2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Optimized Co-processing of Algal Bio-Crude Through a Petroleum Refinery

23 May 2013
Bio-Oil Technology Area Review

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Goal/Objective Statement

Use of conventional refining infrastructure reduces cost and time to market

- Sapphire produces an algae bio-crude that is similar to petroleum crude oil
- This project will establish the optimal refinery operating conditions required to upgrade algae bio-crude produced via the Sapphire process
- Identifying the operating conditions required for algae crude upgrading is critical for bringing algae bio-crude to market and to establish the sales price and full value chain economics of the algae derived biofuels
- Alignment with DE-FOA-0000686:
  - Algae bio-crude oil is produced in a sustainable manner from algae biomass produced in open ponds from captured CO_2 and sunlight
  - Algae bio-crude is not a finished transportation fuel and must be upgraded through insertion into a petroleum refinery downstream of the crude unit
  - Algae bio-crude is produced by thermochemical liquefaction (hydrothermal treatment) of algae biomass

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Project Quad Chart Overview

Timeline

Start Date: Jan 30, 2013

End Date: Mar 31, 2014

Barriers

Oil Composition: Higher Oxygen and Nitrogen than petroleum feedstocks

Catalyst Life: must confirm no detrimental impacts on catalyst life

Processing Conditions: must confirm oil can be upgraded at typical conditions

Budget

Total Project funding: $846,335

DOE / Sapphire: $500,920 / $345,415

FY2013 Funding (DOE/Sapphire): $456,356 / $222,453

Project has been funded for less than one year

Partners and Roles

Third Party Vendors providing services:

- University of Kentucky – bench scale testing
- SwRI – Pilot Scale Hydrotreating
- Baker Hughes – Pilot Scale Coking

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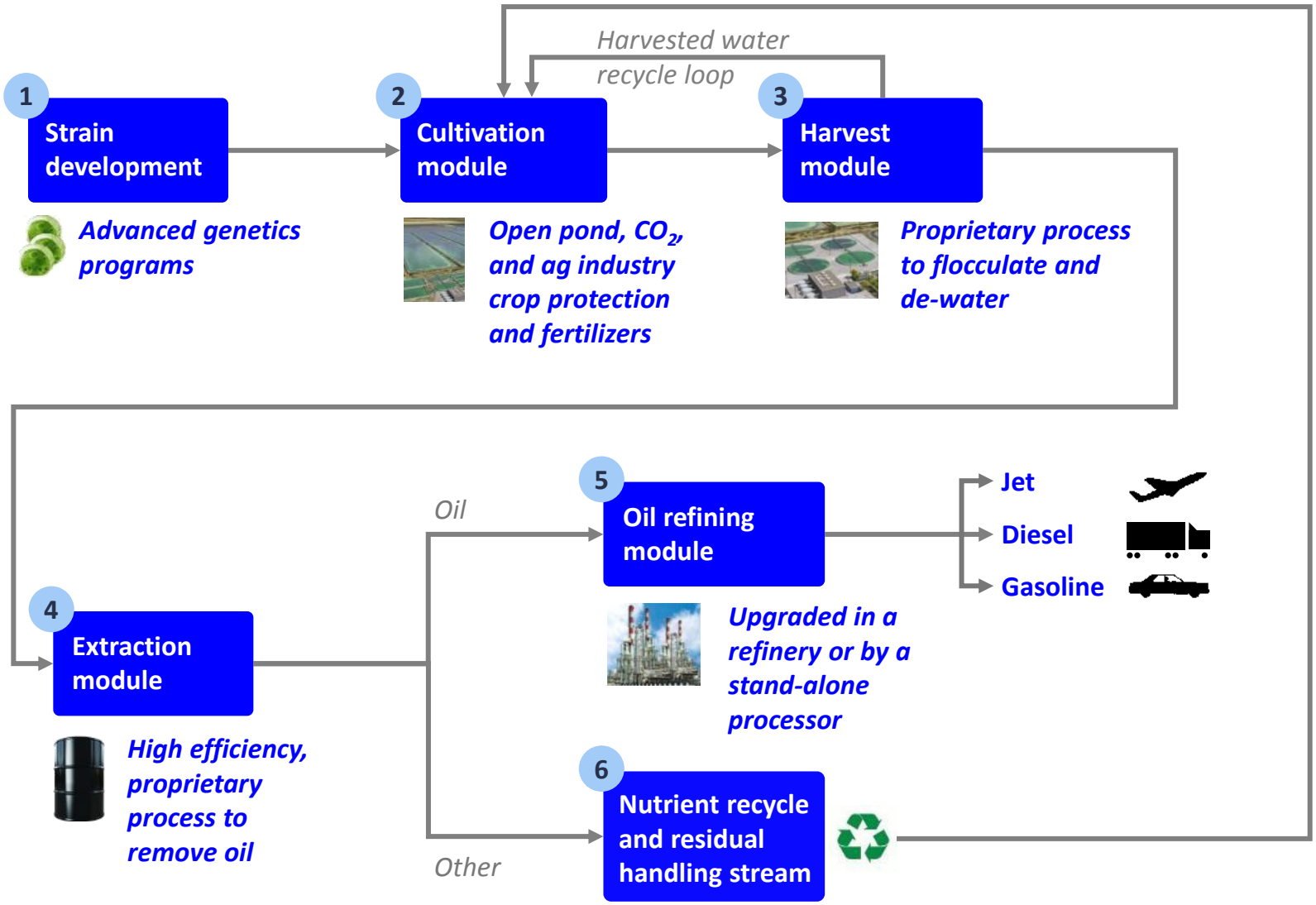
Overview of Sapphire's process for making algae-derived bio-crude



