General Atomics
Algae Biofuel Program
Liquid Biofuels Have Attractive Characteristics

- Ethanol and Biodiesel Blends
- Technically Proven
- Good Political Base in the US
- Infrastructure Costs - Tolerable & Incremental
- Already in Use

Contribution is limited by Feedstock Availability
Unique Potential of Algae Biodiesel
Near-term Energy Independence

- Soybean Based Biodiesel will max out at a few percent of the possible biodiesel fuel market

- 20 million acres of algae would supply the majority of US transportation fuel
  - US currently uses 970 million acres for crops & grazing

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil Gal/Acre/Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>48</td>
</tr>
<tr>
<td>Peanuts</td>
<td>113</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>124</td>
</tr>
<tr>
<td>Coconut</td>
<td>287</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>635</td>
</tr>
<tr>
<td>Algae</td>
<td>~5,000</td>
</tr>
</tbody>
</table>
The National Benefits are Compelling

- Domestic oil production and economic growth
- Elimination of foreign oil imports
- A 100% renewable fuel source
- Cleaner burning fuel
- Non-toxic, non-carcinogenic, biodegradable, transportation fuel so spills or leaking underground fuel tanks will not damage the environment.
- Reduced net CO$_2$ emissions because the algae can be grown on CO$_2$ and sunlight

And the Cost Drivers Appear to be Controllable
# Current Cost Component Assessment

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Conventional ($/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae growth</td>
<td>$15.00 – $20.00</td>
</tr>
<tr>
<td>Water and nutrient supply</td>
<td>$0.40 – $0.70</td>
</tr>
<tr>
<td>Carbon dioxide supply</td>
<td>$1.20 – $2.40</td>
</tr>
<tr>
<td>Harvesting</td>
<td>$0.80 – $1.60</td>
</tr>
<tr>
<td>Oil extraction</td>
<td>$1.50 – $2.60</td>
</tr>
<tr>
<td>Inoculation</td>
<td>$1.10 – $5.50</td>
</tr>
<tr>
<td><strong>Algae oil subtotal</strong></td>
<td><strong>$20.00 – $32.80</strong></td>
</tr>
</tbody>
</table>

Algae Growth Clearly Dominates but Every Component Must be Reduced to Reach $1/gal Oil.
Some Prior Approaches Based on Laboratory Biology, not Biochemical Processing

The costs can be substantially reduced
Key technical advances are needed to reach $1/gal algae oil

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Conventional ($/gal)</th>
<th>Once key technical advances are achieved ($/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae growth</td>
<td>$15.00 – $20.00</td>
<td>$0.25 – $1.20</td>
</tr>
<tr>
<td>Water and nutrient supply</td>
<td>$0.40 – $0.70</td>
<td>$0.03 – $0.10</td>
</tr>
<tr>
<td>Carbon dioxide supply</td>
<td>$1.20 – $2.40</td>
<td>$0.10 – $0.20</td>
</tr>
<tr>
<td>Harvesting</td>
<td>$0.80 – $1.60</td>
<td>$0.02 – $0.08</td>
</tr>
<tr>
<td>Oil extraction</td>
<td>$1.50 – $2.60</td>
<td>$0.28 – $0.45</td>
</tr>
<tr>
<td>Inoculation</td>
<td>$1.10 – $5.50</td>
<td>$0.03 – $0.13</td>
</tr>
<tr>
<td>Algae oil subtotal</td>
<td>$20.00 – $32.80</td>
<td>$0.71 – $2.16</td>
</tr>
</tbody>
</table>
Three Phase Program to Prove Process Economics

- **Guided by Cost Sensitivities**
- **Phase I: Technology Development**
  - Algae growth
  - Process unit operations
  - Pre-Pilot-Scale plant design
  - Demonstrate advances to achieve $2/gal algae oil
- **Phase II: Pre-Pilot-Scale Testing**
  - Install algae growth ponds
  - Install harvesting and separation equipment
  - Conduct engineering-scale design data tests
  - Demonstrate advances to achieve $1/gal algae oil
- **Phase III: Demonstration Plant**
  - Demonstrate technical performance and economic viability

4 years
San Diego Algae Growth System

- 125 L medium raceways (26x)
- 1,400 L pond
- 7,000 L pond
- 22,000 L pond
- Fully equipped indoor algal lab
- Fully equipped analytical lab
Initial Outdoor Work in Small Raceways
Needed Technical Advances Currently Under Development at GA’s Algae Facilities

And the results to-date have been promising
Texas System - Operation is DARPA Funded

- (2) 22,000 L ponds
- (4) 7,500 L ponds
- (2) 4,000 L ponds
- (5) 125 L raceways
- New 22,000 L pond - low cost/high efficiency
- Fully equipped analytical lab
Hawaii System on Kauai - DARPA Funded

- (2) 20,000 L ponds
- (1) 2,000 L pond
- (6) 125 L raceways
- CO₂ provided by flue gas
  - Kapaia Power Plant
- Algae production on line early 2010
- Support and inoculum provided by Kuehnle AgroSystems and Hawaii BioEnergy
- Location amenable to scale-up in phase II
Australia System in Adelaide - DARPA Funded

- (2) 125 L raceways
- Co-located with larger algae growth facility
- Winter species testing over summer months
- Summer species testing over winter months
Summary

- Algae have potential to provide large quantities of affordable biofuels
- GA has embarked on program to achieve low cost algal oil
- Collaborating with more than 20 other organizations
- Awarded contract by DARPA with goal of $1/gal algal oil for an affordable algal-derived JP-8
- Solid plan underway to achieve the goal