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2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

9.3.2.1 Whole Algae Liquefaction Model Development

DATE MAY 22, 2013

TECHNOLOGY AREA REVIEW: ALGAE

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Goal Statement

Develop sufficient data to formulate a robust and detailed techno-economic model of the whole algae hydrothermal liquefaction (HTL) process

In addition to HTL, this process application includes:

- Catalytic hydrotreatment (HT) of the HTL bio-oil product
- Catalytic hydrothermal gasification (CHG) applied to the aqueous byproduct

Alignment with Goals of DOE BETO in the Multi-Year Program Plan

- *In The MYPP* "Intermediate production is defined as the deconstruction and/or **processing of algal biomass** into products such as, but not limited to, extracted lipids and lipid extracted biomass, or **hydrothermally liquefied biomass**. Maximizing throughput and efficiency while producing both energy-dense biofuel intermediates and useful remaining biomass are key objectives for intermediate production technology."
- "By 2013 (Q4), **establish cost goals and technical targets for one alternate algal system and complete techno-economic analysis for one additional algal-production-to-finished-fuel technology pathway**, including feasibility..."

Quad Chart Overview

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Timeline

- Project start date: 10/01/2012
- Project end date: 9/30/2015
- Percent complete: 10%

Barriers

- Barriers addressed
  - Ft-N. Algal Feedstock Processing
  - Tt-G: Fuel Synthesis and Upgrading

Budget

- FY2013 New Start
- Funding for FY13 $243k
- No ARRA Funding

Partners

- Interactions/ collaborations:
- National Alliance for Biofuels and Bio-products (NAABB)
- ANL, NREL, PNNL – Algae Harmonization task
- Project management
  - Monthly calls
  - Harmonization meetings
  - *Quarterly Progress Reports*

Project Overview

History:

- New start for FY13
- Builds on initial algae HTL data from National Alliance for Biofuels and Bio-products (NAABB) and harmonized algae models

Context:

- Algae is an important biomass source per the Multi-Year Program Plan (MYPP); no conversion targets yet established
- Hydrothermal Liquefaction (HTL) is well suited for processing wet algal feeds to produce intermediate oils with higher yields than solvent extraction baseline

Project Objectives:

- Establish research targets for HTL algae conversion to stable intermediates and products based on experimentally derived data
- Expand whole algae HTL model to include HT upgrading and CHG water treatment

Project Overview
HTL Algae Process

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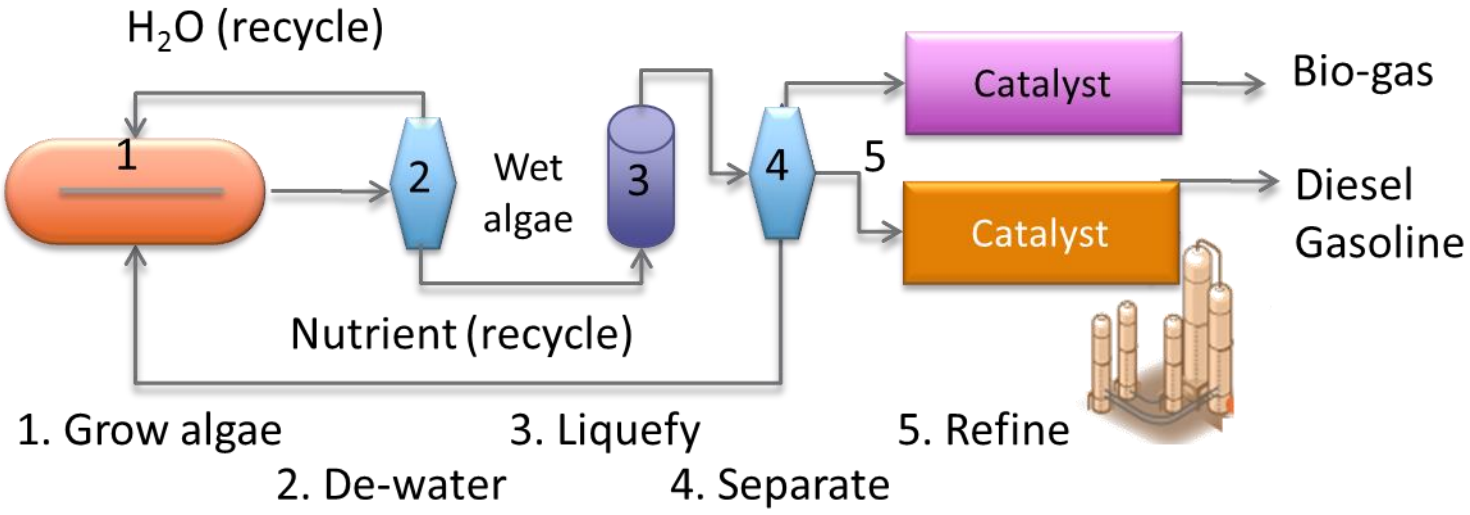


