

# *Biofuels from Algae*

**Senate Water, Energy and  
Telecommunications Committee**  
**House Technology, Energy and  
Communications Committee**

Work Session:

Global Oil and Alternative Energy Strategies

*February 21, 2008*

*Olympia, WA*

*Andrew T. Braff, Attorney at Law*

 **Wilson Sonsini Goodrich & Rosati**  
PROFESSIONAL CORPORATION

- 1. Microalgae: Part of the Solution to Global Problems?**
- 2. Microalgae for Liquid Transportation Fuels: A Brief History**
- 3. Current Activities**
- 4. Challenges for Using Microalgae as a Biofuel Feedstock**

---

**1. | Microalgae: Part of the Solution**

---

## Global Problems – Oil Price/Supply

- Peak Oil Approaching
- Current Oil and Diesel Prices on the rise



### Oil breaks \$100, hits new all-time high

Crude soars as investors weigh the possibility of OPEC production cuts; Texas refinery explosion may have also lifted prices.

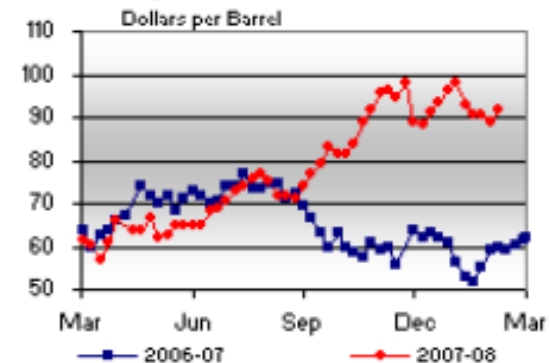
February 19 2008: 3:28 PM EST

NEW YORK (AP) -- Oil prices hit new record highs Tuesday as a Texas refinery fire and fears of an OPEC production cut pushed crude to settle at over \$100 a barrel for the first time ever.

U.S. crude for March delivery jumped \$4.51 to settle at \$100.01 a barrel on the New York Mercantile Exchange, topping the previous settlement record of \$99.62 set Jan. 2.

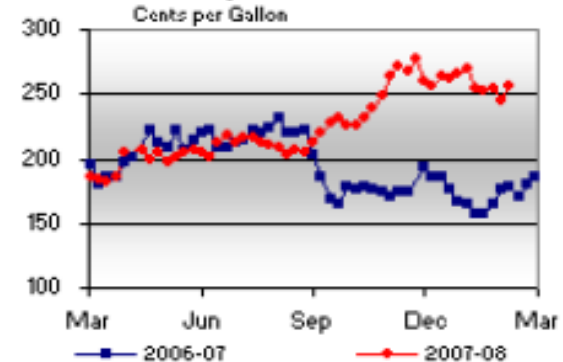
Oil also hit a new all-time trading high of \$100.10 a barrel, besting the previous high of \$100.9 set Jan. 3.

Spot Crude WTI Prices



2006-07 2007-08

New York Spot Diesel Fuel Prices



2006-07 2007-08

	Spot Prices		Change From Last	
	02/08/08		Week	Year
Crude Oil WTI	91.77		↑ 2.74	↑ 31.91
Gasoline (NY)	228.9		↑ 6.6	↑ 70.2
Diesel Fuel (NY)	256.5		↑ 10.8	↑ 78.1
Heating Oil (NY)	255.1		↑ 9.9	↑ 82.7
Propane Gulf Coast	135.4		↓ -9.1	↑ 34.3

Note: Crude Oil WTI Price in Dollars per Barrel.

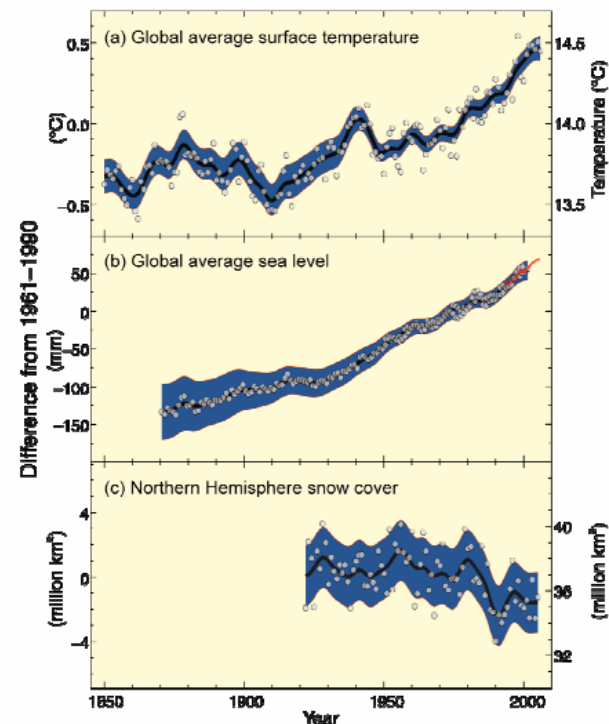
## Global Problems – Climate Change

### Climate Change

According to the U.N. Intergovernmental Panel on Climate Change (IPCC), 4<sup>th</sup> Assessment Report (Nov. 17, 2007), “warming of the climate system is *unequivocal*, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.” (<http://www.ipcc.ch/ipccreports/ar4-syr.htm>)



Changes in temperature, sea level and Northern Hemisphere snow cover



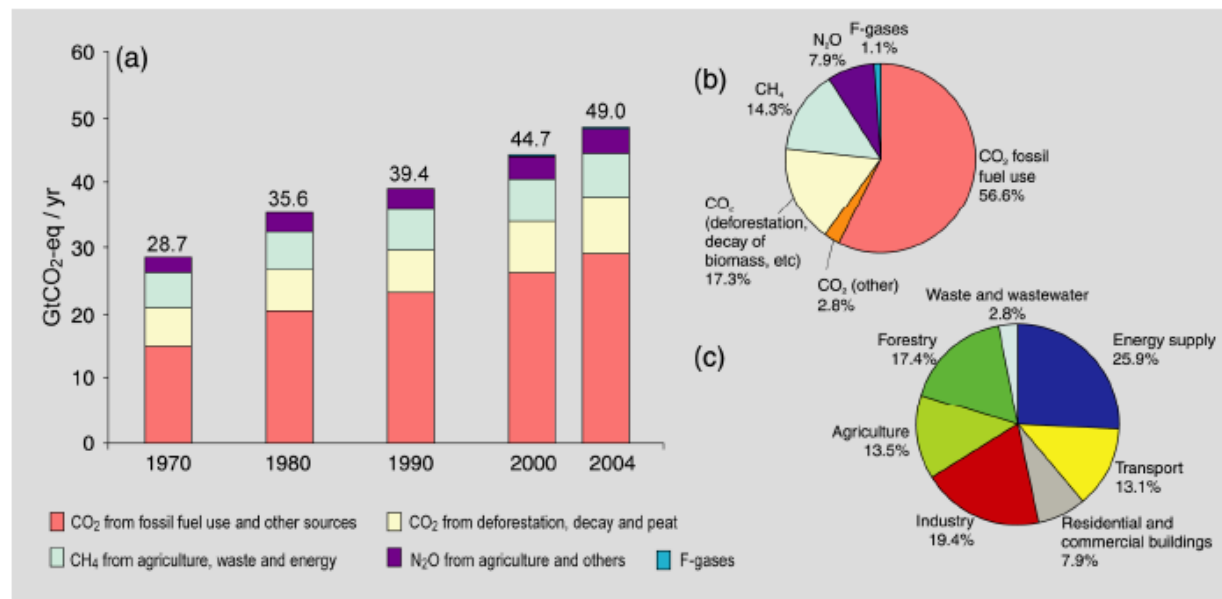
## Global Problems – Climate Change

### Causes of Climate Change - GHG Emissions

- According to the IPCC Assessment, “global GHG emissions due to human activities have grown since pre-industrial times, with an increase of **70%** between 1970 and 2004.”
- “CO<sub>2</sub> is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004.”
- “Global atmospheric concentration of CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determine from ice cores spanning many thousands of years.”

