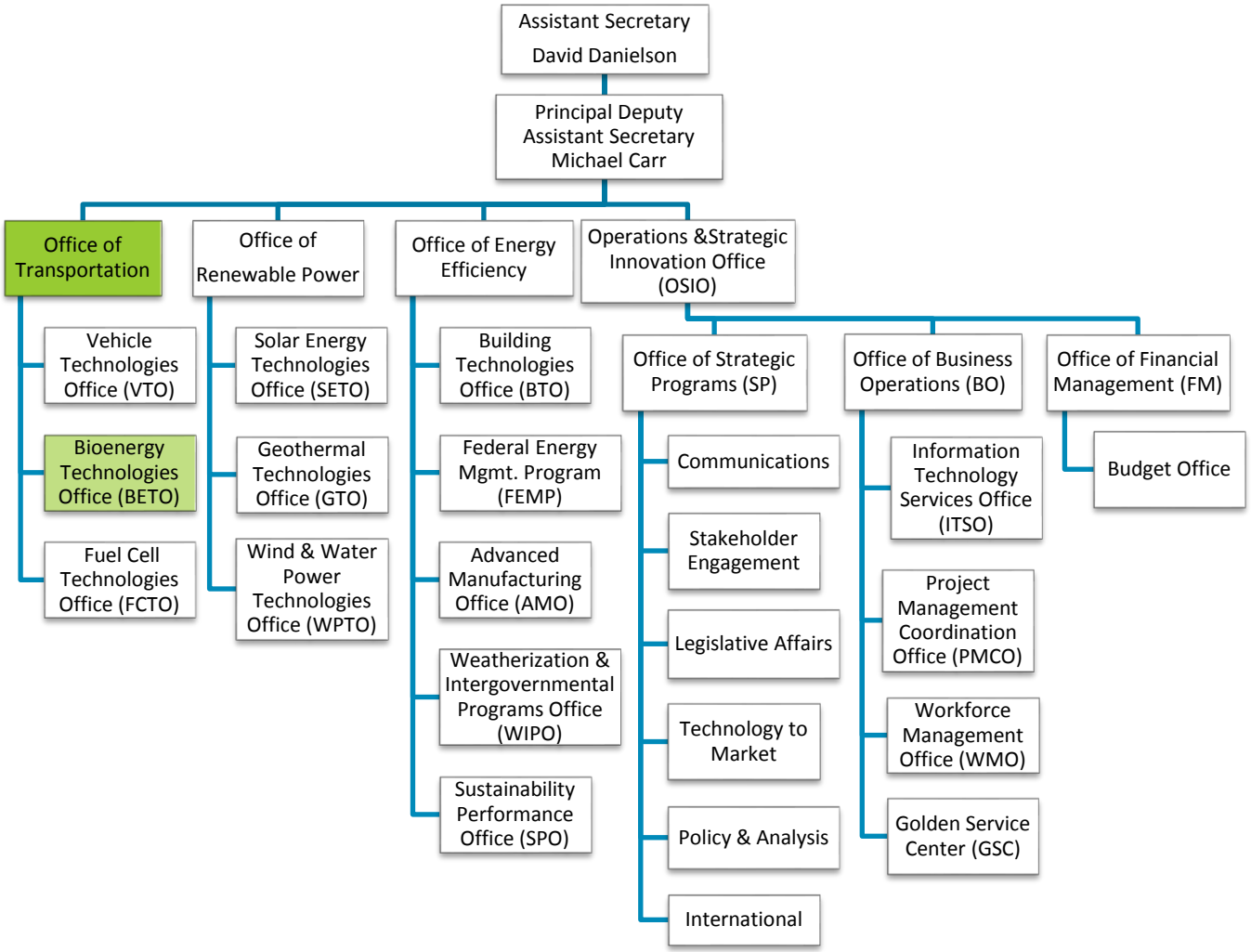
Jonathan L. Male

Director,
Bioenergy Technologies Office

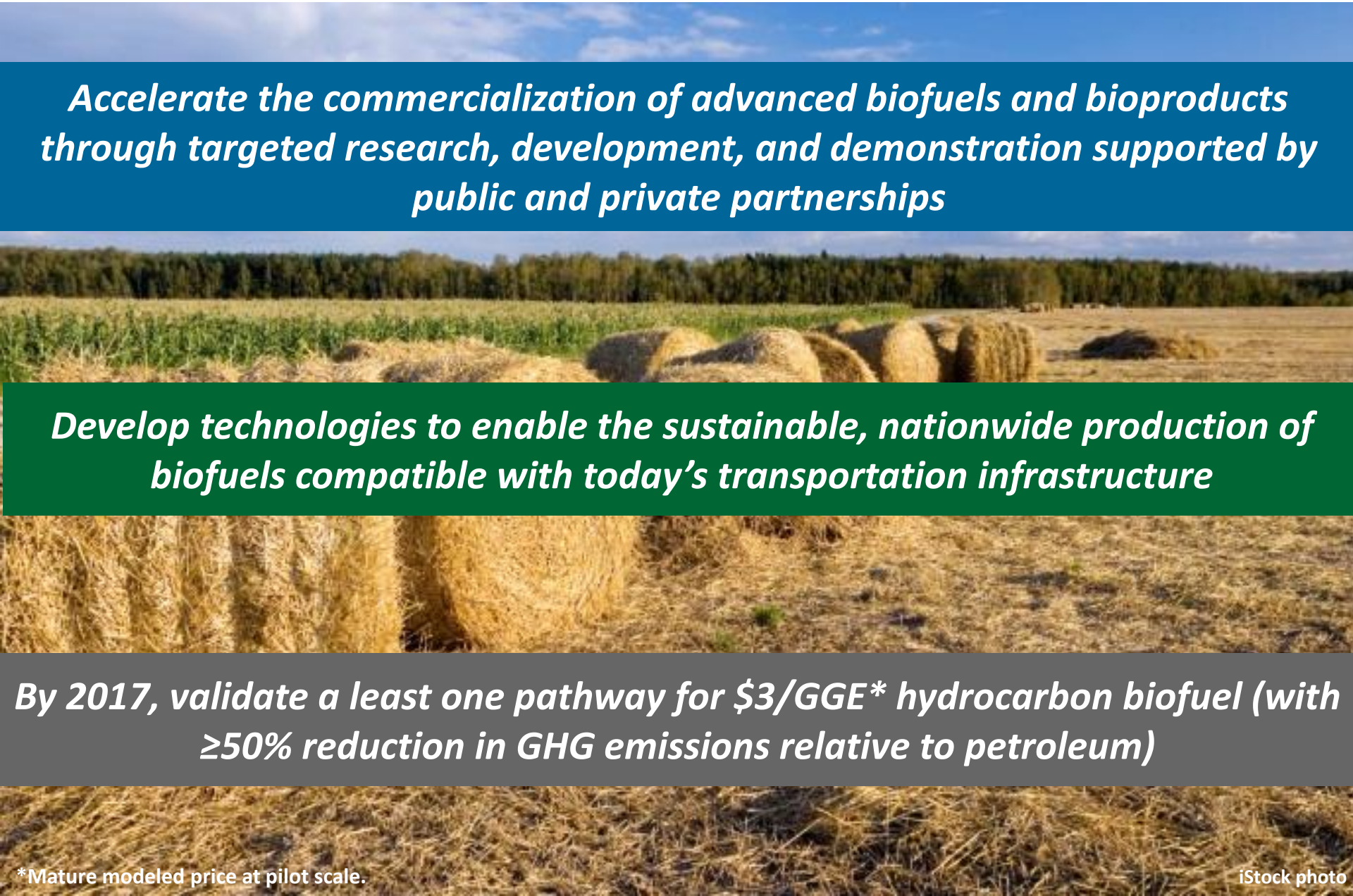
Outline

I. BETO Core Focus Areas
II. Criteria for BETO Investments
III. Motivation for “Wet” Waste-to-Energy
IV. Relevant Existing BETO Efforts
V. Context for this Workshop
VI. Questions

EERE Organization Chart



Bioenergy Technologies Office



Accelerate the commercialization of advanced biofuels and bioproducts through targeted research, development, and demonstration supported by public and private partnerships

Develop technologies to enable the sustainable, nationwide production of biofuels compatible with today's transportation infrastructure

By 2017, validate a least one pathway for $3/GGE* hydrocarbon biofuel (with ≥50% reduction in GHG emissions relative to petroleum)

*Mature modeled price at pilot scale.