- HTL is both an extraction and a conversion process
  - Lipid is almost completely recovered
  - In addition, a portion of proteins and carbohydrates are converted to oil
  - The total oil yield is higher than other known extractions
- Since HTL is a wet process using only water, no drying or solvent recovery is needed

Wet Algae

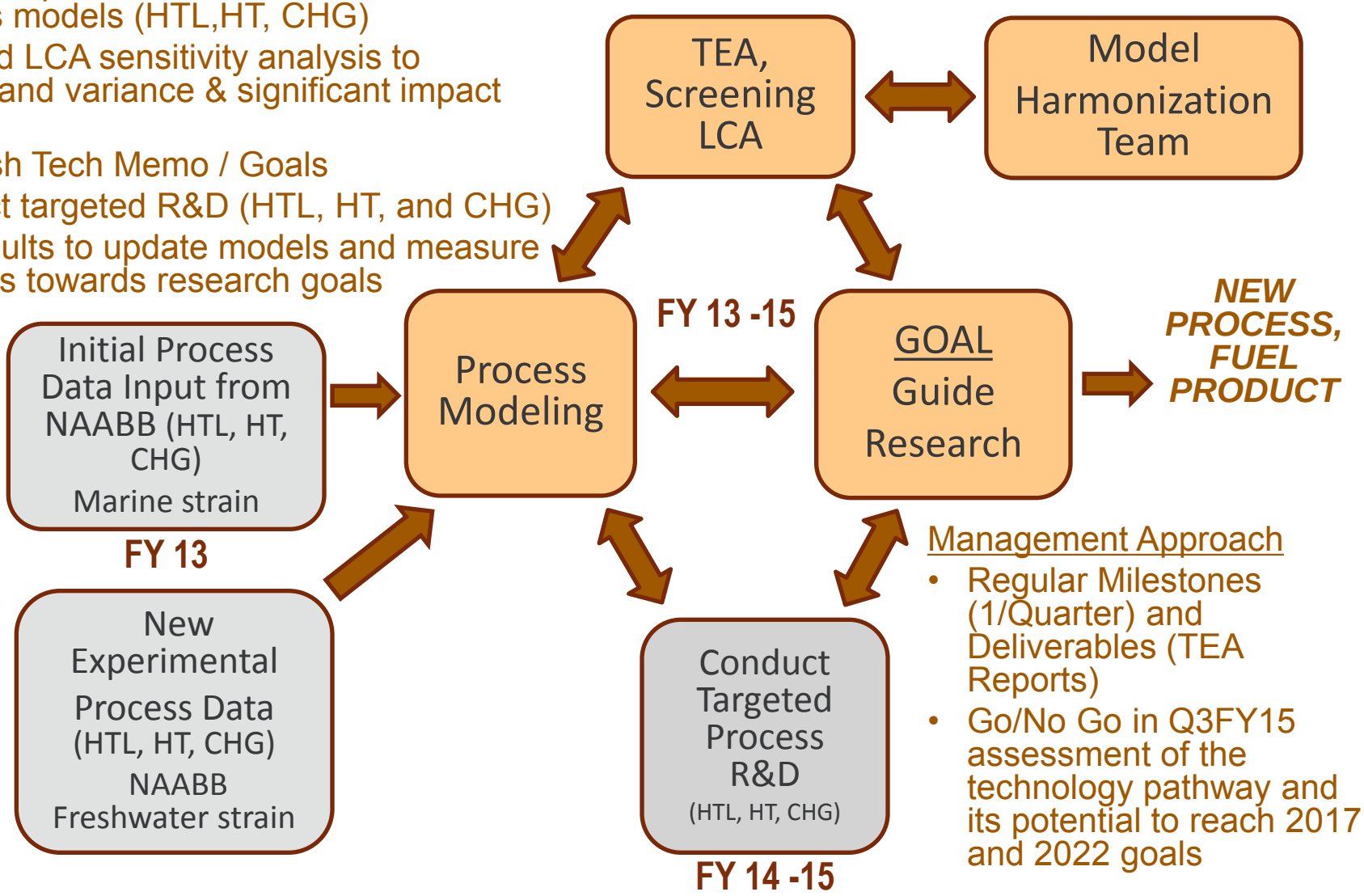
Algae HTL Oil

Component	Weight %
Lipid content of whole algae	33%
Bio-oil from HTL as % algae AFDW	64%
% of algae carbon in HTL oil	69%

Approach

Technical Approach

- Use initial process data from NAABB to build process models (HTL,HT, CHG)
- TEA and LCA sensitivity analysis to understand variance & significant impact areas
- Establish Tech Memo / Goals
- Conduct targeted R&D (HTL, HT, and CHG)
- Use results to update models and measure progress towards research goals