## Global Problems – Climate Change

Global anthropogenic GHG emissions



**Figure SPM.3.** (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.<sup>5</sup> (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO<sub>2</sub>-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO<sub>2</sub>-eq. (Forestry includes deforestation). {Figure 2.1}

Source: IPCC 4<sup>th</sup> Assessment Report

## Global Problems – Climate Change

### Climate Change – Impacts

#### – Water Resources:

- Increased water demand – Increase in water usage will need to be met by waste water re-use;
- Increased water quality problems (e.g., algal blooms);
- Adverse effects on quality of surface and groundwater;
- Contamination of water supply, decreased fresh water availability due to saltwater intrusion;
- “First generation” biofuel feedstocks generally all require fresh water and therefore are competing with other necessary uses of such water.
- Biofuels will require more water than use of fossil fuels.
- U.S. Freshwater withdrawals – 340 billion gpd in 2000.

#### – Agriculture

- Decreased yields in warmer environments
- Damage to crops due to droughts, heavy precipitation, and high winds
- All would impact “first generation” biofuel feedstocks



## Global Problems – Energy Security

### Energy Security

- Crude Oil:
  - U.S. Crude Oil Production: 5,102,000 bpd
  - U.S. Crude Oil Imports: 10,118,000 bpd (5,517,000 bpd from OPEC)
  
- Petroleum:
  - U.S. Petroleum Consumption 20,687,000 bpd
  - U.S. Net Petroleum Imports: 12,390,000 bpd
  - Dependence on Net Petroleum Imports: 59.9%

## Global Problems – Energy Security

### Energy Security

Crude Oil Imports (Top 15 Countries)  
(Thousand Barrels per Day)

Country	Dec-07	Nov-07	YTD 2007	Dec-06	Jan - Dec 2006
CANADA	1,780	1,919	1,864	1,830	1,802
SAUDI ARABIA	1,675	1,530	1,453	1,471	1,423
VENEZUELA	1,246	1,227	1,150	1,045	1,142
MEXICO	1,234	1,484	1,410	1,245	1,577
NIGERIA	1,210	1,245	1,082	1,010	1,037
ANGOLA	439	408	496	610	513
IRAQ	378	508	485	419	553
ALGERIA	348	184	443	406	362
ECUADOR	195	154	198	240	272
BRAZIL	171	78	167	130	133
KUWAIT	158	154	176	163	179
AZERBAIJAN	134	77	57	68	27
LIBYA	116	66	84	46	66
COLOMBIA	113	197	137	74	141
UNITED KINGDOM	93	42	102	93	130

Source: Energy  
Information Administration

## Global Problems – Food Prices

### Increasing Food Prices – “Agflation”

- The food price index of the Food and Agriculture Organization of the United Nations climbed 36% in 2007. This is after a 14% increase in 2006. Index is based on export prices for 60 internationally traded foodstuffs.
- According to the Economic Research Service of the USDA, the all-food Consumer Price Index increased 4.0% between 2006 and 2007, the highest annual increase since 1990. The Service is anticipating a 3.0-4.0% increase in 2008.
- Causes:
  - Drought in Australia
  - Growing prosperity in India, China and Latin America
  - Production of First Generation Biofuels

## Global Problems – Food (and Drink) Prices

Economist.com

### The end of cheap food

Dec 6th 2007

From *The Economist* print edition

Rising food prices are a threat to many; they also present the world with an enormous opportunity



FOR as long as most people can remember, food has been getting cheaper and farming has been in decline. In 1974-2005 food prices on world markets fell by three-quarters in real terms. Food today is so cheap that the West is battling gluttony even as it scrapes piles of half-eaten leftovers into the bin.

That is why this year's price rise has been so

### The New York Times

THE FOOD CHAIN

### A New, Global Oil Quandary: Costly Fuel Means Costly Calories

By KEITH BRADSHER

Published: January 19, 2008

KUANTAN, [Malaysia](#) — Rising prices for cooking oil are forcing residents of Asia's largest slum, in Mumbai, [India](#), to ration every drop. Bakeries in the United States are fretting over higher shortening costs. And here in Malaysia, brand-new factories built to convert vegetable oil into diesel sit idle, their owners unable to afford the raw material.

modbee.com  
The Modesto Bee

### Get ready to ante up more for beer

By SHANNON DININNY  
THE ASSOCIATED PRESS

last updated: October 27, 2007 05:03:22 AM

SUNNYSIDE, Wash. -- Fans of Snipes Mountain Brewery's cloudy Hefeweizen relish the subtle wheat flavor of the bright, summery brew, and like beer drinkers everywhere, they know when their brew is a little too hoppy or bitter.

California to Oregon face the challenge of making their recipes or new brews thanks to a key beer ingredient and

## Global Problems – Deforestation

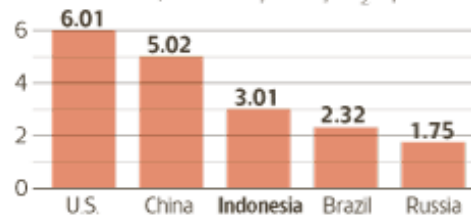
### Palm oil, perhaps the best terrestrial feedstocks for biodiesel, has an image problem.

- Palm vs. Soy Yield: 1 acre of palm = 8 acres of soy.
- Disclosure: Imperium Renewables is a client of WSGR

#### Greenhouse gas emissions

Widespread rain forest logging and burning has transformed Indonesia into the world's third largest emitter of greenhouse gases.

Annual emissions, in billions of tons of CO<sub>2</sub> equivalent



Source: Indonesian consulting firm Pelangi Energi Abadi Citra Envir



#### Dark side of a hot biofuel

In Indonesia, oil palms feed world thirst for clean fuel, but forests, climate and species pay a steep price

By Tom Knudson - [tknudson@sacbee.com](mailto:tknudson@sacbee.com)

Published 12:00 am PST Sunday, January 20, 2008

For more than 30 years, Indonesia's oil palm plantations have fed a global market for vegetable oil, most used in everyday food products from cream cheese to candy bars, cookies to hamburger buns. As concern about climate change and oil prices has grown, interest in palm oil as a green, renewable fuel has soared.

