Algae-Derived Biofuels

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Microalgae as a Biofuel Source

- Global shortages of fossil fuel spurring research into sustainable obtainable energy
- Biofuels considered a new energy source
- Algae produce more oil per U.S. cropping area than many other oil crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil Yield Gallons/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>18</td>
</tr>
<tr>
<td>Cotton</td>
<td>35</td>
</tr>
<tr>
<td>Soybean</td>
<td>48</td>
</tr>
<tr>
<td>Mustard seed</td>
<td>61</td>
</tr>
<tr>
<td>Sunflower</td>
<td>102</td>
</tr>
<tr>
<td>Rapeseed/Canola</td>
<td>127</td>
</tr>
<tr>
<td>Jatropha</td>
<td>202</td>
</tr>
<tr>
<td>Oil palm</td>
<td>635</td>
</tr>
<tr>
<td>Algae (10 g/m²/day at 15% TAG)</td>
<td>1,200</td>
</tr>
<tr>
<td>Algae (50 g/m²/day at 50% TAG)</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Lipid Production and Extraction

- Lipids are a stored energy source
- Algae produce lipids that are unsaturated and require little to no pretreatment before transformation into biodiesel
- Modified Bligh and Dyer Lipid Extraction Method
  - To extract the organic (lipids) portion of the algae sample

<table>
<thead>
<tr>
<th>Algae Strain</th>
<th>Lipid (% dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenedesmus obliquus</td>
<td>12-14</td>
</tr>
<tr>
<td>Scenedesmus quadricauda</td>
<td>1.9</td>
</tr>
<tr>
<td>Scenedesmus dimorphus</td>
<td>16-40</td>
</tr>
<tr>
<td>Chlamydomonas rheinhardii</td>
<td>21</td>
</tr>
<tr>
<td>Chlorella vulgaris</td>
<td>14-22</td>
</tr>
<tr>
<td>Chlorella pyrenoidosa</td>
<td>2</td>
</tr>
<tr>
<td>Spirogyra sp.</td>
<td>11-21</td>
</tr>
<tr>
<td>Dunaliella bioculata</td>
<td>8</td>
</tr>
<tr>
<td>Dunaliella salina</td>
<td>6</td>
</tr>
<tr>
<td>Euglena gracilis</td>
<td>14-20</td>
</tr>
<tr>
<td>Prymnesium parvum</td>
<td>22-38</td>
</tr>
<tr>
<td>Tetraselmis maculata</td>
<td>3</td>
</tr>
<tr>
<td>Porphyridium cruentum</td>
<td>9-14</td>
</tr>
<tr>
<td>Spirulina platensis</td>
<td>4.9</td>
</tr>
<tr>
<td>Spirulina maxima</td>
<td>6-7</td>
</tr>
<tr>
<td>Synechococcus sp.</td>
<td>11</td>
</tr>
<tr>
<td>Anabaena cylindrica</td>
<td>4-7</td>
</tr>
</tbody>
</table>

Benefits of Algae as a Biofuel

• More beneficial for the environment than cultivation of crops like corn for biodiesel
• Photosynthesis is an efficient CO$_2$ sequestration mechanism
• Does not impact human food consumption or use of high percentage of cropping areas
• Can use industrial flue gases that contain CO$_2$
• Can reduce dependency on fossil fuels and other nonrenewable resources
Countries that Use Algal Oil

- India
  - Nutritional source, wastewater treatment
- Japan
  - Nutritional and food sources
- Australia
  - Bioenergy initiatives
- Taiwan
  - Photobioreactor systems
- Israel
- EU
- USA
General Process

Harvest
- Pumping water through screen
- Traveling screen conveyor
- Drag net
- Paddlewheel screen
- Static guides To focus floating algae
- Ultrasound Flocculation
- Precision/Intelligent Harvesting Technology

Conversion
- Hydro thermal Processing
- Anaerobic Digestion
  - Pretreatment
  - Transesterification
  - Fermentation

Products
- Crude oil
- Methane
- Biodiesel
- Ethanol

http://biodiesel.org/pdf_files/fuelfactsheets/Production.PDF
**LIPID EXTRACTION**

1. Grow the algae
2. Starve it of nutrients
3. Break algae open
4. Use solvents to separate the fats from sugars
5. Evaporate solvent
6. Transform fat to biodiesel

- Fats
- Sugars
- Biodiesel
Biodiesel from Algae

**How Algae Biodiesel Works** Bioreactor Process

1. Cultivation of Microalgae species
2. Harvesting of Microalgae
3. Extraction of Oil from Microalgae
   - Transesterification
   - Biodiesel

**Diagram:**
- Input: Water, Algae, CO₂, Nutrients
- Output: Centrifuge, Dryer, Oil press, Press cake, Algae oil, Recycled Water, Recycled Biomass
- Process: Feeding vessel, Photo-bioreactor
Oil from Algae

**Biodiesel from algae**
High oil prices and advances in biotech over the past decade have refueled the algae biofuel race.