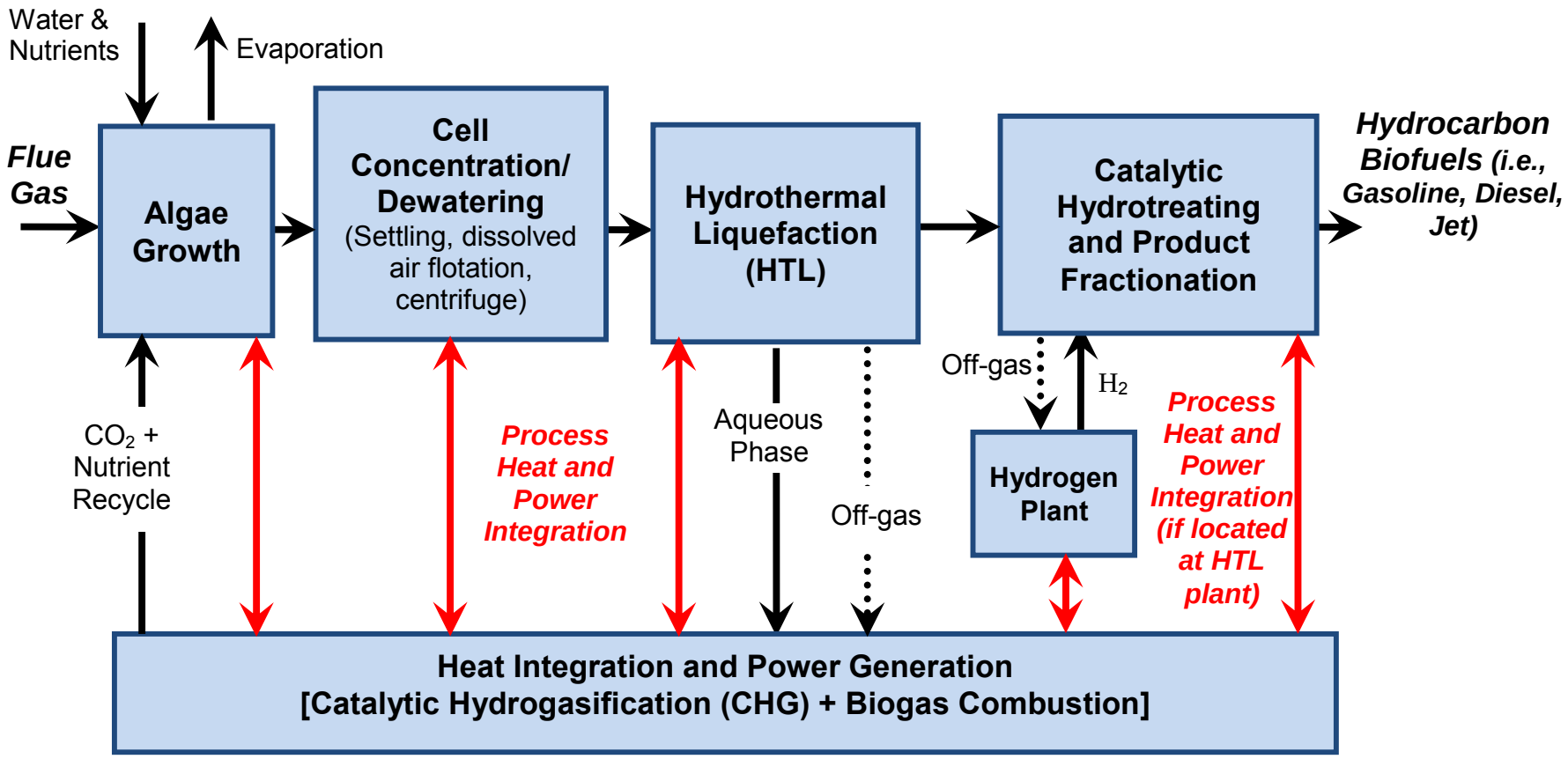


Management Approach

- Regular Milestones (1/Quarter) and Deliverables (TEA Reports)
- Go/No Go in Q3FY15 assessment of the technology pathway and its potential to reach 2017 and 2022 goals

Technical Accomplishments / Progress / Results

Key Milestone: Developed preliminary AspenPlus based process model for algae HTL, HTL oil upgrading to fuel, and CHG wastewater processing