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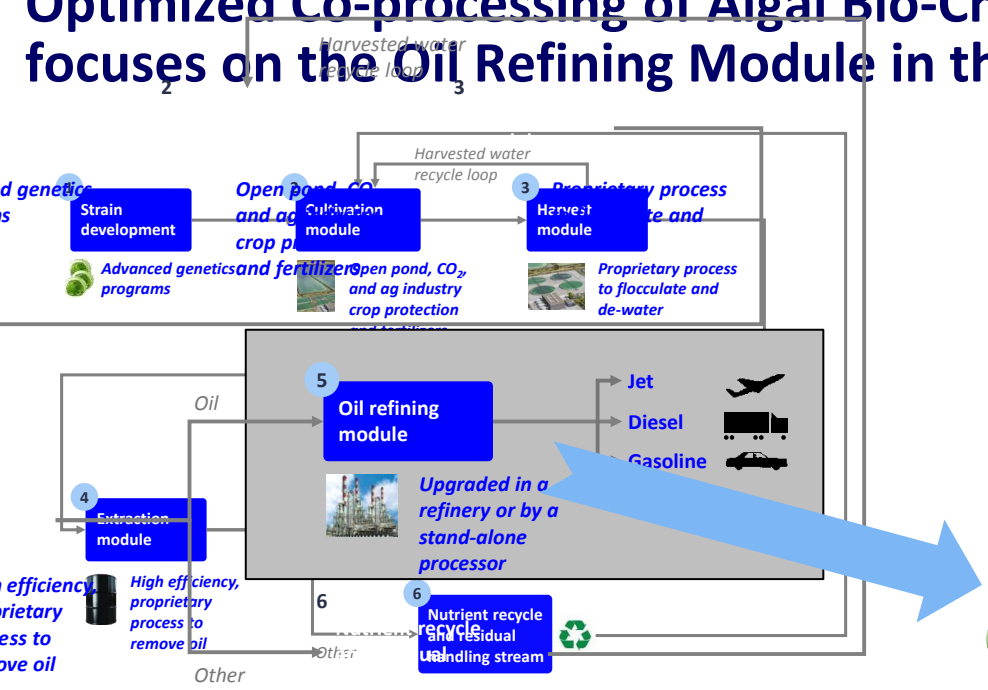
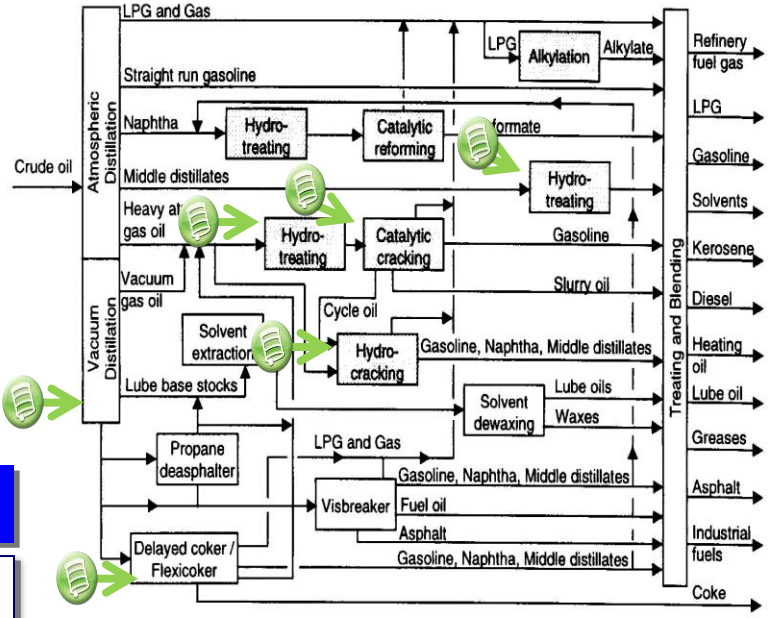
Optimized Co-processing of Algal Bio-Crude Through a Petroleum Refinery focuses on the Oil Refining Module in the Sapphire Process



Typical Oil Refinery



Must demonstrate oil refining is possible

Sapphire is not installing oil upgrading capacity

Sapphire oil quality is different than petroleum derived crude oil

Refiners will be apprehensive purchasers without data to confirm upgrading is possible in their refineries

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1 - Approach

Verify technical feasibility at the smallest scale possible

- Evaluate the yield and process conditions for each of the refinery processes using Sapphire Algae bio-crude produced at the IABR in New Mexico and blended with refinery intermediate streams
- Verify product quality and that process conditions found in typical refineries can be used to upgrade Sapphire algae bio-crude at greater than 5% bio-crude composition
  - Hydrotreating – lab scale (6cm^3 reactor), pilot scale (4 liter reactor, 175 gallons of product)
  - Coking – pilot scale (8 gallon coke drum)
  - Hydrocracking – lab scale (6cm^3 reactor)
  - Fluid Catalytic Cracking – scale tbd
- Experimental set up and monitoring done by experienced Sapphire researchers with oil industry and catalysis background

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2 – Technical Accomplishments / Progress / Results

Experimental programs have been set up

- Presentation on prior algae bio-crude oil upgrading work that is the foundation for hydrotreating aspects of this project were presented at Spring AIChE meeting
- Sourced all petroleum oil required for testing and produced all algae bio-crude
- Set up testing programs with three vendors for oil blending, hydrotreating, hydrocracking and coker testing
- Secured initial agreement with petroleum refiner
- Working on identifying pilot scale FCC testing partner – will progress with previously identified lab scale (FCC MAT) partner if no large scale partner is identified
- Project is progressing to plan after first three months

3 - Relevance

Provide oil industry with data required to confidently purchase bio-crude

- Verifying that bio-crude oils produced from the thermochemical conversion of algae can be upgraded in existing refiners without equipment modification is critical to the future purchase of bio-crude oil by petroleum refiners and ultimately end users
- Renewable fuels that are compatible with the existing petroleum infrastructure will spur the creation of a domestic bio industry
- Bio-crude oil will be able to be sold at parity with petroleum derived feed if:
  - It is compatible with existing refinery process conditions (temp, pressure, catalyst, metallurgy)
  - Has product yield that is similar to or better than petroleum feedstock
  - Upgrading data is available to refiners to review prior to sale
- This project will establish the process conditions and yield for each upgrading process option and then use refinery techno-economic analysis (LP's) to determine the economics of each insertion point

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4 - Critical Success Factors