**The process**

1. After initial growth, algae is deprived of nutrients to produce a greater oil yield.
2. Extraction of oil. A press produces 70-75% of the oils from the plant.
3. Solvents used to separate sugar from oil; solvents then evaporate.
4. Oil is ready. Can be used as oil directly in diesel engines or refined further into fuel.

**Yield of various plant oils**
(Gallons per hectare)

- Soy: 118
- Safflower: 206
- Sunflower: 251
- Castor: 373
- Coconut: 605
- Palm: 1,572
- Algae: 26,417

**About algae**

- Among the fastest growing plants; about 50% of their weight is oil.
- Contains no sulfur; non-toxic; highly biodegradable.
- Algae fuel is also known as algal fuel or oilgae.

Source: algae.com, MCT Photo Service
Graphic: Scott Bell
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Pressing oil from the algae

- Dry the algae and press the oil from it.
- Can retrieve up to 70% of the oil.
- While drying must prevent the algae from becoming contaminated.
- Cheapest and simplest method
Chemical Oil Extraction

• Use hexane solvents to remove the oil.
• Hexane is a neurotoxin.
• Must be careful when using.
• Removes oil out of almost all things.
Super Critical Oil Extraction

• Most efficient method.
• Uses carbon dioxide at critical pressure and temperature (CO2 is almost a liquid).
• Carbon dioxide.
• Rapid diffusion of the oil.
• Very expensive process.
Biodiesel production

Parent oil used in making biodiesel consists of triglycerides (Fig. B1) in which three fatty acid molecules are esterified with a molecule of glycerol. In making biodiesel, triglycerides are reacted with methanol in a reaction known as transesterification or alcoholysis. Transesterification produces methyl esters of fatty acids, that are biodiesel, and glycerol (Fig. B1). The reaction occurs stepwise: triglycerides are first converted to diglycerides, then to monoglycerides and finally to glycerol.

\[
\begin{align*}
\text{CH}_2\text{OCOR}_1 & \quad \text{CH}_2\text{OCOR}_2 + 3 \text{HOCH}_3 \\
\text{CH}_2\text{OCOR}_3 & \quad \text{Catalyst} \\
\text{Triglyceride} \quad & \text{Methanol} \\
\text{(parent oil)} & \text{(alcohol)}
\end{align*}
\]

\[
\begin{align*}
\text{CH}_2\text{OH} & \quad \text{CH}_2\text{OH} + \text{R}_1\text{COOCH}_3 \\
\text{R}_2\text{COOCH}_3 & \quad \text{R}_3\text{COOCH}_3 \\
\text{Glycerol} & \text{Methyl esters} \\
& \text{(biodiesel)}
\end{align*}
\]

Fig. B1. Transesterification of oil to biodiesel. R\textsubscript{1-3} are hydrocarbon groups.

Transesterification requires 3 mol of alcohol for each mole of triglyceride to produce 1 mol of glycerol and 3 mol of methyl esters (Fig. B1). The reaction is an equilibrium. Industrial processes use 6 mol of methanol for each mole of triglyceride (Fukuda et al., 2001). This large excess of methanol ensures that the reaction is driven in the direction of methyl esters, i.e. towards biodiesel. Yield of methyl esters exceeds 98% on a
TAG (triacylglycerol)

- Three chains of fatty acids attached to a glycerol
- Natural oil from the algae

http://www.nrel.gov/docs/legosti/fy98/24190.pdf
Transesterification

- Start with triacylglycerol (TAG)
- End up with ester alcohol (biodiesel)
Other Beneficial Uses of Algae

• Removes nitrogen and phosphorus from wastewater
• Used extensively in aquaculture
• Used in nutraceuticals and food
• Cosmetics