## Global Problems – High Feedstock Prices for Terrestrial Biofuels

**Soybean Oil:** 60,000  
lbs. of soybean oil =  
\$60.21 (\$46.50 back in  
Dec. 2007)



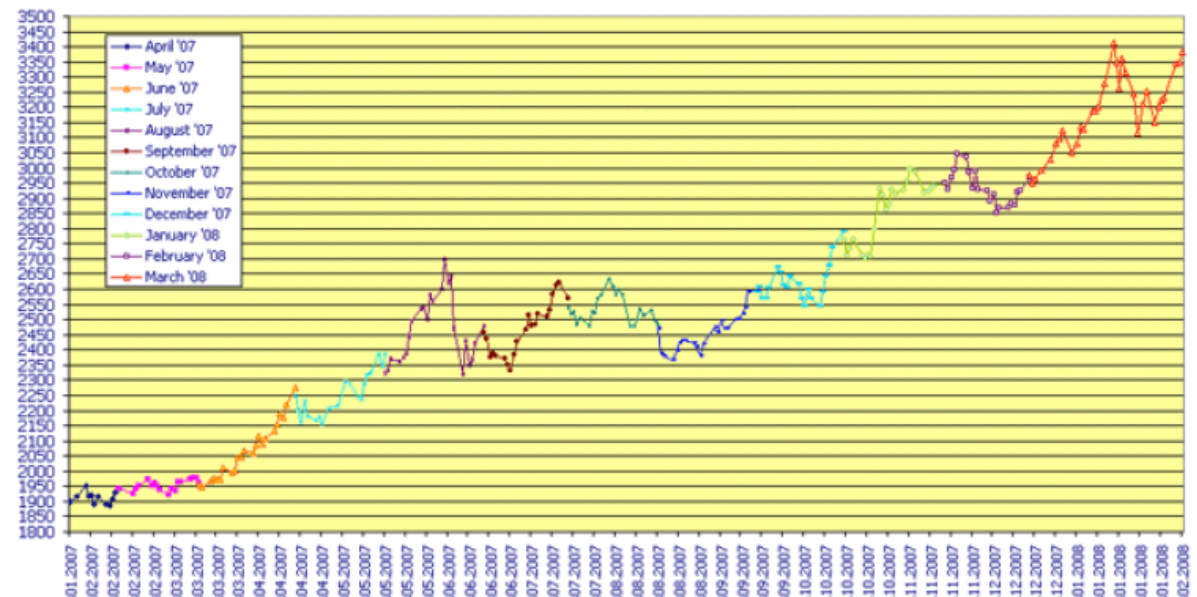
Source: Chicago Board of  
Trade, February 20, 2007.

## Global Problems – High Feedstock Prices for Terrestrial Biofuels

**Palm Oil:** Palm oil contract on the Bursa Malaysia Derivatives Exchange hit a record at just over 3,450 MYR (U.S. \$1,000) per ton.

**Seattle Employee Discontent:** Because of the squeeze in margins, Seattle employees sent a petition with more than 700 signatures to Mayor Greg Nickels questioning the Seattle City Employees' Retirement System's financial support of Imperium Renewables. According to the Seattle Post-Intelligencer, the System invested \$10m in Imperium.

2007-2008 (Palm Oil Chart):



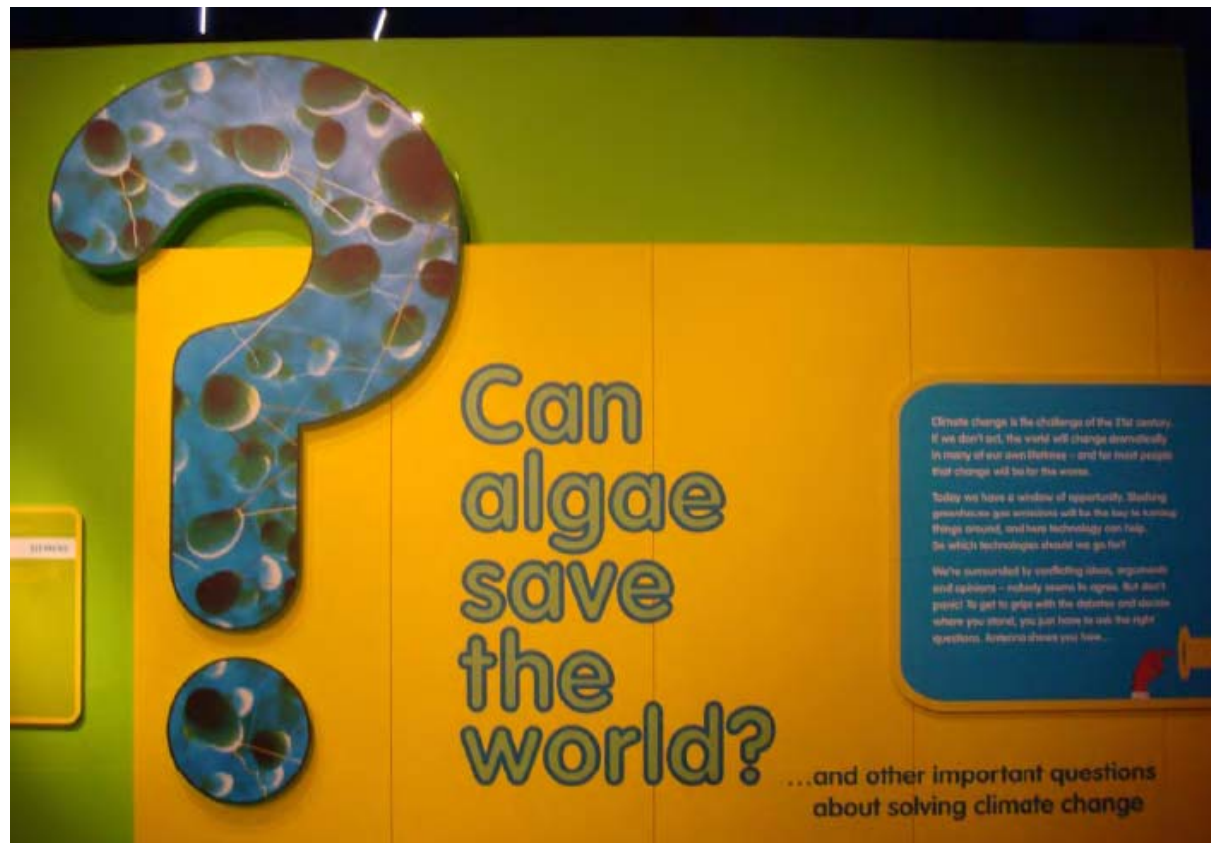
Source: <http://www.palmoil.com>

## Global Problems – Terrestrial Feedstocks Won't Cut It

- **Triglycerides from current oilseed crops and waste oils would barely dent annual U.S. diesel demand.**
  - U.S. Diesel Demand: \*\*\*60 bgy\*\*\*
  - Terrestrial Feedstock Limits: According to Philip Pienkos at NREL's National Bioenergy Center:
    - The entire U.S. soybean crop could provide approximately **2.5 bgy**.
    - World-wide production of biodiesel from all oilseed crops would yield only **13 bgy**.
  - Food vs. fuel issue
- **For biofuels to displace even a moderate amount of fossil fuels used in the transportation sector requires development of an abundant source of triglycerides (TAGs).**