iStock photo

BETO's Core Focus Areas

Program Portfolio Management

• Planning • Systems-Level Analysis • Performance Validation and Assessment
• MYPP • Peer Review • Merit Review • Quarterly Portfolio Review
• Competitive • Non-competitive • Lab Capabilities Matrix

Research, Development, Demonstration, & Market Transformation

Feedstock Supply & Logistics R&D

- Terrestrial
- Algae
- Product Logistics Preprocessing

Conversion R&D

- Biochemical
- Thermochemical
- Deconstruction
- Biointermediate
- Upgrading

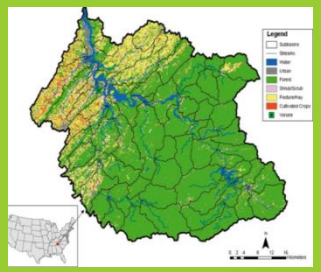
Demonstration & Market Transformation

- Integrated Biorefineries
- Biofuels Distribution Infrastructure

Cross Cutting

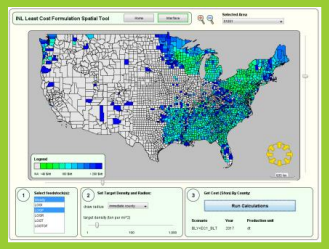
Sustainability

- Sustainability Analysis
- Sustainable System Design



Strategic Analysis

- Technology and Resource Assessment
- Market and Impact Analysis
- Model Development & Data compilation



Strategic Communications

- New Communications Vehicles & Outlets
- Awareness and Support of Office
- Benefits of Bioenergy/Bioproducts

Assistant Secretary Dr. David Danielson's Five Questions

- **HIGH IMPACT:** Is this a high impact problem?
- **ADDITIONALITY:** Will the EERE funding make a large difference relative to what the private sector (or other funding entities) is already doing?
- **OPENNESS:** Have we made sure to focus on the broad problem we are trying to solve and be open to new ideas, new approaches, and new performers?
- **ENDURING U.S. ECONOMIC BENEFIT:** How will this EERE funding result in enduring economic benefit to the United States?
- **PROPER ROLE FOR GOVERNMENT:** Why is what we are doing a proper high impact role of government versus something best left to the private sector to address on its own?

INNOVATION

Omnibus Language for FY 2015: Focus on Waste Biomass

- The Department is directed to include biosolids derived from municipal wastewater treatment and agricultural processes, and other similar renewables
- Biosolids from wastewater treatment is encouraged as a feedstock for all research, development, and demonstration activities conducted within the available funding.
- Technologies utilizing biosolids must provide evidence of the potential to reduce the volume of waste materials and reduce greenhouse gas emissions over current uses of this feedstock.

Waste streams being considered include:

- Municipal solid waste (organic fraction)
- Landfill gas
- Waste streams from waste water treatment plants (sludge and biosolids)
- Industrial organic wastes (e.g. food and beverage, ethanol stillage)
- Animal manure

https://www.congress.gov/crec/2014/12/11/modified/CREC-2014-12-11-pt2-PgH9307.htm

Wet Waste-to-Energy: Opportunity

BETO's Interest in Wet Waste to Energy: Beyond Biogas

- Key "Wet" Waste Streams to Target in the U.S. could include, and are not limited to:
  - Landfill Gas
    - Potential for 2.5 million metric tonnes of methane/year[1]
  - Municipal Sludge
    - Potential for 2.3 million metric tonnes of methane/year[1]
  - Animal Manure
  - Industrial Organic Wastewaters (including ethanol stillage)
  - Organic fraction of Municipal Solid Waste
    - NREL estimates total potential of these three streams at nearly 8 million tons of methane/year[1]
    - Duke projects the possibility of 3-5% of US Natural Gas Supply at $3-6/MMBTU[2]
    - Rigorous Techno-Economic and Life Cycle Analyses necessary in order to determine practical feasibility of converting biogas to fuels and bioproducts

- BETO sees biogas as a feedstock to produce transportation fuels and co-products
- BETO views wet waste streams as a **complement to existing biomass work** with e.g. energy crops, agricultural residues, woody wastes, and algae
- Opportunities exist for blending with terrestrial feedstocks

1. Biogas Potential in the United States, National Renewable Energy Laboratory, 2014
2. Biogas in the United States, An Assessment of Market Potential in a Carbon Constrained Future, Nicholas Institute Rerport, Februarry, 2014

