Goal Statement

Develop emerging technologies and data at the conversion interface of algal biofuels production focused on hydrothermal liquefaction (HTL)

- Initial focus wrap-up of NAABB (HTL processing, cultivation modeling and strain development tools)
- Current focus advanced HTL processing methods, process integration and scale-up

 Alignment with Goals of Algal Feedstocks R&D Technology Area

- *Priority Technology Pathway*
- *Whole algae hydrothermal liquefaction and upgrading*
## Timeline
- Project Start: 2/1/2013
- Project Finish: 9/30/2017
- Percent complete: 34%

## Budget

<table>
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<tr>
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<th>Total Costs FY 10 – FY 12</th>
<th>FY 13 Costs</th>
<th>FY 14 Costs</th>
<th>Total Planned Funding (FY 15-Project End Date)</th>
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<td>DOE Funded</td>
<td>$0</td>
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<td>Project Cost Share (Comp.)*</td>
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## Barriers
- AFT-H. Overall Integration and Scale-Up
- AFT-I. Algal Feedstock Preprocessing
- AFT-J. Resource Recapture and Recycle
- Tt-J. Catalytic Upgrading of Bio-Oil Intermediates to Fuels and Chemicals

## Partners
- Other interactions/collaborations
  - National Alliance for Biofuels and Bioproducts (NAABB)
  - ANL, NREL, PNNL - Algae Harmonization task
  - LANL, PNNL, NREL - Algal Biotechnology Hub
  - Sapphire, Bioprocess Algae
  - Regional Algal Feedstock Testbed (RAFT)
  - Genifuel
  - Pall Corporation - Separations
AHTL processes wet algal biomass to finished fuels
AHTL enables nutrient recycle

Thermochemical Interface Project
focused on advanced HTL
processing methods to reduce
conversion cost, improve
sustainability and enable scale-up.

HTL accounts for ~75% of conversion cost
1 - Project Overview (cont.)

- **FY13 project** focused on completing NAABB data sets and analysis
  - HTL processing NAABB strains
  - Cultivation modeling and analysis

- **FY14 project focus** shifted to developing advanced HTL processing methods and strain development tools for NAABB production strain
  - HTL plug flow reactor, feed concentration/salinity, process parameters, separations, catalytic HTL
  - Transformation methods and stress gene targets for winter production strain *Scenedesmus sp.*

- **FY15 project focus** on HTL process development, scale-up and integration
  - Variable algal feedstocks, HTL plug flow reactor, process parameters, enhanced oil/water separations
  - HTL nutrient recycle for algal cultivation
  - Scoping and design of a modular/engineering- scale HTL skid with capability for a range of biomass feedstocks

HTL data used for AHTL pathway modeling and SOT Targets
2 – Approach (Technical)

Technical Approach

- Use experimental process data to build AHTL process model and design case
- TEA and LCA sensitivity analysis to understand significant impact areas
- Establish SOT / Targets
- Conduct targeted R&D
- Use results to update models and measure progress towards research goals

**Initial Experimental Process Data**
(HTL, HT, CHG)
NAABB Strains
FY13-14

**AHTL Model Project**
(Focused R&D Upgrading and Water Treatment )
FY13-17

**Thermochemical Interface Project**

**Conduct Targeted HTL Process R&D**
(PF config., temp/LHSV, separations, feed solids/salinity, catalytic HTL)
Scale-up
FY14-17

**Process Modeling**

**SOT GOAL**
Guide Research

**TEA, Screening LCA**

**Algae Model Harmonization Team**

**AHTL PROCESS, FUEL PRODUCTS**
2 – Approach (Management)

**Critical Success Factors**
- Decreasing HTL conversion costs
  - Plug flow, processing efficiency, biocrude yield and quality
- Demonstrating AHTL process integration
- Validation of fuel products

**Top Potential Challenges**
- HTL process capital and operation costs
- Strategies to mitigate process turndown (seasonal productivity effects)

**PM Approach**
- Regular Milestones (1/Quarter) and Deliverables, Data Input for AHTL Model and Validation of SOT Technical Targets
- Go/No Go decision point based on MYPP 2016 decision point
  - (select integrated approaches for high-yield algal biofuel intermediates)
- Regular meetings with BETO
- Management and integration of supporting projects and partners
Adapted the Biomass Assessment Tool (BAT) to predict increased annual biomass productivity related to a cultivation method (ARID) with thermal management.

Completed analysis of cultivation variables important for achieving high productivity:
- Data from 5 sites and 3 years (565 observations)
- Conducted by New Mexico State University

Supports Algal Feedstock Development
Developed transformation methods for winter production strain *Scenedesmus obliquus*

Completed transcriptional analysis identifying gene targets associated with stress (N/Salinity) for improving strain productivity

Supports Algae Biotechnology HUB concept established in FY15 between LANL, PNNL and NREL for developing tools for strain improvements
AHTL Processing Completed for Five Strains

- Completed continuous HTL (CSTR/PF) processing for four additional strains (NAABB)
  - *Chlorella 1412* (freshwater)
  - *Tetraselmis* (seawater)
  - *Kirchneriella sp.* (freshwater)
  - *Pavlova sp.* (seawater)
  - *Cal Poly* (WWT mixed culture)
- Completed CHG processing of the aqueous phase
- Completed upgrading of the biocrudes to fuels**
- Provided critical process data to inform AHTL process model, TEA and LCA, and SOT

**Kirchneriella sp** not processed due to emulsion
3-Technical Accomplishments / Progress / Results (cont’d)

Advanced HTL Processing Methods Developed

- Demonstrated 8% increase in biocrude yield by increased salinity/solids content in algal feedstock (Reduced CapEx/OpEx)
- Developed clean-up methods that improve biocrude quality resulting in improved hydrotreating catalyst lifetime. (Reduced OpEx, Biocrude Quality)
- Developed novel product separation method for continuous processing (Reduced CapEx/OpEx)
- Demonstrated continuous pure plug flow HTL operations with product collection were successfully demonstrated with high yield. (Reduced Capex)
- Completed initial catalytic HTL testing showing modest improvements to bio-oil quality, but no improvements yield.

