Biofuels and Algae Markets, Systems, Players and Commercialization Outlook

Rice Global E&C Forum November 20, 2009
BIODIESEL 2020: A GLOBAL MARKET SURVEY

- 685 page study, February 2008
- **Country Studies**
  US, Brazil, EU, China, India
- **Feedstock Markets and Trends**
  Soy, Rapeseed, Palm, Jatropha, Castor, Yellow Grease, Fats
- **2nd Generation Projects and Trends**
  Algae, Renewable Diesel, BioCrude, Biomass to Liquids, Green Diesel
- **Outlook and Opportunities**
ALGAE 2020: Biofuel Markets, Co-Products, Green Chemicals
BioPlastics, Livestock Feed and Commercialization Outlook

- **Algae Market Potential and Applications**
  - Biodiesel & Biocrude
  - Drop In Fuels – Renewable Diesel, Gasoline
  - Aviation Fuels
  - Livestock Feed and Aquaculture Feed Markets
  - Nutraceutical and Pharmaceutical Markets
  - Green Plastics, Chemicals, Polymers Markets

- **Algae Production Methods Overview**
  - Production Systems Overview: Open Ponds vs Closed Photo Bioreactor Systems (PBRs), Growing Algae in The Dark
  - Inputs for Algae Systems CO2 and NO2
  - Extraction Methods
  - Biorefining Technologies – 1st Gen & 2nd Gen

- **Algae Project Profiles and Case Studies**

- **Outlook for Commercialization: 2010-2015**

June, 2009
1. GLOBAL BIOFUELS MARKETS
USA Biofuels Targets

- Federal RFS – 36 billion gallons by 2022
- 21 Billion Gallons from Advanced Biofuels

US Algae Market Potential

- US Military is #1 Consumer of Diesel Fuel in The World
- Industrial Diesel markets represent 25% of petrol consumption
- More than 95% of passenger cars use gasoline, 3% on diesel

**PROBLEM:** The US can not produce enough corn and soybeans to meet targets, even with cellulosic corn

**OPPORTUNITY:** Algae can serve as a feedstock for First Generation Biodiesel and Ethanol Plants, Aviation Fuels Markets and Biocrude for Biogasoline

SOURCE - ALGAE 2020 AND BIODIESEL 2020 STUDIES
USA BIODIESEL MARKET OVERVIEW

US Biodiesel Production 2004-2008

source Emerging Markets Online, Algae 2020 study, NBB, USDA, FAO

SOURCE - ALGAE 2020 STUDY
USA BIODIESEL MARKET OVERVIEW

US Biodiesel Production and Capacity

Source: Emerging Markets Online Consulting Services, Algae 2020 study

OPPORTUNITY
Feedstock Shortages
Algae Production
EU Biofuels Targets

- Target 2 - 5.75% by 2010
- Proposals: 10% by 2020 (EU Revision)
- Feedstock sustainability concerns #1 for 2009

EU Algae Market Potential

- More than 50% of cars run on diesel
- PROBLEM: Europe can not produce enough rapeseed, sunflower to meet targets
- OPPORTUNITY: Algae can serve as a feedstock for First Generation Biodiesel and Ethanol Plants, Aviation Fuels Markets and Biocrude for Renewable Diesel and Gasoline

SOURCE - Algae 2020 and Biodiesel 2020 studies
Europe Biodiesel Production and Capacity

Opportunity

Feedstock shortages of rapeseed in EU
Algae can bridge production/capacity gap
Europe's decreasing production, and increasing consumption presents opportunities for algae crude oil for biodiesel and drop in fuels - renewable diesel, renewable gasoline, and aviation fuel.
China’s Biofuels Targets

- 2010 - to increase biofuels production to nearly 4 million MT by 2010
- 2020 - target to replace 15 percent of China’s transportation energy needs by producing 12 million+ tons of biofuels

China’s Biofuel Markets

- Traditional use of waste vegetable oil
- Plans for bigger plants using non-food sources such as jatropha, recycled waste and sewage feedstock
- China is Installing Two 500 MW Coal-Fired Power Plants Every Week for The Next 10 Years, According to Estimates from MIT & China’s MOST
- Opportunity – Algae For Carbon Capture & Production of Clean Biofuels, Biocrude & Drop-in Fuels
- China – 1.3 Billion Sources of Renewable Energy!
China Crude Oil Demand to 2030

Target Markets - Algae Biocrude Oil for Drop In Fuels - Renewable Diesel, Gasoline, Aviation

Producers of algae crude oil or "green crude" are receiving increased investments for use in biodiesel refineries, as well as for use in petroleum refineries to produce drop in fuels - renewable diesel, renewable gasoline, and clean aviation fuels.