## Microalgae – Part of the Solution?

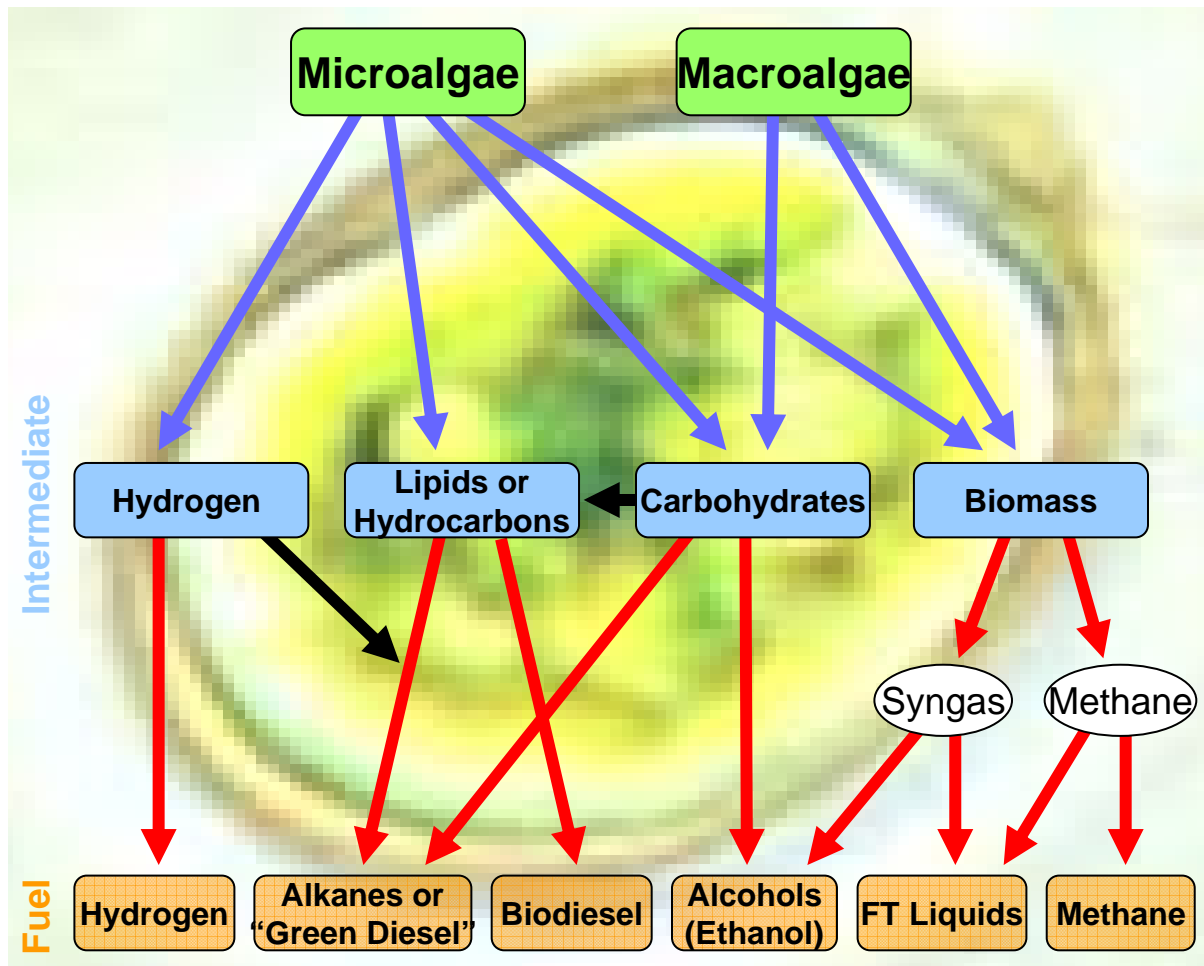


**The Science  
Museum, London,  
UK - 2007**

## Microalgae – Part of the Solution?

- **Microalgae are microscopic aquatic plants that carry out the same process and mechanism of photosynthesis as higher plants.**
- **What are the Inputs:**
  - Land
  - Sunlight
  - Water
  - Carbon Dioxide
  - Nutrients
- **Process:** Microalgae convert sunlight, water and carbon dioxide into biomass and oxygen. Biomass contains lipid oils/TAGs.
- **Some Strains Highly Productive:** Reported yields of *Botryococcus Braunii*:
  - 65% Gasoline
  - 15% Aviation Fuel
  - 18% Diesel Fuel
  - 2% Residual Oil
- **Problem with *B. Braunii*:** Grows very slowly. Doubles every 3 days vs. 3 hours for fast growing microalgae. “So we can have fat algae or we can have fast algae, but fat fast algae, now there is a challenge” (J. Benemann).

## Microalgae – Part of the Solution?



### Fuel Pathways

Source: P. Pienkos, NREL, *The Potential for Biofuels from Algae*, Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

## Microalgae – Part of the Solution?

### Algae has a much higher productivity potential than terrestrial biofuels.

- Yields are approximately 10x that of terrestrial crops (depending on crop)
- CAUTION: Media hype has cited up to a potential of 24,000 gallons per acre per year. This is 2x the maximum theoretical efficiency.
- Experts suggest that 2,000 gallons per acre per year would be a significant accomplishment.
- Seabiotic (Israeli Company) Yields: 20 g/m<sup>2</sup>/day

Crop	Oil Yield Gallons/acre
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed/Canola	127
Jatropha	202
Oil palm	635
Algae (10 g/m <sup>2</sup> /day at 15% TAG)	1,200
Algae (50 g/m <sup>2</sup> /day at 50% TAG)	10,000

Source: P. Pienkos, NREL, *The Potential of Biofuels from Algae*, Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

## Microalgae – Part of the Solution?

### High Oil Prices:

- Current biofuel use displaces approximately 3% of fossil fuel use world-wide, and we are already feeling constraints in the form of food prices, land, and high-cost biofuel feedstocks due to their relative scarcity.
- Microalgae's rapid growth rates when compared to terrestrial feedstocks and lipid oil content on a cellular level serves as a potential high-impact, high-volume substitute.
- High oil prices begin to make certain feedstocks such as algal oil attractive.
- Expanding feedstock diversity acts as a hedge against crude and other petroleum-based products by incrementally reducing dependence on fossil fuels.

## Microalgae – Part of the Solution?

### Climate Change - CO<sub>2</sub> Emissions:

- CO<sub>2</sub> is Primary Input. CO<sub>2</sub> is a primary input required by microalgae to grow. Microalgae takes a waste (CO<sub>2</sub>) and converts it into a high-density liquid form of energy (lipid oil for biodiesel; starch/polysaccharides for ethanol).
- CO<sub>2</sub> Utilization. During the Aquatic Species Program, tests proved that “outdoor ponds could be run with extremely high efficiency of CO<sub>2</sub> utilization. Careful control of pH and other physical conditions for introducing CO<sub>2</sub> into the ponds allowed greater than 90% utilization of injected CO<sub>2</sub>.”
- CO<sub>2</sub> Requirements for 60 BGY Biodiesel via Microalgae:
  - 10 g/m<sup>2</sup>/day @ 15% TAG Productivity: 1.4 billion tons/year (56% of U.S. Power Plant Emissions)
  - 50 g/m<sup>2</sup>/day @ 50% TAG Productivity: 0.9 billion tons/year (36% of U.S. Power Plant Emissions)



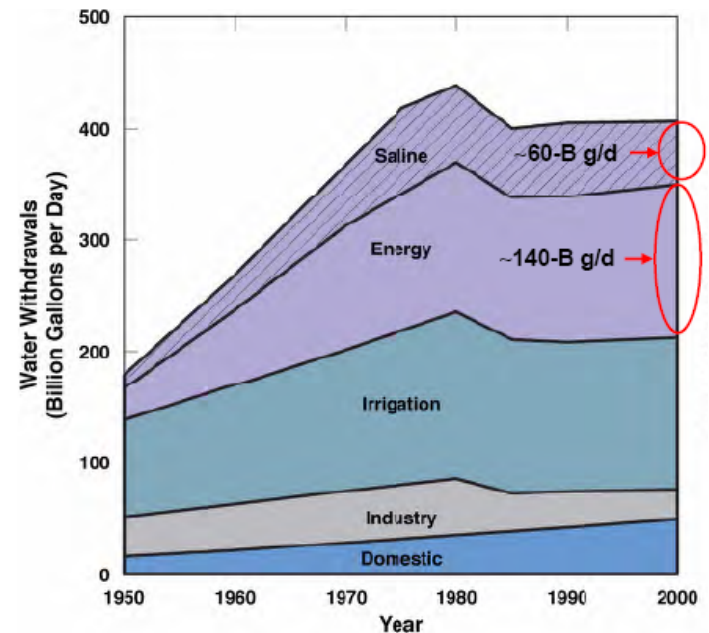
**Source:** A. Ben-Amotz, presentation to Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

**Pictured:** Open pond system utilizing flue gas off Israel Electric Company power plant.

## Microalgae – Part of the Solution?

### Water Resources:

- Use Far Less Water. Microalgae systems use far less water than traditional oilseed crops.
  - 10 g/m<sup>2</sup>/day @ 15% TAG for 60bgy of biodiesel: 120 trillion gallons per year
  - 50 g/m<sup>2</sup>/day @ 50% TAG for 60bgy of biodiesel: 16 trillion gallons per year
  - Water used to Irrigate Corn Crop in U.S.: Over 4000 trillion gallons per year
- “Dirty Water”. Species flourish in brackish, saline and wastewater. Relieves pressure on freshwater supplies.
  - Wastewater nutrients support highly productive algal cultures
  - 25,000 acres of wastewater ponds just in California
  - 5,100 wastewater treatment facilities nationwide



Source: R. Pate, Sandia National Laboratories, *Algal Biofuels from the Energy-Water Nexus Perspective*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

## Microalgae – Part of the Solution?

### Energy Security:

- Microalgae can grow in one form or another in temperatures from below freezing (Antarctica – not ideal) to approximately 70°C (geysers in Yellowstone Nat'l Park).
- No country has a monopoly on Photobioreactors; U.S. has ample suitable land.
- Diversification of energy portfolio. Microalgae can be “home grown”.

### Food Prices:

- Microalgae is a non-food resource and is not currently used in agricultural feed products.
- One coproduct of microalgae production is high-protein agricultural feed that can supplement the feed markets and potentially reduce prices.
- Microalgae such as *spirulina* is used as nutritional supplements; however, it does not occupy a central place in the human food chain such as corn, soy or other oil seed crops, whether for human consumption or agricultural use.



## Microalgae – Part of the Solution?

### Land Resources/Limits Deforestation:

- Microalgae growing operations will likely not occur in areas used currently for crop production or in forested areas.
  - Non-Arable Land/Desert (e.g., Salton Sea, CA; Roswell, NM; Nevada, etc.). Cheap land is necessary to keep costs down!!
  - Ocean
- U.S. currently uses 970 million acres for crops and grazing.
- According to David Daggett (Boeing), it would take 85 bgy of soy oil to meet 100% jet fuel requirement. This would require a land area the size of Europe. **For algae, think Belgium.**

10 g/m<sup>2</sup>/day@15%  
Productivity  
(~1,200 gal/acre-yr)

48 million acres for 60bgy  
biodiesel



50g/m<sup>2</sup>/day@50%  
Productivity  
(~10,000 gal/acre-yr)

6 million acres for  
60bgy biodiesel



**Source:** P. Pienkos, NREL, *The Potential for Biofuels from Algae*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

## Microalgae – Part of the Solution?

### **Coproducts/Other Benefits:**

- Electrical power generation (syngas/methane via anaerobic digestion)  
(RECs associated with Renewable Portfolio Standards)
- Wastewater treatment/Water reclamation (recycled, nutrient-free water)
- High-Protein Animal Feeds
- Agricultural Fertilizers
- Biopolymers
- Glycerin
- CO<sub>2</sub> Biofixation (Carbon Credits: 2-35 cents/gallon Chicago Climate Exchange to EU Emission Trading Scheme)

## Microalgae – Part of the Solution?

### Three General Technological Methods:

#### 1. Open Pond



**Source:** M. Massingill, Kent SeaTech, *Biofuels From Microalgae: The Controlled Eutrophication Process*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

**Pictured:** Artist's rendition of Kent SeaTech's scale-up facility

#### 2. Photobioreactor



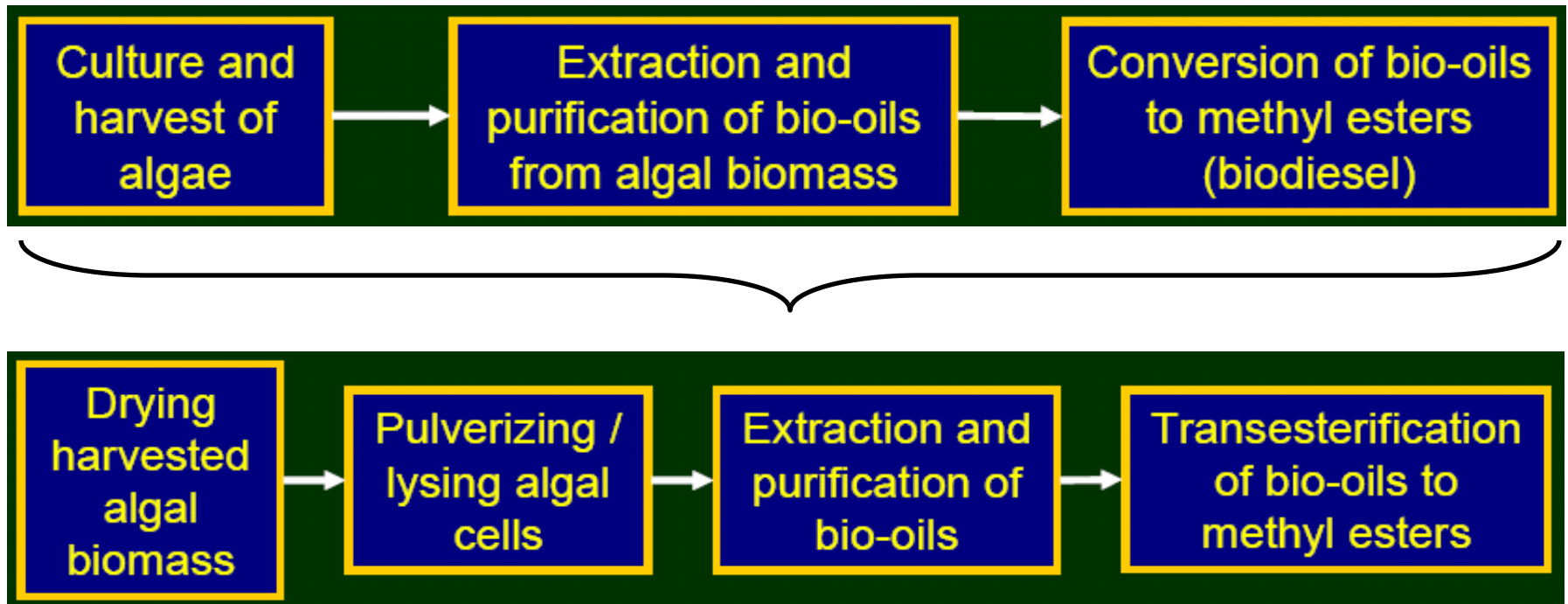
**Source:** K. Ogilvie, Blue Marble Energy, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

**Pictured:** GreenFuel Photobioreactor Demonstration Facility

#### 3. Hybrid

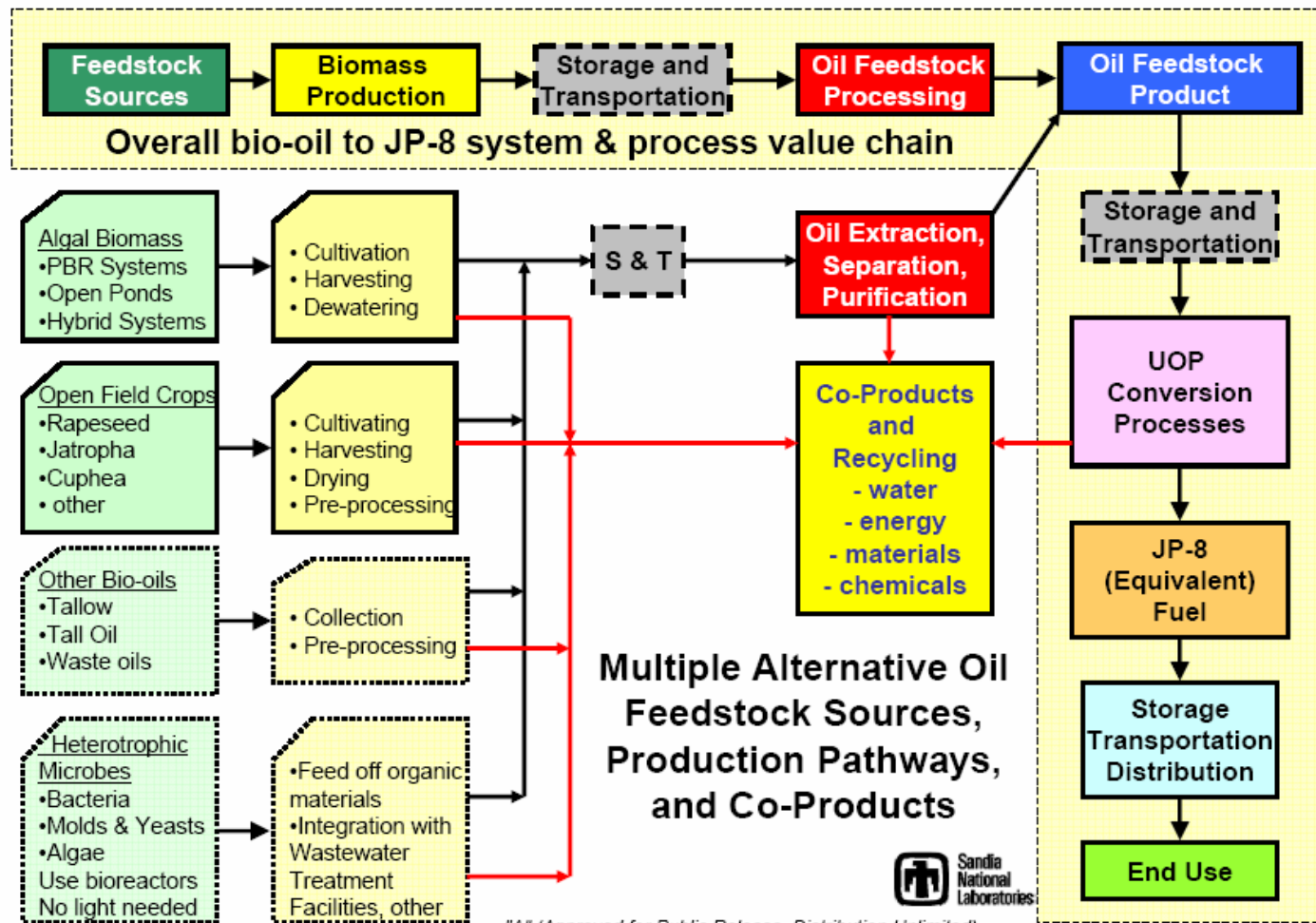
## Microalgae – Part of the Solution?

### General Process Block Diagram:



Source: C. Guay, Community Fuels, *Algal Biodiesel: Obstacles and Opportunities*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

## Multi-Source Bio-Oil-to-JP8 Systems Analysis Framework



Source: R. Pate, Sandia National Laboratories, *Algal Biofuels from the Energy-Water Nexus Perspective*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).

---

**2. | Microalgae for Liquid Transportation  
Fuels: A Brief History**

---

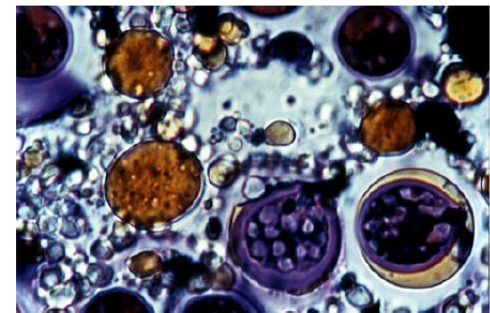
## A Brief History: Pre-ASP

- Over a century ago, pond scum (*Anabaena cylindrica*, a cyanobacterium) collected from a Massachusetts reservoir was found to produce almost pure hydrogen gas (Jackson and Ellms, 1896). Microalgae biofuels R&D mainly focused on H<sub>2</sub> production until recently.
- Approximately a century ago, blooms of the hydrocarbon producing green alga *Botryococcus brauni* were collected on the beaches of Australia and used as fuel.
- In 1948, Paul Cook engaged in some of the first research on algae mass culture and cultivation with Stanford Research Institute (SRI International)
- In 1953, microalgae biofuels were mentioned in conjunction with an algae pilot plant operated on a rooftop at MIT (Burlew, 1953).
- In the 1950s, algae biomass production for wastewater treatment and conversion to methane was studied at U.C. Berkeley (Oswald & Golueke, 1960).
- In the 1980s, the Soviets undertook experiments using large photobioreactors to grow *Chlorella* for the production of animal feed.

## Brief History: Aquatic Species Program

- Creation of ASP: For 17 years (1978-1995), the National Renewable Energy Laboratory (“NREL”) and its predecessor Solar Energy Research Institute (“SERI”) oversaw the Aquatic Species Program (“ASP”).
  - OPEC Oil Crisis
  - Examined the use of aquatic plants as sources of energy, particularly hydrogen and transportation fuels.
- Primary Focus of the ASP: Produce biodiesel from high lipid-content algae grown in open raceway-style ponds and utilizing waste CO<sub>2</sub> from coal fired power plants.
- Pilot Plant: During the ASP, 1,000m<sup>2</sup> pond systems were built in Roswell, NM.
  - **Productivity**: Up to 50 grams of algae per square meter per day (max theoretical is 100 grams per square meter per day – J. Weissman).

Department of Energy’s  
Aquatic Species Program:



Biodiesel from Algae

*Part I:*

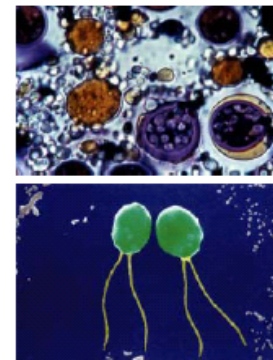
*Program Summary*



## Brief History: Aquatic Species Program (Cont.)

- Algal Strain Library: Hosted a collection containing over 3,000 strains of organisms. This collection was studied and eventually “winnowed down” to 300 species.
- Preliminary Economic Analyses: At least three reports focused on the techno-economic analyses of microalgae biodiesel production (e.g., Benemann, J.R. and W.J. Oswald, *Systems and economic analysis of microalgae ponds for conversion of CO<sub>2</sub> to biomass*, Final Report (1996)).
- Shutdown: The ASP was shut down in 1995 under pressure to reduce budgets and during a time of low oil prices.
- Close-Out Report: Provides a summary of the research activities carried out from 1980 to 1996 with an emphasis on algae for biodiesel production. Considered the “Bible” for the current algae-for-energy movement.

A Look Back at the  
U.S. Department of Energy's  
Aquatic Species Program:  
Biodiesel from Algae

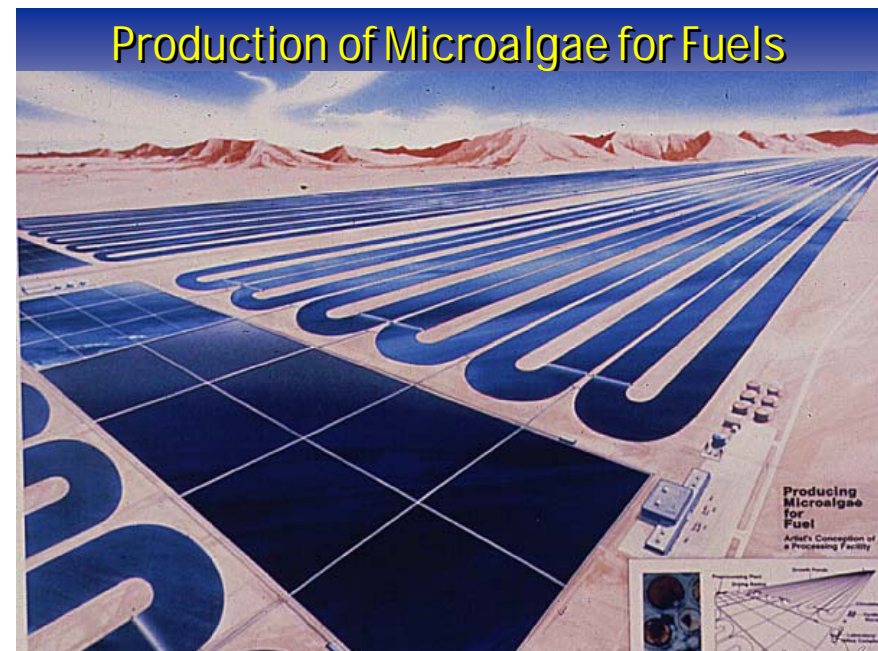


Close-Out Report

## Brief History: 1990-2000

- Japanese Studies: From 1990 to 2000 a major program on microalgae for CO<sub>2</sub> capture/utilization was carried out in Japan. Unlike the open pond approach used by the ASP, the Japanese **focused on closed photobioreactors** and fiber optic distribution of solar energy throughout the tubes in hopes of increasing the surface area exposed. \$500 million spent. **Conclusion**: Photobioreactors are too expensive.

- Hydrogen Research Dead: On January 31, 2006, President Bush reduced emphasis on hydrogen and shifted focus to other sources of renewable energy, primarily cellulosic ethanol.



Source: Artist rendition, Aquatic Species Program, U.S. DOE, NREL 1987.

---

**3. | Current Activities and Developments**

---

## Current Activities and Developments

### Microalgae Biofixation Network

- Formed under the auspices of the International Energy Agency's Greenhouse Gas R&D Programme
- Members: U.S. DOE, Eni (Italian utility), National Energy Technology Laboratory, Eletrobras (Brazil), TERI (India), SRI International, Pacific Northwest National Lab
- Current Chair: **Blaine Metting of Pacific Northwest National Labs (Tri-Cities) currently serves as its chair.**
- Report: Produced a report entitled: *Microalgae Biofixation Process: Applications and Potential Contributions to Greenhouse Gas Mitigation Options.*
- Report's Focus: Report analyzes, on a global scale, technology that may be available in the near- to mid-term (2010 to 2020) for practical applications of microalgae in biofuels production.
- Conclusion: "The most plausible immediate applications are in conjunction with advanced wastewater treatment processes..."



## Current Activities and Developments

The poster features a central green banner with the text "Algae Biomass Summit" and "Algae for Energy" in white serif font. Above the banner are the logos for Wilson Sonsini Goodrich & Rosati (W&R) and Byrne & Company Limited. Below the banner, the text "Sponsored by:" is followed by logos for MDV (Morrison Davidow Ventures), Harris Group Inc. (Engineering for Optimum Performance), (XL) RENEWABLES, BOEING, and Stewart National Title Services. At the bottom, the dates "November 14-16, 2007" and location "San Francisco, California" are listed in a green serif font.

**W&R** Wilson Sonsini Goodrich & Rosati  
PROFESSIONAL CORPORATION

**BYRNE**  
& Company Limited

*Present:*

**Algae Biomass Summit**  
*"Algae for Energy"*

**Sponsored by:**

**MDV** **Harris Group Inc.** **(XL) RENEWABLES**  
MORRISON DAVIDOW VENTURES Engineering for Optimum Performance

**BOEING** **stewart**  
national title services

*November 14-16, 2007*  
*San Francisco, California*

## Current Activities and Developments - ABS

- **First ever large-scale international gathering of technologists, scientists, policymakers, entrepreneurs and services providers dedicated to pursuing the use of algae as an energy feedstock.**
- **Over 350 attendees from many states and countries**
  - United States
  - Canada
  - Israel
  - New Zealand
  - The Netherlands
  - Chile
  - United Kingdom
  - Philippines
  - Switzerland
  - Japan
  - Spain
  - France
  - Italy
  - Finland
  - Thailand
  - India
  - Germany
  - Australia

## Current Activities and Developments - ABS

- Paul Dickerson, Office of Energy Efficiency and Renewable Energy, U.S. DOE
- Dr. John Benemann, Co-Author, ASP Close-Out Report
- Dr. Joseph C. Weissman, SeaAg Inc., and Aurora Biofuels
- Dr. Philip T. Pienkos, NREL
- Dr. Greg Mitchell, Scripps Institute of Oceanography, UCSD
- Dr. Qiang Hu, Arizona State University
- Mr. David Daggett, The Boeing Company
- Dr. Ami Ben-Amotz, Seambiotic and the National Institute of Oceanography (Israel)
- Dr. Amha Belay, Earthrise Nutritionals, LLC
- Dr. Ronald Pate, Sandia National Laboratories
- Dr. Tryg J. Lundquist, California Polytechnic University
- Dr. Ripudaman Malhotra, SRI International
- Mr. Michael H. Gilbert, Global Green Solutions
- Mr. Michael Weaver, Bionavitas, Inc.
- Josh Green, Mohr Davidow Ventures
- Dr. Douglas Kirkpatrick, DARPA
- Mr. Michael Massingill, Kent SeaTech Corp.
- Dr. Michael H. Huesemann, PNNL
- Messrs. Jim Sears and Mark Allen, A2BE Carbon Capture, LLC
- Dr. Mark Tegen, Inventure Chemical
- Mr. Martin Tobias, Imperium Renewables
- Dr. Mark Huntley, University of Hawaii
- Mr. Ron Reeves, Center for Excellence in Hazardous Materials Management
- Dr. Bryan Willson, Solix Biofuels
- Mr. Matthew Caspari, Aurora BioFuels, Inc.
- Mr. Kelly Ogilvie, Blue Marble Energy
- Mr. David Jones, LiveFuels, Inc.
- Dr. Christopher Guay, Community Fuels
- Mr. Ben Cloud, XL Renewables, Inc.
- Mr. Jeff Hassannia, Diversified Energy
- Mr. Matt Jones, Nth Power
- Ms. Robin Kodner, Bodega Algae, Inc.
- Ms. Jennifer Fonstad, Draper Fisher Jurvetson
- Mr. Sanjay Wagle, Vantage Point Venture Partners

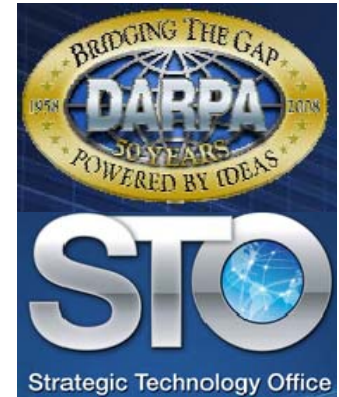
## Current Activities and Developments

### Formation of Trade Association

- Assisting in the formation of a trade association to protect the interests of those pursuing research and commercialization of algae applications.
- Steering Committee formed
  - 8 Members
  - Press release publicly announcing steering committee expected shortly
  - 1 representative from Washington



## Current Activities and Developments DARPA Broad Agency Announcement 08-07



- **Announcement:** BAA08-07 made public in the Summit's Keynote Address by Dr. Douglas Kirkpatrick on November 15.
  - Extension of BAA06-43 for conversion of agricultural feedstocks to JP-8 (EERC, UOP, GE Global)
- **Goal:** Spur development of a highly efficient system for low-cost algal oil production (non-competitive with food) and optimizing its conversion to JP-8, the fuel used by all military aircraft, tanks and non-nuclear ships.
  - Commercialization plan to Transition the technology to marketplace
  - Cost Targets: Phase 1 cost of <\$2 gallon for TAG; Phase 2 cost of <\$1 gallon for TAG (or <\$3 gallon finished cost at 50mmgy)
  - Contemplates construction of a facility (or multiple facilities) to produce 50mmgy of JP-8.
- **Teams:** Approximately ½ dozen teams submitted abstracts on January 10, 2008 and will likely be submitting proposals on February 25, 2008.
  - Large defense contractors, Fortune 500 companies, Start-ups, Universities, Government labs.

## Current Activities and Developments

### Other Noteworthy Developments

- Federal Recognition in Energy Independence and Security Act (P.L. 110-140, Dec. 19, 2007)
  - **Section 201:** Adds “algae” to the list of feedstocks qualifying as *renewable biomass*, which also qualifies as *advanced biofuel* for purposes of meeting the dramatically expanded Federal Renewable Fuel Standard.
    - **RFS Mandate:** 36 bgpy of renewable fuel, advanced biofuel, cellulosic biofuel, and biomass-based diesel must be blended into transportation fuel sold or introduced into commerce in the contiguous 48 states.
  - **Section 228 - Report:** Secretary of Energy must submit a report on progress of the R&D being conducted on the use of algae as a feedstock for the production of biofuels. Report is to address:
    - R&D challenges
    - Regulatory or other barriers that hinder the use of this resource
    - Recommendations on how to encourage and develop this source as a viable transportation fuel.
    - Report due within 90 days of enactment.

## Current Activities and Developments

### Other Noteworthy Developments

- Boeing Collaboration
  - Boeing gathers biojet samples and conducts screening tests;
  - NASA conducts lab tests and flame tube tests;
  - GE & Rolls Royce test biojet samples in jet engines;
  - Virgin Atlantic and Air New Zealand to conduct biojet fuel flight demonstrations;
  - Boeing will “neither confirm nor deny” collaboration with NZ-based Aquaflow Bionomic Corporation;
  - “Algae feedstock looks very promising”  
- Dave Daggett, Boeing



#### Virgin Atlantic to fly a 747 plane on biofuel

February test flight to measure carbon output

**AP** Associated Press

updated 8:03 a.m. PT, Mon., Jan. 14, 2008

LONDON - Virgin Atlantic said Monday it would fly one of its Boeing 747 planes on biofuel during a demonstration flight from London to Amsterdam next month.

## Current Activities and Developments

### Other Noteworthy Developments

- **Chevron Corp./NREL**
  - **CRADA:** Announced entry into collaborative research and development agreement on Oct. 31, 2007;
  - **Goal:** Advance technology to produce liquid transportation fuels using algae;
  - **Funding:** Chevron Technology Ventures is funding the program.



*News Release NR-2607*

**Chevron and NREL to Collaborate on Research to Produce Transportation Fuels using Algae**  
**Joint effort to identify and develop algae strains for feedstock in next-generation biofuels**

**October 31, 2007**  
Chevron Corporation (NYSE: CVX) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) announced today that they have entered into a collaborative research and development agreement to study and advance technology to produce liquid transportation fuels using algae.

## Current Activities and Developments

### Other Noteworthy Developments

- Solazyme/Imperium Agreement

- On June 6, 2007, Seattle-based Imperium Renewables and South San Francisco-based Solazyme entered into an agreement.
- Solazyme will grow its proprietary strains of microalgae, extract the oil, and deliver it to Imperium.
- Imperium will convert the algal oil into biodiesel at its Seattle facility.



#### John Cook's Venture Blog

« [Optimum grabs \\$5 million to regulate energy use](#) | [Main](#) | [Tuesday roundup: Sandlot Games goes mobile, ClayValet's launch, Verizon opens up, etc.](#) »

#### **Imperium looks to algae for fuel, a future in farming?**

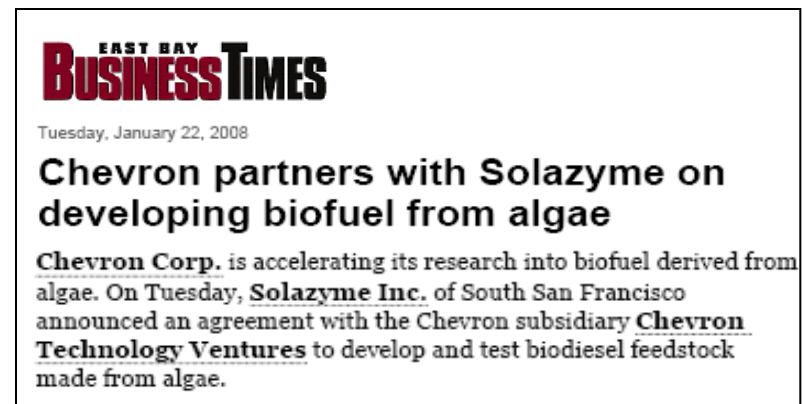


In a [BusinessWeek story](#) titled "Here comes pond scum power," Imperium Renewables Chief Executive Martin Tobias and others discuss the promise of algae in biofuel production.

## Current Activities and Developments

### Other Noteworthy Developments

- Solazyme/Chevron Partnership
  - **January 22, 2008:** Solazyme and Chevron Technology Ventures announced an agreement to develop and test algal-based biofuel feedstock.
  - **Sundance:** Solazyme powered a Mercedes with algal-based biodiesel at the Sundance Film Festival in Park City Utah last month.
  - **“Soladiesel”™** exceeds ASTM D6751 standards for use in existing diesel engines.



## Current Activities and Developments

### Other Noteworthy Developments

- Shell/HR Biopetroleum
  - **JV:** On Dec. 11, 2007, Royal Dutch Shell and Hawaii-Based start-up, HR Biopetroleum, have formed a joint venture (Cellena).
  - **Pilot:** JV will build a pilot facility in Hawaii on a site leased from the Natural Energy Laboratory of Hawaii Authority (NELHA). Nutritional supplement grower Cyanotech also has a facility at NELHA.
  - **Facility:** Open pond system using saltwater pumped in through OTEC system



#### News & Media releases

##### **Shell and HR Biopetroleum build facility to grow algae for biofuel**

11/12/2007

Royal Dutch Shell plc and HR Biopetroleum today announced the construction of a pilot facility in Hawaii to grow marine algae and produce vegetable oil for conversion into biofuel.

The announcement is a further step in Shell's ongoing effort to develop a new generation of biofuels using sustainable, non-food raw materials. Algae hold great promise because they grow very rapidly, are rich in vegetable oil and can be cultivated in ponds of seawater, minimising the use of fertile land and fresh water.

## Current Activities and Developments

### Other Noteworthy Developments

- **General Atomics/CEHMM Collaboration**
  - **June 4, 2007:** Defense contractor General Atomics opened an office in Carlsbad, NM as part of a collaboration with the Center of Excellence for Hazardous Materials Management.
  - **Open Pond:** CEHMM is constructing outdoor ponds for growing salt-water microalgae on unused, non-arable land for the production of biodiesel.



FOR IMMEDIATE RELEASE  
Jun 04, 2007

#### **General Atomics Opens Office in Carlsbad, NM to Create Biofuel From Algae**

San Diego, CA. 4 June 2007. General Atomics (GA) of San Diego, California has opened an office in Carlsbad, New Mexico to develop biofuel from algae. GA is collaborating with the Carlsbad-based, not-for-profit Center of Excellence for Hazardous Materials Management (CEHMM), which studies a wide range of issues related to reducing the impact of hazardous materials on the environment.



## Current Activities and Developments

### Air Force Office of Scientific Research/NREL Meeting

February 19-21, 2008



- **What:** Microalgal lipid-to-biofuels workshop
- **Who Was Invited:** 30-40 experts, primarily from academia and the National Laboratory System
- **Objectives:**
  - Elucidate various scientific approaches and tools needed for controlling and/or augmenting algal lipid biosynthesis;
  - Identify specific problems/barriers that prevent achievement of goals;
  - Develop a basic science research “roadmap” from which recommendations can be made to overcome barriers.

## Current Activities and Developments

### Washington Connections

- Bionavitas, Inc.
- Blue Marble Energy
- Boeing
- Imperium Renewables
- Inventure Chemical
- Pacific Northwest National Laboratory
  - