Biofuels from Microalgae: The Promise and Challenge of Algae as a Renewable Source of Biofuels

Mike Hightower\textsuperscript{1} and Ron Pate\textsuperscript{2}

1 – Sandia National Laboratories, Energy Systems Analysis
2 – Sandia National Laboratories, Earth Systems Analysis and DOE/EERE Office of Biomass Program

Ground Water Protection Council
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Energy Water Roadmap Recommendations for Alternative Fuels Sector Research

- Reduce water use for cooling in biofuels and alternative fuels production
- Reduce water use in processing
- Develop low fresh water use technologies such as algal biodiesel
- Assess non-traditional water use for fuels applications
- Assess hydrologic impacts of large cellulose biofuels scale-up and oil shale
Gallons of Oil per Acre per Year (approximate)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Gallons of Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>18</td>
</tr>
<tr>
<td>Soybeans</td>
<td>48</td>
</tr>
<tr>
<td>Safflower</td>
<td>83</td>
</tr>
<tr>
<td>Sunflower</td>
<td>102</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>127</td>
</tr>
<tr>
<td>Oil Palm</td>
<td>635</td>
</tr>
<tr>
<td>Micro Algae</td>
<td>700 - 7000</td>
</tr>
</tbody>
</table>

Key Attributes of MicroAlgae as Biofuel Feedstock

- Reduced land footprint and indirect land use impacts
- Can use non-fresh water to reduce demands on fresh water
- High production potential for both whole biomass and neutral lipids
- Potential source of high quality feedstock for advanced biofuels production
- Need not compete with agricultural lands and water for food/feed production
- Can potentially recycle CO₂, organic carbon, & nutrients from waste streams

However, affordable and productive commercial scale operations not yet demonstrated.
Building on Past DOE Investments in Algae Aquatic Species Program ... A Look Back

Initial algae biofuels R&D during the period 1978-1996

DOE investment ~ $25M

Excerpt from ASP Close-Out Report (1998) ...

In 1995, DOE made the difficult decision to eliminate funding for algae research within the Biofuels Program ... [T]his report should be seen not as an ending, but as a beginning. When the time is right, we fully expect to see renewed interest in algae as a source of fuels and other chemicals. The highlights presented here should serve as a foundation for these future efforts.
**Biofuel Policy Drivers for DOE and others**

**EPACT-2005 and EISA-2007**

**Renewable Fuel Standard (RFS2)**

- Conventional (Starch) Biofuel
- Biomass-based diesel
- Cellulosic Biofuels
- Other Advanced Biofuels

### 15 BGY cap on conventional (starch) biofuel

**EISA** defines **Cellulosic Biofuel** as “renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions...that are at least 60 percent less than baseline lifecycle greenhouse gas emissions.” The EPA interprets this to include cellulosic-based diesel fuel.

**EISA** defines Advanced **Biofuel** as “renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions...that are at least 50 percent less than baseline lifecycle greenhouse gas emissions.” This includes biomass-based diesel, cellulosic biofuels, and other advanced fuels such as sugarcane-based ethanol and algae-based biofuels.
Successive Generations of Biofuels

Corn Ethanol
- Commercially available (no DOE research ongoing)
- Reduced GHG emissions
- Capped by RFS

Cellulosic Ethanol
- Focus of current DOE research
- Potential to lower GHG emissions 86%
- Uses biomass from waste and non-agricultural land

Advanced Biofuels
- Emerging efforts on new advanced biofuels and pathways, including algae
- Exploit opportunities to reduce environmental footprint
- Energy content and fuel economy similar to petroleum-based fuels

Mature Commercial Technology
Emerging Technologies
Increasing Energy Densities and Fuel Infrastructure Compatibility

An element is the “Algae Pathway”
- Stakeholder workshop held December 10, 2008

National Algal Biofuels Technology Roadmap released June 28, 2010
http://www1.eere.energy.gov/biomass/
The 2010 investment in algae totals ~$180M, and includes:

- $49M for the NAABB consortium
- $35M for algae R&D, as directed by Congress
- $50M for the Sapphire to deploy open pond algal biofuel system
- $25M for the Algenol to pilot an photobioreactor algal biofuel system
- $22M for Solazymes to pilot a heterotrophic algal biofuel system

*Includes regular FY2010 appropriations and 2009 ARRA funds
The Algal Supply Chain: How we get from Algae to Fuel

Algal Cultivation
- Strain Biology/Selection
- Cultivation Strategy
- Resources and Siting

Algal Harvesting and Processing
- Harvesting/Dewatering Technology
- Fractionation/Extraction Technology

Conversion of algae components into biofuels and other products
- Fuel Synthesis, Conversion or Upgrading Technology
- Infrastructure and Market of Fuel or Product

Is this economically and environmentally sustainable?
Can the system be scaled up to the necessary scales for fuels?
The **Ideal Algae** would be:

- **Productive**
- **Stable in culture**: robust in response to environmental changes and predators/pathogens

Algae producers have an important decision to make...