Wet Waste-to-Energy: National Lab Projects

ANL

- Waste-to-Energy Life Cycle Analysis
- Enhanced Anaerobic Digestion and Hydrocarbon Fuel Precursor Production

NREL

- Waste-to-Energy Techno-Economic Analysis
- Reforming Pyrolysis Aqueous Waste Streams to Process Hydrogen and Hydrocarbons
- Biogas to Liquid Fuels and Chemicals Using a Methanotrophic Microorganism

INL/NREL/SNL

- Determining the Impact of MSW as a Feedstock Blending Agent on Pretreatment Efficacy, Hydrolysate Production and Convertibility

PNNL

- Hydrothermal Liquefaction/Catalytic Hydrothermal Gasification of Aqueous Waste Streams

Biogas Roadmap From the USDA/EPA/DOE

The *Biogas Opportunities Roadmap* identifies voluntary actions that can be taken to reduce methane emissions through the use of biogas systems and outlines strategies the Federal government can undertake to overcome barriers to a robust biogas industry in the United States.

- Promote biogas utilization through existing agency programs by ensuring that existing criteria for technical and financial assistance considers the benefits of biogas systems.
- Foster investment in biogas systems by improving the collection and analysis of industry financial and technical data.
- Strengthen markets for biogas systems and system products by reviewing opportunities to overcome barriers to integrating biogas into electricity and renewable natural gas markets.
- Improve communication and coordination across federal agencies by establishing a Biogas Opportunities Roadmap Working Group.


U.S. DEPARTMENT OF ENERGY
LOAN PROGRAMS OFFICE
INVESTING in
AMERICAN ENERGY
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RENEWABLE ENERGY & EFFICIENCY

TECHNOLOGY AREAS OF INTEREST

Advanced Grid Integration & Storage

- Renewable energy generation, including distributed generation, incorporating storage
- Smart grid systems incorporating demand response

Drop-in Biofuels

- New bio-refineries or bio-crude refining processes
- Modifications to existing ethanol facilities to produce drop-in molecules

Waste-to-Energy

- Methane from landfills or ranches via biodigesters
- Utilizing municipal solid waste, crop waste, or forestry waste

Enhancement of Existing Facilities

- Powering non-powered dams or upgrading existing hydro facilities
- Retrofitting existing renewable facilities with innovative technology (e.g. wind turbine retrofits)

Efficiency Improvements

- Improve or reduce energy usage in residential, institutional, and commercial facilities, buildings, and/or processes
- Recover, store, or dispatch waste energy or underutilized renewable energy sources

QUALIFYING PROJECTS ARE NOT LIMITED TO THESE TECHNOLOGIES.

Biochemical Upgrading (BCU) Selection Announcement

On October 9th, 2014 DOE announced up to $13.4 million for five projects to develop advanced biofuels and bioproducts that will help drive down the cost of producing gasoline, diesel, and jet fuel from biomass.

- **The University of Wisconsin** of Madison, Wisconsin will receive up to $3.3 million to develop a process to produce high value chemicals from biomass, which can be used as plasticizers (an additive in certain plastics) and in the production of industrial chemicals and resins.
- **American Process, Inc.** of Atlanta, Georgia will receive up to $3.1 million to develop and demonstrate processes to upgrade cellulosic sugars to solvents in their demonstration facility.
- **The National Renewable Energy Laboratory** of Golden, Colorado will receive up to $2.5 million to develop a conversion process demonstrating the production of muconic acid from biogas. This acid can be converted into an array of bioproducts, including fuel, plasticizers, and lubricants.
- **Natureworks, LLC** of Minnetonka, Minnesota will receive up to $2.5 million to develop a fermentation process, using biogas and bacteria, for the production of lactic acid. This process could be used for the commercialization of biomethane to fuels.
- **Vertimass LLC** of Irvine, California will receive up to $2 million to commercialize technology to convert ethanol into diesel fuel, gasoline, and jet fuel blend stocks compatible with the current transportation fuel infrastructure.

Demonstration Portfolio – Selected Project

INEOS, Vero Beach, Florida

- Expected to produce 8 million gallons per year of cellulosic ethanol and 6 MW of power from wood and vegetative waste, including palm fronds.
- DOE Share = $50M; Cost share = $82M.
- Created 400 construction jobs; 65 permanent jobs are expected for operation.
- Major construction began in October 2010, commissioning was completed in June 2013, and the facility initiated commercial production of cellulosic ethanol in July 2013.
- First commercial production of cellulosic ethanol in the United States.
- Process is based upon the fermentation of syngas to alcohol.