Technical Accomplishments / Progress / Results (cont'd)

Important technical accomplishments to date for the AspenPlus based process model

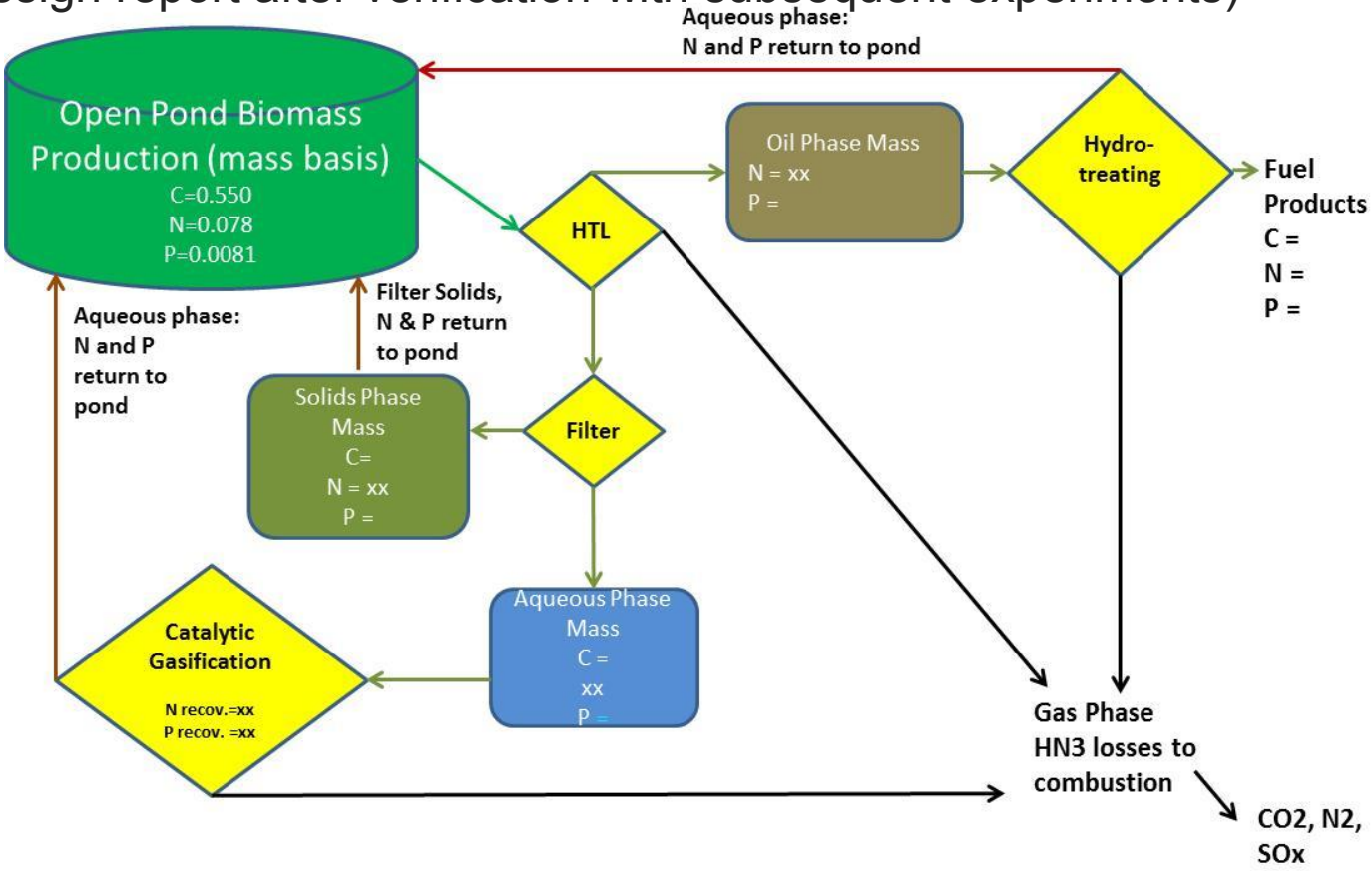
- Flowsheet based on experimental data from PNNL generated for NAABB for ***Nannochloropsis salina*** grown under high productivity, low stress conditions