Source: Algae 2020 study, Emerging Markets Online Consulting Services, IAE, EIA forecasts
China Oil Production and Demand Forecast to 2030

Target Markets for Algae Biocrude, Drop In Fuels & Biodiesel

China's decreasing production, and increasing consumption presents opportunities for algae crude oil for biodiesel and drop in fuels - renewable diesel, renewable gasoline, and aviation fuel.

Source: Algae 2020 Study, Emerging Markets Online Consulting Services, IAE, EIA forecasts
India’s Biodiesel Targets:

- National Biodiesel Program started 2006
- Two Phases – jatropha plantation program
- Target – 20% of diesel fuel by 2012
- Growth for rural, city and regional areas
- Socio-economic plans for growth in marginal areas to benefit rural farmers

India’s Biodiesel Markets:

- Key focus: Jatropha plantation, production
- Opportunity for Algae to Serve a Huge Growing Market and 20% Government Target
India Crude Oil Demand to 2030

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India Oil Production and Demand Forecast to 2030

Target Markets for Algae Biocrude, Drop In Fuels & Biodiesel

India's decreasing production, and increasing consumption presents opportunities for algae crude oil for biodiesel and drop in fuels - renewable diesel, renewable gasoline, and aviation fuel.

Source: Algae 2020 Study, Emerging Markets Online Consulting Services, IAE, EIA forecasts
Scale of Biofuels Systems is Critical To Meeting the US 21 Billion Gallon RFS2
2008 + Trend Towards Large-Scale Projects Using Lower Cost Feedstocks
<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Gallons Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy</td>
<td>40-50 US gallons/acre</td>
</tr>
<tr>
<td>Canola/Rapeseed</td>
<td>120-150 US gallons/acre</td>
</tr>
<tr>
<td>Jatropha</td>
<td>175-250 US gallons/acre</td>
</tr>
<tr>
<td>Palm</td>
<td>650 US gallons/acre</td>
</tr>
<tr>
<td>Algae</td>
<td>5-10,000 US gallons/acre</td>
</tr>
</tbody>
</table>
Applications for Algae to Biofuels – Multiple Uses

- Biodiesel
- Biomass for Power Generation
- Carbon Capture from Coal Power Plants
- Bio-Crude to Renewable Diesel
- Bio-Crude to Bio-Ethanol
- Bio-Crude to Biogasoline

Source: Algae 2020 and Biodiesel 2020 studies, Emerging Markets Online
2. ALGAE PRODUCTION METHODS
Algae Growth Systems – Common Method 1 of 2

Ponds and Raceway Systems – 98% of All Algae Production is in Ponds

Diagram – Algae Farm Using 64 Open Pond “Raceways” to Grow Algae

Source: citation from analysis in Algae 2020 and Biodiesel 2020 studies, Emerging Markets Online
Algae Growth Systems – Common Method 2 of 2
Photo Bio Reactor Systems:
Long Term Possibilities - Short Term Problems (*Green Fuels, Algaeink, Vertigro*)
Good for Innocculum, Testing and High-Value Specialty and Pharmaceutical Markets
Not Yet Ready for Commercial Fuels in The Next 2-3 Years

*Note: Failure is Success if You Learn From it*

A Photo-Bioreactor in Translucent Tube from GreenFuels

Global Green Solutions/Vertigro Vertical Photo Bioreactor System

Source citations mentioned in  Algae 2020 and Biodiesel 2020 studies Emerging Markets Online

Images courtesy of greentuelonline.com and valcent.net
Solazyme – 3rd Method – Microbial Fermentation – High Yield Algae
Growing Algae in The Dark Converting Starches to Lipids/Oils for Biocrude, Drop In Fuels

- Solazyme **Grows Algae in The Dark** Converting Sugar and Starches to Lipids/Oils
- Solazyme **has already raised $70 million** in capital, including Chevron as a key investor
- Solazyme’s fuel has met ASTM Standard D 1655 *For Aviation/Jet Fuel*

Source citations mentioned in Algae study, Emerging Markets Online

Images courtesy of solazyme.com
Applied Algae Production Systems
Algae to Biodiesel, Ethanol, Biocrude and Jet Fuel
Algae fats/lipids can be converted to **biodiesel**, sugars converted to **ethanol**

Source: cited in Algae 2020 and Biodiesel 2020 studies, Emerging Markets Online
ALGAL BIOMASS PRODUCTION SYSTEMS

System Inputs
- Algal Species
- Sunlight
- Water Source
- CO2 Source
- Nutrients npk
- Suitable Land
- Finance

Production
- Ponds & PBRs
- Fermentation Systems
- Equipment
- Energy & Labor
- System Monitors
- Biometric Analysis
- CAPEX Estimates
- OPEX Estimates
- Target Markets & Strategies

Harvesting
- Sedimentation
- Centrifuges
- Filtration
- Microstraining
- Foam Fractionation
- Bio Flocculation
- Electro Flocculation
- Shrimp & Fish