- Species of algae chosen will effect all downstream processing including the type of biofuel produced
- Could also consider cultivating mixed algae communities

**Different “types” of algae exist**
Algal Cultivation Strategies

Several Types of Algae Cultivation Vessels Exist

Open systems - typically outdoor open ponds

Closed systems - enclosed clear plastic vessels (bags or tubes) known as Photobioreactors, or dark tanks (such as fermentation tanks)

Offshore systems - growing algae in the open ocean - usually contained in some way (bags or ropes)
Important Challenges for R&D:

What is the best strategy for cultivating algae when you balance productivity with economics?

- Unlikely to be one-size-fits-all approach for every region
- Sunlight or sugars?
- System must also be optimized for production of desired product (ex. lipid or whole biomass)
Resources & Siting for Cultivation

- **Resources required to grow algae:**
  - Land
    - Algal productivity eases land requirement
    - Can use non-arable land
  - Water
    - Many algae can grow in non-fresh water
  - CO₂ or Sugars
  - Nutrients
  - Electricity

- **Siting options (location)-**
  - many propose to cultivate algae coupled with:
    - Wastewater Treatment (provides nutrients and non-fresh water source)
    - Aquaculture (provides infrastructure)
    - Point CO₂ sources (CO₂ re-use)
    - Marine Environments (ample non-fresh water)
    - Sugar Waste Streams (ex. pulp and paper)

Proximity, sustainable availability, and cost of all resources will effect price of biofuel.
Challenges for R&D:
Can one access all necessary inputs to cultivate algae and still maintain a cost-effective and sustainable process?

Is system recycling of water, nutrients, and energy feasible and necessary?

Pacific Northwest National Laboratory Report to DOE. Wigmosta, MS et al., *manuscript in preparation.*
Harvesting & Dewatering

Challenges for R&D:

- Many technology options currently exist that must be evaluated. Develop improved harvesting and dewatering technologies.
- New or improved technologies must reduce energy intensity, capital and operating costs, and have scalability!
- Downstream processes that can handle wet algae are advantageous.

Algae in culture are relatively dilute—most of the water must be removed before algae can be processed into fuel. This is a very energy-intensive step in making algae biofuels. Current technologies are either expensive, unscalable, and/or adversely affect down-stream processing.
Conversion to Fuel and Products

Algal Biomass

Carbohydrates
- For feed or other products; Power
  - Biochemically converted into fermentable sugars for fuels (Ethanol)

Proteins

Lipids
- Direct Synthesis of Fuel or Precursers:
  - Alcohols (Ethanol)
  - Renewable Hydrocarbons
  - Products
- Whole Algae Conversion:
  - Biochemical
  - Thermochemical
  - Anaerobic Digestion for Power

Upgrading into Biodiesel (FAME), Renewable Gasoline, Diesel, and/or Jet Fuel
Locations of IBR Projects
Algae projects are circled: Algenol, Sapphire, and Solazyme

For more information, visit: http://www.eere.energy.gov/biomass/integrated_biorefineries.html
Algae R&D Consortia Projects

• National Alliance for Advanced Biofuels and Bioproducts (NAABB)
  • $49M in Recovery Act funds
  • Led by the Donald Danforth Plant Sciences Center
  • Director: Dr. Jose Olivares (Los Alamos National Laboratory)
  • Biology, Cultivation, Harvest/Dewater, Extraction, Thermochemical Conversion, Sustainability, Co-products

• Cellana Consortium (Cellana)
  • up to $9M in appropriated funds
  • Led by Cellana, Inc.
  • Director: Dr. Mark Huntley (U. Hawaii)
  • Cultivation (marine hybrid system), systems integration, co-products

• Consortium for Algal Biofuels Commercialization (CAB-Comm)
  • up to $9M in appropriated funds
  • Led by UC San Diego
  • Director: Dr. Steve Mayfield (UCSD)
  • Crop protection, Lifecycle Analysis

• Sustainable Algal Biofuels Consortium (SABC)
  • up to $6M in appropriated funds
  • Led by Arizona State University
  • Director: Dr. Gary Dirks
  • Biochemical conversion, Fuel Testing
Conversion to Fuel and Products

Challenges for R&D:

• Investigate many technology options for converting algal biomass into different biofuels
  – Also consider production of co-products that will aid in cost-effectiveness of entire system
  – Issues include catalysts, energy intensity, GHG emissions, conversion rates

A gasifier being used by a NAABB partner to convert whole algal biomass to fuels

Extracted Algal Oil: Solazyme, CA
1. Feedstock supply: Strain selection/development, cultivation strategy, siting & resources

2. Feedstock processing: Harvesting/dewatering, fractionation and extraction

3. Conversion into Fuel: synthesis, conversion, or upgrading into fuels and co-products

4. Infrastructure, Fuel and Product Markets, and Regulations/Standards

5. Systems Integration and Scale-up of all Technologies***

Information Resources

- EERE Info Center - www1.eere.energy.gov/informationcenter
- Biomass R&D Initiative – www.biomass.govtools.us
- Grant Solicitations - www.grants.gov
- DOE Office of Science - http://www.er.doe.gov/