- Model assumptions:
  - ✓ Hydrothermal liquefaction data (processing at nominal 20 wt% solids, plug flow reactor, 3000 psi, ~350 ºC, no catalyst or buffering agent)
  - ✓ Hydrotreating of HTL oil (deoxygenation and denitrification) data (fixed bed reactor, up to 2000 psi with hydrogen in excess of stoichiometric consumption)
  - ✓ Catalytic hydrogasification data of HTL water data to produce treated water for recycle and medium BTU gas for process use (3000 psi, 350 ºC, fixed bed catalytic process)

Technical Accomplishments / Progress / Results (cont'd)

Sustainability

Obtained additional elemental analysis to allow development of a preliminary assessment of the availability of N and P for recycle (values to be presented in final design report after verification with subsequent experiments)



Technical Accomplishments / Progress / Results (cont'd)

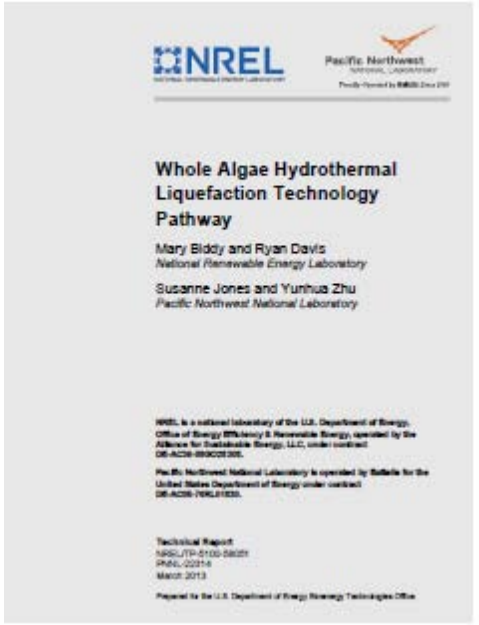
Harmonization

Summarized key flows for Harmonization Team – a multi-lab effort to bring together all parts of algae farm siting, cultivation, harvest, and conversion to fuels in a sustainable way

- ANL developing the life-cycle analysis (LCA)
- NREL developing the farm cultivation and harvest data
- PNNL developing the resource assessment
- PNNL developing the algae conversion model

Tech Memos: collaborated with NREL to completed Tech Memo for whole Algae HTL

- Provides a technical reference for this pathway for the Spring 2013 MYPP update
- Met January 31st deadline for draft to BETO
- Met end of March completion data for final report


NREL

Whole Algae Hydrothermal Liquefaction Technology Pathway

Mary Biddy and Ryan Davis
National Renewable Energy Laboratory

Susanne Jones and Yunhua Zhu
Pacific Northwest National Laboratory

Technical Report

Technical Progress FY13

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Milestone/Deliverables	Planned Completion Date	Completion
Delivery of Tech Memo TEA	Jan, 2013	✓
One Low Lipid HTL Algae Test (NAABB Data)*	Feb, 2013	✓
One Low Lipid CHG Algae Test (NAABB Data)*	Feb, 2013	✓
One Low Lipid HT Algae Test (NAABB Data)*	Mar, 2013	✓
Second Algae HTL, HT, CHG Test (Chlorella DOE1412)	May, 2013	On schedule
Deliver Technology Assessment Case TEA with Sensitivity Analysis	Jun, 2013	Planning Underway
Support at least 2 change control board meetings in Q4 to facilitate updating the whole algae HTL process in the BETO MYPP	Sep, 2013	Planning Underway
Draft manuscript of whole algae processing and economic viability for submission to peer reviewed journal	Sep, 2013	Planning Underway