Defense Production Act (DPA) Initiative

In September 2014, 3 projects were selected under the DPA Initiative to build commercial biorefineries to produce:

- Drop-in fuels for military applications
- Domestic fuels from non-food biomass feedstocks
- Cost-competitive biofuels (w/o subsidies)

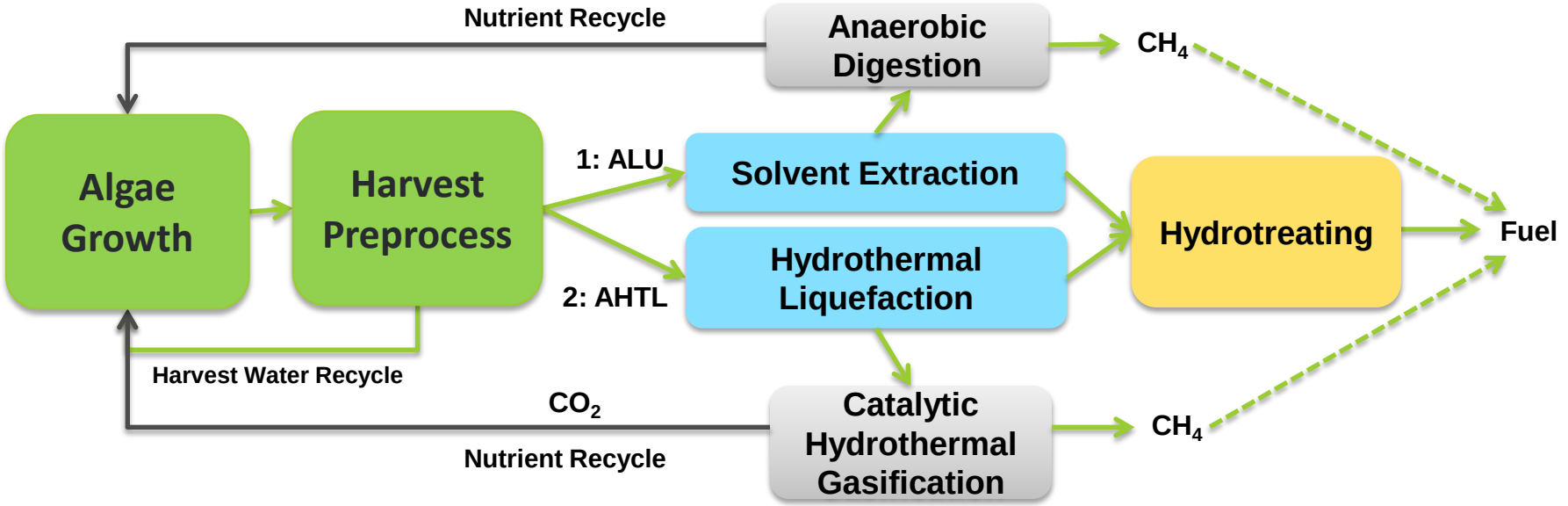
Company	Location	Feedstock	Capacity	Groundbreaking	Off-Take Agreements
Emerald Biofuels	Gulf Coast	Fats and Greases	82.0 MM g/y	TBA	TBD
Fulcrum Bioenergy	McCarran, NV	MSW	10.0 MM g/y	Spring/Summer of 2015	Cathay Pacific
Red Rock Biofuels	Lakeview, OR	Woody Biomass	12.0 MM g/y	TBA	Southwest Airlines

Benchmarking Progress: Technology Pathway Baselines

High Priority Pathways

- Advanced algal lipid extraction and upgrading (ALU).
- Whole algae hydrothermal liquefaction and upgrading (AHTL).

Pathways analysis will result in national laboratory-led design case studies for the BETO to benchmark progress towards $3/gallon algal biofuel.



Baseline and Projections: HTL Pathway

- A major NAABB Consortium breakthrough is a new technology pathway which implements the hydrothermal liquefaction (HTL) of whole wet algae biomass.
- HTL avoids the steps of biomass drying and solvent extraction of lipids, and is ideal for lower lipid content strains as well as algae cultures of more than one strain.
- The Pacific Northwest National Lab HTL Design Case shows pathway to high-impact algal biofuel, projecting a $4.49 per gallon gasoline equivalent price by 2022.