Extraction
- Expeller Press
- Hexane Solvent
- Supercritical CO2
- Enzymatic Hydrolysis
- Microwave
- Cavitation
- Ultrasonic Cavitation
- Cellular Decompression

System Outputs
- Biodiesel and Biocrude
- Renewable Diesel, Gasoline
- Animal and Fish Feed
- Livestock Feed Protein Additives
- Organic Fertilizer
- Pharmaceutical Products
- Green Plastics, Chemicals
- Omega 3, 6 and DHA oils
- Clean Power Generation

Source: Algae 2020, Emerging Markets Online Consulting Services
Applied Systems – Algae to 2nd Gen Bio-Crude for Petroleum, Aviation Fuels

Process Diagram: Algae Conversion to Biomass, Then Bio-Crude Oil

Source: cited in Algae 2020 study, Emerging Markets Online
3. ALGAE PROJECTS AND CASE STUDIES
SAPPHIRE ENERGY
“Green Crude” and *Renewable Gasoline* for Petrol Refineries, Aviation Fuel
Pond-Based Fuels For Biocrude and Renewable Gasoline

Sapphire produces “*Green Crude*” for petrol refineries and aviation fuel
and *recently raised $100 Million* from Bill Gates & Rockefeller Foundation

Source citations mentioned in the Algae 2020 study, Emerging Markets Online
**Algae-to-Energy’s production system – four key components:**

1) **Deep Water Ponds** – able to produce higher volumes per acre vs raceway ponds

2) **Extraction Systems** – at lower costs licensed from Missing Link Technology (MLT)

3) **Harvesting Systems** – lower cost systems, innovative methods licensed from MLT

4) **Products** – Biocrude, Drop-In Fuels, Animal Feed, Bio-Polymers and Plastics

Source citations mentioned in Algae 2020 Study, Emerging Markets Online

Images courtesy of originoil.com
PETROALGAE - Turning Algae into **Green Diesel** and **Animal Feed**

Pond-Based Systems for Producing Renewable Diesel and Animal Feed Proteins

PetroAlgae system uses multi-culture system with algae, cyanobacteria & micro-crops

1. **Production** - PA grows crops in segmented micro-crop growing areas
2. **Extraction** - PA extracts proteins from the biomass for animal feed
3. **Green Diesel** – the remaining biomass can be refined into Green-Diesel fuel

Source citations mentioned in Algae 2020 Study, Emerging Markets Online

images courtesy of originoil.com
**ALGENOL – Turning Algae into Ethanol**

Algenol’s Algae to Ethanol Process Diagram

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**Algenol’s Algae Ethanol** Project in Mexico project uses seawater and Powergen CO2, and produces clean energy and drinking water.

Source citations mentioned in Algae 2020 study, Emerging Markets Online

*Image courtesy of algenbiotuels.com*
ALGAE INVESTMENTS TRENDS

The Key Trends are:

(a) Investment in Companies with "Proof of Concept" With Pilot or Demonstration Phase Projects Ready to Scale Up

(b) Investment in Companies Producing Drop-in Fuels: Biocrude for Renewable Diesel, Renewable Gasoline, Aviation

(c) Investment in Synthetic Biology Projects for Higher Value Markets: Pharma/Nutraceuticals and Specialty Green Chemicals
<table>
<thead>
<tr>
<th>Organization</th>
<th>Investment</th>
<th>Project Scope/R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapphire Energy</td>
<td>$100 million in R&amp;D from Bill Gates’ Cascade Investments and Rockefeller Foundation</td>
<td>Algae for biocrude demonstration project in Las Cruces, California, and the production of renewable gasoline</td>
</tr>
<tr>
<td>Solazyme</td>
<td>$75 million in R&amp;D finance so far from private investors, Chevron</td>
<td>Algae for biocrude, jet fuel and biodiesel in San Francisco, California</td>
</tr>
<tr>
<td>GreenFuels</td>
<td>$92 Million in project finance</td>
<td>Green fuels plans to produce 25,000 tons of algae for Auranita SA in Spain</td>
</tr>
<tr>
<td>UK Carbon Trust</td>
<td>$40 million challenge for algae commercialisation by 2020</td>
<td>In October 2008, UK Carbon trust announced a fund to award up to $40 million in grants for algae projects</td>
</tr>
<tr>
<td>Aurora Biofuels</td>
<td>Raised a second round of funding of $20 million from Oak Investment Partners, Gabriel Venture Partners and Noventi</td>
<td>Aurora Biofuels is an algae-to-biodiesel startup with roots at University of California at Berkeley.</td>
</tr>
<tr>
<td>Algalink</td>
<td>Undisclosed amount from KLM airlines, new Chinese ventures</td>
<td>New investments in the Netherlands based algae production manufacturer.</td>
</tr>
<tr>
<td>Petrosun</td>
<td>$40 million in funding from China</td>
<td>Formation of Petrosun China, a 50/50 joint venture with Shanghai Jun Ya Yan Technology Development</td>
</tr>
<tr>
<td>NREL</td>
<td>$25 million from 1970s to 1990s</td>
<td>Renewed investment in 2008 from Chevron, the US DOE, and several other firms.</td>
</tr>
</tbody>
</table>