***NAABB also completed and provided high lipid data set for same algae**

Relevance

This project contributes to meeting the goals and objectives of the Algae Conversion technology area and the overall Office, as found in the Bioenergy Technologies Office Multi-Year Program Plan (November 2012):

"By 2013, **establish cost goals and technical targets for one alternate algal system and complete techno-economic analysis for one additional algal production to finished fuel technology pathway** including feasibility and trade-off analysis with higher value co-products."

- MYPP Barriers addressed:
  - Ft-N. Algal Feedstock Processing
  - Tt-G: Fuel Synthesis and Upgrading

- This project provides an **effective and low risk approach** to formulate robust and detailed techno-economic model of the algae hydrothermal liquefaction (HTL) process

- PNNL is **working with various industrial partners** to evaluate HTL processing for their specific algal feedstocks

Critical Success Factors

- **Critical success factors which will define technical and commercial viability**
  - ✓ Improve the overall carbon yields to fuel (HTL and HT)
  - ✓ Improve separations oil/aqueous phase (HTL)
  - ✓ Nutrient recycle process from (HTL and CHG)
  - ✓ Improve catalyst life (CHG and HT)
  - ✓ Improve reactor designs and process conditions (HTL, HT, CHG)
- **Potential challenges for project success**
  - ✓ Meet tight schedule (June 30 deliverable of preliminary TEA for external review, August targets delivered for publication in September MYPP)
  - ✓ Biomass supply for FY14-15 will have to be coordinated with RAFT Testbeds
- **Project is advancing the State of Technology and is positively impacting commercial viability of microalgae biofuels**
  - ✓ HTL processing route has potential to increase fuel yield from algal biomass by a factor of 2X and enable nutrient recycle
  - ✓ Accelerating the development of process data and models for an optimized HTL processing route including CHG wastewater processing, and HT upgrading

Future Work FY14 -15

- Conduct targeted research based on sensitivity analysis to optimize yields and processing conditions
  - ✓ HTL, CHG and HT bench scale processing campaigns
- Update models and SOT

FY14 Milestones/Deliverables

Type	Title/Performance Measure	Due Date
ML	Development of the current state of technology and greatest probabilities for annual technical advancement from 2012 to 2022	6/30/2014
DL	Improvement in the subsequent upgrading of the HTL oil yields	9/30/2014

FY15 Milestones/Deliverables/Go-No Go

Type	Title/Performance Measure	Due Date
GN	Go/No-Go assessment of the technology pathway and its potential to reach 2017 and 2022 goals	6/30/2015
DL	Improvement in the HTL oil yield from at least one algae species from 100-110 gal/ton of algae to at least 120 gal/ton of algae	9/30/2015

Summary

- **Relevance:** The project contributes to meeting the goals and objectives of the Algae Conversion Technology Area
- **Approach:** The project approach provides effective and low risk approach to formulate robust, and detailed techno-economic model for algae
- **Technical Accomplishments:** The project has leveraged process data from NAABB to build initial models, complete Tech Memo, and provide modeling input to algae model harmonization group
- **Future Work:** The project will conduct targeted research in FY14-15 to optimize yields, and processing conditions. This data will be used to update model and SOT
- **Success Factors and Challenges**: The critical success factors and challenges for the project have been identified and can be managed
- **Technology Transfer**: The project will support technology transfer to industry by providing validated process model and economics

Additional Slides

Responses to Previous Reviewers' Comments

This is a new project in FY2013 and was not peer reviewed in 2011

Publications and Presentations,

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Whole Algae Hydrothermal Liquefaction Technology Pathway

Biddy MJ, R Davis, SB Jones, and Y Zhu. 2013. *Whole Algae Hydrothermal Liquefaction Technology Pathway* . PNNL-22314, Pacific Northwest National Laboratory, Richland, WA.

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22314.pdf