Whole Algae HTL

- 40-70% of the carbon in algae captured in oil.
- Carbon retained during hydrotreating (70-90 wt%)
- Waste-water cleanup captures additional carbon as biogas.

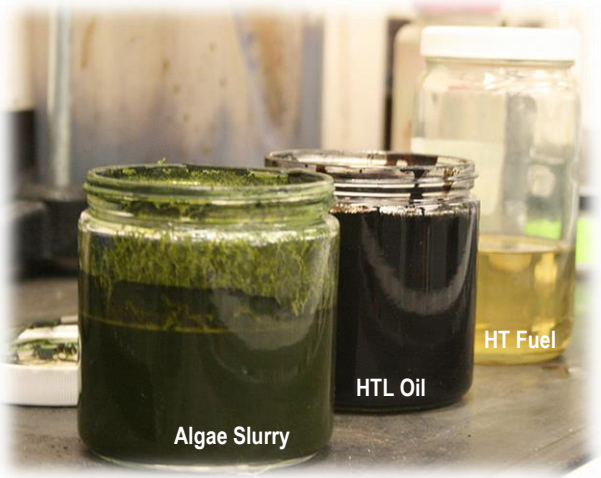


Photo courtesy of PNNL

Source: Process Design and Economics for Conversion of Algal Biomass to Hydrocarbons: Whole Algae Hydrothermal Liquefaction and Upgrading, Pacific Northwest National Laboratory, March 2014. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23227.pdf

Hydrothermal Liquefaction (HTL) – Overview

Hydrothermal Liquefaction (HTL)

- Conversion of a biomass slurry (e.g., wood, algae, other) to bio oil and aqueous product
  - ~ 350°C
  - ~ 3000 psig

Slurry Feedstock

HTL

Bio oil Product

+

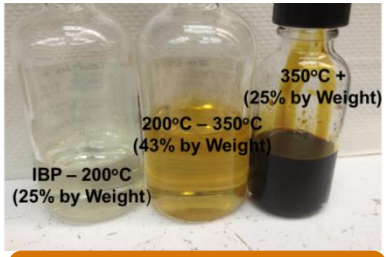
Aqueous Product (contains organics)

Current Efforts:

Bio oil product is refined via **Catalytic Hydrotreament** and fractionated by **Distillation** to gasoline, diesel, jet fuel, and bottoms

Catalytic Hydrotreatment

Catalytic Hydrothermal Gasification (CHG)



Fuel Fractions

Distillation

Hydrotreated Bio oil

Clean Aqueous Product

Current Effort:

Catalytic Hydrothermal Gasification (CHG) may be used to convert aqueous product to medium BTU gas and clean water

NAABB-Genifuel-Reliance-PNNL

Continuous 1 metric ton/day (40 L/hr) pilot HTL/CHG pilot system for algal feedstock; NAABB-Reliance-PNNL-Genifuel Hydrothermal System 2014

- 2012 - present
- NAABB leverages results from NABC
- One of several HTL piloting efforts with algae feedstocks

