Large Scale Production of Microalgae for Biofuels

Dr. Bryan Willson
Chief Technology Officer

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3 Main Points

• Solix is a leading developer of closed photobioreactor-based production systems for algae-based biofuels

• Solix’s cost trajectory shows that fuel production from algae can be cost-competitive with petroleum - but requires full value extraction from the production co-products

• Solix has now begun operation of the world’s largest closed photobioreactor for biofuel production.
Outline

**Solix / Algae Intro**

Production in Open Ponds
Production in Closed PBRs
Solix AGS System
Harvesting & Extraction
Scaleup: Coyote Gulch
Production Costs
Solix Business Model
Conclusions
About Solix

- *Focused on the development and commercialization of large-scale algae-to-biofuels systems*
- *Launched in March, 2006*
- *Privately funded*
- *65+ employees*
- *Headquartered in Fort Collins, Colorado, USA*
- *1st scaleup site on the Southern Ute Indian reservation in southwest Colorado*
- *Significant strategic partners in advanced biology, midstream processing, fuel processing, and scaleup engineering*
Photosynthetic / Algae

Photosynthesis in Micro-algae

Sunlight

CO₂

Water

Carbon Fixing

BIOMASS:
Carbs
Protein
Lipids
Annual Production

- Soybean: 40 to 50 gal/acre
- Rapeseed: 110-145 gal/acre
- Mustard: 140 gal/acre
- Jatropha: 175 gal/acre
- Palm oil: 650 gal/acre
- Algae est.: 5,000-10,000 gal/acre
  7,000 “nominal”
These “up” stream and “down” stream partnerships have been identified and established.
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Open Pond Cultivation: Dunaliella - Eilat, Israel
Open Pond Production: Earthrise Spirulina - California
Open Pond Production: Seambiotic - Ashkelon, Israel
Open Pond Attributes

**Advantages**
- Lowest capital cost
- Only technology demonstrated at large scale - to date
- Can maintain specific cultures of extremophiles

**Disadvantages**
- Allows contamination of specific culture with local species / strains
- Potential for loss / migration of GMO
- Susceptible to weather
- Water loss from evaporation / percolation
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Direct Light PBRs: GreenFuels, 1st Gen
Direct Light PBRs.
Solix 1st Generation
Photosynthetic Efficiency

Efficiency, $\approx P/E_d$

Irradiance, $E_d$

$\eta_p = P/E_d$

$\sim 15\%-20\%$ of full sun
Impact of Light Intensity

**Note:** 10X increase in light, but only 3.5X increase in output. Implies a 3X reduction in photosynthetic efficiency.

Conversely, if diffuse light can be used over extended surface area, 3X increase in output possible.

*Fig. 8.3.* Interrelationships between incident PFD, optimal population density and net output rate. A = 90% shade; B = 60% shade; C = 30% shade; D = no shade, full sunlight (from Hu & Richmond, 1994). Reprinted with permission from Kluwer Academic Publishers (J. Appl. Phycol.).
Extended Area PBRs

Glass Plate Photobioreactor
(Pulz, Richmond, others)

Glass Tube Photobioreactor
(Pulz, IGV, Ketura, Torzillo, others)
IGV Diffuse

≈5 m² illuminated area for 1 m² of ground area

Utilizes diffuse light, short photic distances (approaches ideal cycle time of 20 ms) for high photosynthetic efficiency

*Figure 8.* Meandering plate cultivator 100 to 6000 L. IGV Institut für Getreideverarbeitung.
Figure 4: The cultivation in the PBR 4000 from 21.04.2006 to 21.05.2006 with sunlight and no artificial light
Closed PBR Attributes

Advantages
- Allow growth of specific cultures
- Allows environmental control
- Potential for much higher growth rates (with extended surface area and/or high turbulence)

Disadvantages
- Potential for high capital cost
- Potential for high energy costs
- Low-cost production has not been demonstrated
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Cost vs. Productivity

Direct Light PBR: Low Cost & Productivity

Diffuse PBR: High Cost & Productivity
1st Generation PBR. July ‘06
Solix G3 Technology:
- Extended surface area
- Water supported
- Integrated CO₂ / air sparging
- G4 under development
Solix G3 (cont)
Solix G3 (cont)
Winter Operation: ‘07 & ‘08
Continuing AGS Improvements

**Solix G4a Technology:**
- Membrane CO$_2$ delivery
- Membrane O$_2$ removal, internal
- Reduced thickness / higher density
Potential Open-Water Application
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Harvesting & Extraction
Extraction
CLIMATE CHANGE, Global Risks, Challenges & Decisions
COPENHAGEN 2009, 10-12 March

Colorado State University

Properties and Suitability of Liquid Fuels Derived from Algae

Anthony J. Marchese, Ph.D.

Engines & Energy Conversion Laboratory
Colorado State University
Fort Collins, CO, USA
http://www.engr.colostate.edu/~marchese
• Algal oil is unique in that it tends to contain a significant quantity (~5-20% by volume) of long highly unsaturated oils, which are rarely observed in more traditional biodiesel feedstocks, such as soy and rapeseed (canola) oil.

• The two most common types of long and highly unsaturated oils found in algae oil tested to date are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).
Fatty acid content varies widely depending on the feedstock. The chemical composition has implications in terms of combustion characteristics.

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- methyl dodecanoate (coconut)
- methyl linoleate (soy)
- eicosapentaenic acid methyl ester (algae)
• Automates conditions for optimal productivity of different organisms in different climates

• Gives predictive and diagnostic capabilities
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Scaling Up...
Coyote Gulch Amine Plant
Basin A
Coyote Gulch
Basin A
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SOLIX
ALGAE TO ENERGY

R&D Roadmap

$250/Gal

$2/Gal
The path to fuel cost parity will require both incremental and step function improvements
Business Model

- **Solix** contributes:
  - production/processing technology
  - project development and operational expertise
- Partner contributes:
  - CO2, land and capital
- Value from:
  - Fuel, co-products and CO2

- Solix is teaming with international partners in order to develop large-scale production
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- Economical biofuel production appears feasible, using low-cost high productivity photobioreactors.
- Requires tight coupling of biology and engineering.
- Value of co-products must be captured; may approach or exceed value of oil.
- Systems modeling/integration required to achieve cost targets.
Contact Information

Dr. Bryan Willson
Chief Technology Officer, Solix Biofuels
Bryan.Willson@solixbiofuels.com
+1 (970) 491-4783

Professor of Mechanical Engineering
Colorado State University