(MAJOR MILESTONE FY14)

- Demonstrated at least two new advanced HTL processing methods that improve yield, separation and/or biocrude quality.
Technology Transfer - HTL Processing/Upgrading Assistance provided to BETO IBRs and Industry

- Completed continuous HTL processing for Sapphire productions strain
- Completed continuous HTL, HT processing and fuel characterization for Bioprocess Algae (BPA)
- Assisted Genifuel and Reliance, in design/start-up 1 metric ton/day HTL/CHG pilot system for algal feedstocks
  - 2015 FLC Award
- Assisting Algenol and Reliance in process development and scale-up of HTL processing (Work for Others Contracts)
3 – Technical Accomplishments/Progress/Results (FY 15 Milestones)

**Advanced HTL Task**
- Secure diverse types of algal biomass in quantities needed for HTL testing.

**HTL Engineering Scale Skid Task**
- Complete design basis for the HTL engineering scale skid and stakeholder approval.

**Nutrient Recycle Task**
- Develop recycle methods for N/P from HTL processing waste streams and determine the bioavailability.

**Complete advanced HTL processing experiments with a previously untested algal feedstock.**

**Complete advanced HTL processing experiments for 3 different algal feedstocks to demonstrate consistent yields, and process robustness.**

**Demonstrate a significant HTL advancement: 50% increase in the HTL liquid hourly space velocity and/or a 10% shift in carbon yield from the aqueous phase to the recovered bio-crude.**
Important technical accomplishments HTL Engineering Scale Skid Procurement

- Completed functional design criteria and preliminary design basis
- Completed preliminary hazards analysis
- Completed acquisition strategy
- RFP/SOW under development
- Planning for installation and start-up in Q2 FY16
- Capital funds from Thermochemical Program
Targeted R&D focused on BETO primary technology pathway
- AHTL pathway technical needs and cost targets identified
- Developing new enabling technology for the AHTL pathway

Project has resulted new IP

Project is supporting technology transfer
- 2015 FLC Award
- Multiple collaborations with industrial partners and BETO IBRs

Project is leveraging synergies with Thermochemical Platform
- HTL process development
- Acquisition of engineering scale HTL skid designed for multiple feedstocks

Project has already contributed to 7 publications and 12 invited presentations
Procurement and testing of a modular/engineering scale HTL skid at PNNL will be completed.

Validation of advanced HTL processing methods at engineering scale will be conducted.

Critical data will be provided to update AHTL Model and SOT.

Working with BETO’s commercial partners we will support process integration and generate large fuel samples that can be used to meet fuel specifications.

Integrations of key elements of the AHTL process (nutrient recycle, water treatment, and upgrading processes) will be completed in collaboration with related projects.

Go/No-Go will be structured around meeting specific technical and cost targets associated with MYPP Decision Point in FY16.
Summary

• **Relevance:** Project directly contributes to meeting the goals and objectives of the Algae Conversion Technology Area (AHTL Pathway)

• **Approach:** Conduct HTL process development and scale-up base on AHTL modeling and SOT technical and cost targets

• **Technical Accomplishments:** The project leveraged and completed up key NAABB data sets, developed advanced HTL process technologies, and provided data for AHTL model and SOT

• **Future Work:** The project will conduct targeted research in FY15-17 based on SOT targets to significantly reduce HTL conversion cost, validate at engineering and enable commercialization

• **Success Factors and Challenges:** The critical success factors and challenges for the project have been identified and are being addressed

• **Technology Transfer:** The project is actively supporting technology transfer to industry through collaborations, IP development and licensing, publications and presentations. Received FLC Award in 2015
Additional Slides
Publications


Publications


Presentations


Anderson DB, RT Hallen, SB Jones, DC Elliott, and KO Albrecht. 2013. 9.3.2.1 Whole Algae Liquefaction Model Development. Presented by Dan Anderson (Invited Speaker) at DOE Bioenergy Technologies Office (BETO) Project Peer Review, May 22, 2013, Alexandria, VA.


Presentations


Elliott, D.C., “Conversion of Algal Biomass to Liquid Fuels by Hydrothermal Processing in Continuous-Flow Reactors.” Portland Section meeting, American Chemical Society, Reed College, Portland, Oregon, April 10, 2014.

Elliott, D.C., “Conversion of Algal Biomass to Liquid Fuels by Hydrothermal Processing in Continuous-Flow Reactors.” Southern California section meeting, American Institute of Chemical Engineers, Anaheim, California, April 15, 2014.


Hydrothermal processing technology developed at PNNL supported by NAABB and Conversion Interface Project is being used in BETO IBRs and privately funded efforts.

NAABB cost share provided funding for engineering plans and construction of a 1 tonne/day demonstration system for HTL and CHG processing for algal biomass.