Sale price at parity or above petroleum feedstock is the ultimate goal

- All new refinery feedstocks struggle to garner market prices in the beginning as refiners negotiate price down to account for uncertainty in yield and quality
  - Producing data showing there is no process or yield penalty will eliminate this initial discount
- Algae bio-crude oil is different than petroleum derived feedstocks
  - Oxygen, nitrogen and some metals found in algae bio-crude are not normally found in petroleum feedstocks
  - Must show that these abnormal qualities are not detrimental to refineries
  - There will be limits on concentration of bio-crude in feed but bio-crude must be able to be processed at more than 5% concentration
- Success in demonstrating algae bio-crude can be upgraded in existing refineries will reduce the capital required to convert algae to transportation fuels and speed the time to market for algae bio-crude

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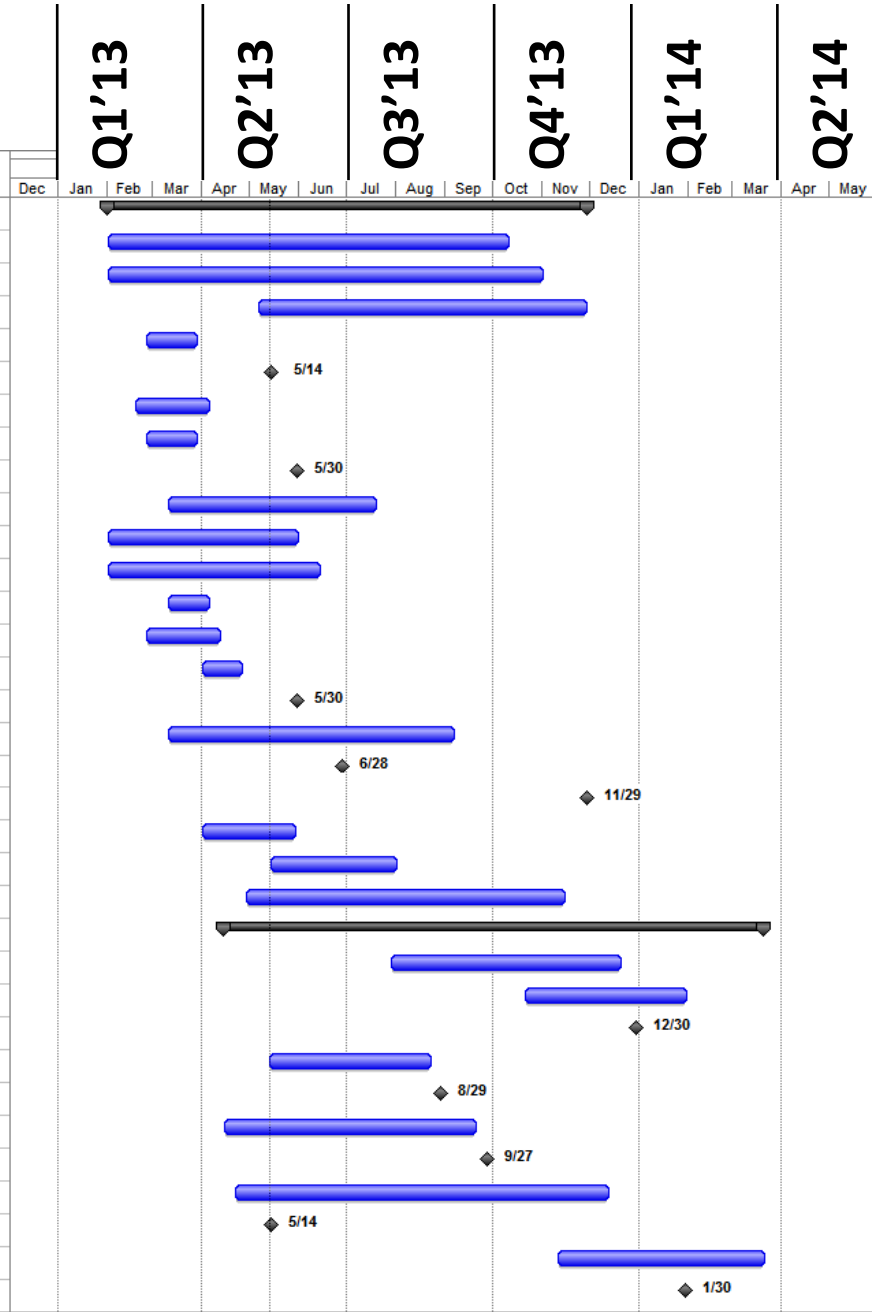
5. Future Work