Source: Algae 2020 - Advanced Biofuels Markets and Commercialization Outlook from Emerging Markets Online
Algae Market Strategies:
Co-Products Besides Fuel are Critical to Success
Algae products are and will be used to manufacture: fuel, feed, food, fertilizer, plastics and green chemicals. Algae meal will be a protein supplement for aquatic and livestock/poultry feeds.
Algae 2020 Market Value Model

Pharmaceutical and Specialty Chemical Products:
- $25k to $800k per MT

Pharmaceutical, Chemical and Nutraceutical Products:
- $2,000 US to $25,000 US per MT
  - Baby Food Formulae Supplements
  - Cosmetics Industry Products and Additives
  - Plastics and High Value Chemical Markets
  - Food Additives for Health Markets
  - Food Additives for Coloring, Carotenoids
  - Healthy Oils: Omega 3, 6 and DHA/Fish Oils

Livestock Markets:
- High-Value Animal Protein, Fish and Livestock Feed Additives
- Mid Value Fish and Livestock Feed Supplements

Bigger Markets, Lower Values:
- $500 US per MT up to $2,500 US per MT

Vegetable Oils for Human Consumption and Biofuels Production:
- Higher Value Oils: Castor, Olive Oil and Canola Oil equivalents
- Mid Value Oils: Soy, Sunflower, Palm Oil equivalents (TAGs)

Algal Biomass for Carbon Capture, Bioremediation and CO2 Carbon Capture

Algal Crude Oil for Biodiesel and Bio-Crude for Drop-In Fuels Refining:
- Algal crude oil with TAG properties useful for Biodiesel production
- Algal green crude oil for upgrading into renewable diesel, aviation fuel, renewable gasoline

Source: Emerging Markets Online Consulting Services; Algae 2020 study
ALGAE COMMERCIALIZATION OUTLOOK
Algae 2020 Market Commercialization Outlook

Timelines for Production and Progression Into Larger Markets

Small Scale Production
2009 –to 2011

Mid-Scale Production
2010-to 2012

Larger-Scale Production
2011 to 2015

Large Scale Production for Fuels
2012 to 2020

Sources: Algae 2020 study, Emerging Markets Online Consulting Services

Algae 2020 Study from Emerging Markets Online Consulting Services http://www.emerging-markets.com
Timeline for Commercialization of Algal Biofuels and Products

**Phase 1: 2010 For High Value Markets - Phase 2: Fuel Markets Begin in 2011-2012**

2009 – Algae R&D Projects Mature, Start of Sales Into Higher-Value Non-Fuel Markets

2010 – Algae Pilot Projects & Demonstration Projects Increase in Scale & Production

2011 – Early Algae Fuel Production Projects Arrive For Defense, Government, CO2

2011 – Early-Stage CO2 Capture Projects Arrive *(Expensive at first, then cheaper)*

2012-2015: **Scale Up:** Commercial Projects, Production, Markets *(Costs decrease)*

2010-2015: **Phase 1: Small Markets:** Higher-Value Commodity Products:
   - Pharma/Nutraceuticals, Animal Feed Supplements, High Value Oils,
   - Green Polymers: Bio-Degradable Chemicals, Materials, Additives

2012-2020: **Increased Production, Competition Lowers Costs, Market Share Up**

2012-2020: **Phase 2: Big Markets:** Algae Grows as a Commodity for Fuels:
   - Biodiesel, Biocrude, Drop in Fuels, Ethanol, Aviation Fuels, Animal Feed,
   - Large-Scale Green Chemical Markets, Plastics, Polymers Emerge

Source ALGAE 2020 STUDY, Emerging Markets Online
Back to the Future? Algae Raceway Ponds from NREL / DOE - 1987
Microalgae Biodiesel Production in Raceway Ponds and Harvesting Ponds – Artist’s Conception

Source: NREL-DOE, cited in Algae 2020 study
Algae Farms - A Look at Future Models - PBRs
Solix - 2012 to 2020 Scale Up

Source: Solix Biofuels
For more information
Contact: Will Thurmond

- President, Emerging Markets Online
- American Biofuels Council – Chairman of Research
- former Chairman of R&D, National Algae Association
- Columnist, Biofuels International & Biofuels Digest
- Email info@emerging-markets.com
- Web: www.emerging-markets.com