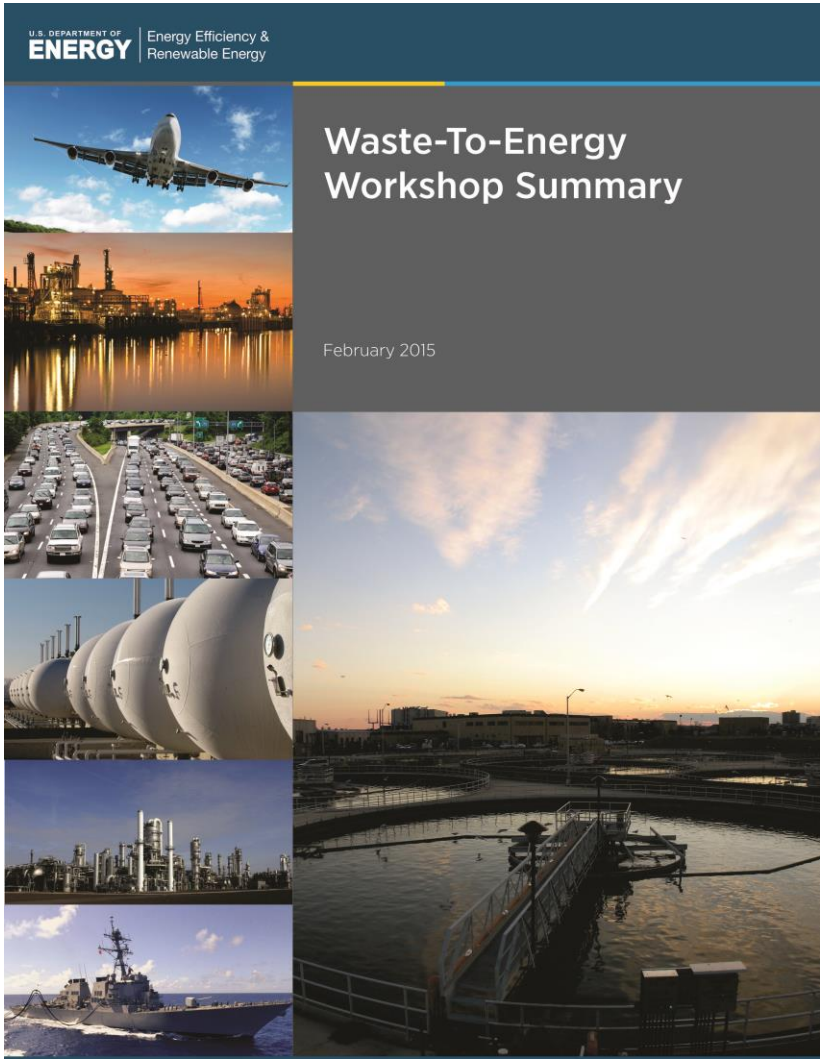
Approx Skid Dimensions: 16’(L) x 7’(W) x 8’(H)

Wet Waste-to-Energy Workshop Stream

- **Develop a better understanding of the techno-economic feasibility of producing transportation fuels and co-products from "wet" waste streams**
  - November, 2014: Anaerobic Digestion, Hydrothermal Liquefaction, and other possibilities. Report forthcoming shortly.
  - March, 2015 (This workshop, joint with DOE Fuel Cells Office): AnMBRs, MxCs, and combinations thereof to produce hydrogen and higher hydrocarbons
  - April, 2015 (together with EPA, NSF, and DOE Water-Energy Tech Team): Energy-Positive Water Resource Recovery
  - Mid-June, 2015: Water Environment Federation Water-Energy Conference
  - Late June, 2015: Bioenergy 2015, with sessions on Renewable Gaseous Fuels and Challenges for Wet Waste-to-Energy
- Current vision is for a joint report from March and April workshops
- **All of this will inform BETO, DOE, EPA, and NSF activities for FY 16 and beyond**

November "Wet" Waste-to-Energy Workshop

- November 5, 2014 in Arlington, VA
- Report will be available on BETO website
- ~85 attendees from private sector, labs, NGOs, and academics
- Four topic areas:
  - Anaerobic digestion (AD) of wastewaters
  - AD of the organic, non-recyclable portion of municipal solid waste (MSW)
  - Hydrothermal liquefaction of wet waste
  - Other collection/sorting/processing options for wet WTE



November Workshop: Functional Areas Ripe for Innovation

Identified activities in which BETO support could accelerate innovation in the field

- **Pre-Processing:** Better understanding and modifying feedstocks to improve downstream processing efforts.
- **Process Research:** Applying research concepts to conversion processes to achieve breakthroughs in operations.
- **Process Engineering :** Applying engineering concepts to known processes to reduce operational or capital costs and make liquid fuels/renewable chemicals more cost-competitive.
- **Analysis:** Conducting detailed and rigorous resource availability and techno-economic analyses to identify feasible combinations of waste streams and target markets.

Objectives for this Workshop

Learning Exercise for DOE:

- **Characteristics:** What are the key characteristics (both technical and non-technical) that will determine success?
- **Challenges:** What technical and non-technical problems need to be overcome?
- **Solutions :** What solutions to these problems are conceivable within the next 20 years?
- **R&D:** What R&D Activities will best contribute to such solutions?
- **Markets**: What are the key opportunities and obstacles in the near and long term?
- **Implementation**: What will it take to connect R&D activities with market opportunities to facilitate commercial success?

Questions?