ID	Task Name
1	**A Upgrading Studies & Testin**
2	A.1.1 Identify and Contact Candidate Refiner
3	A.1.2 Brief Potential Refiners and Align Roles
4	A.1.3 Present Upgrading Study Data & Receive feedbac
5	A.1.4 Secure Initial Refining Partne
6	A.ML.1 Initial Refining Partner Announce
7	A.2.1 Collect 100 gallons of Oil from Sapphire Las Cruces Test Sit
8	A.2.2 Test Oil for Transportability and Storabilit
9	A.ML.2 Oil Blending, Transport and Storage Tests Complet
10	A.2.3 Collect up to 40 bbl. of Oil from Sapphire Las Cruces Test Sit
11	A.3.1 Identify and Secure Vendors to Conduct Studies
12	A.3.2 Establish Final Scope and Work Plan for Studie
13	A.3.3 Secure Agreement for Petroleum Co-processing
14	A.3.4 Determine Process Conditions and Catalyst for Test
15	A.3.5 Perform Pilot Scale Hydrotreating Testin
16	A.ML.3 Large Pilot Scale Hydrotreating Study Complet
17	A.3.6 Perform Pilot Scale Hydrocracking, Cat Cracking or MAT Testing
18	A.ML.4 Screening Hydrocracking Studies Complet
19	A.ML.5 FCC MAT Testing Complet
20	A.3.7 Perform Pilot Scale Coking Testing
21	A.ML.6 Coker Testing Complet
22	A.3.8 Convert Feedstocks to Finished Fuels
23	**B Analysis & Results**
24	B.1.1 Compile Results from Testing and Start Technoeconomic Mode
25	B.1.2 Complete and Updated LCA of Proces
26	B.ML.1 Technoeconomic and LCA Modeling Complet
27	B.1.3 Produce Jet Fuel for ASTM Testin
28	B.ML.2 On-Spec Fuel Produced
29	B.1.4 Initial Testing for EPA Title 40 Part 79 Testing
30	B.ML.3 Part 79 Screening Analysis Complete
31	B.2.1 Present Results and Analysis to External Organizations
32	B.ML.4 Hydrotreating Results Presented at AIChE Meetin
33	B.2.2 Secure Refining Partner for Next Phase Studies
34	B.ML.5 Refining Partner for Post Dec 2013 Upgrading Announce



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Summary

Project is key to gaining industry acceptance of algae bio-crude feedstock

- This work is required before refiners will purchase and process a new feed especially one as different as algae bio-crude
- Go/No Go decision points are based on minimum feed concentration and ensuring process conditions are the same as those found in typical refineries
- Project is in early stages but groundwork has been laid for a successful project
- Experimental protocols and test plans are identical to what petroleum refiners would do if they were doing the testing in house
  - Since Sapphire is performing the testing no single refiner will have superior technical insight into Sapphire bio-crude market price
  - Testing will help Sapphire and other algae bio-crude oil producers get market price for early production
- Success is the identification of a suite of upgrading options that are economically attractive to numerous refiners with different refinery configurations

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Additional Slides

Publications and Presentations

295693 Production and Upgrading Of Renewable Bio-Crude From Large Scale Algae Ponds

Wednesday, May 1, 2013: 3:30 PM

Neil Osterwalder, Dan Sajkowski and Ben Saydah, Sapphire Energy Inc., San Diego, CA

Renewable fuels from algae are moving closer to commercialization as Sapphire Energy showed with their Integrated Algae Bio-Refinery (IABR). The IABR in New Mexico was commissioned in 2012 and is producing algae derived bio crude oil on a continuous basis using Sapphire's proprietary conversion and extraction process. This algae bio-crude contains a wide range of hydrocarbons, fatty acids, aromatics, and nitrogen compounds and other heteroatoms. This chemical profile suggests that algal bio-crude can be economically processed by blending with existing refinery streams and co-processing the combined streams as opposed to the more costly development of algal-specific refineries. Different options of co-feeding the algae crude to a refinery can produce a full suite of refinery products from petrochemicals to gasoline, diesel and other refinery products. This study describes the products that can be produced from algae bio-crude and its implementation into existing refining infrastructure.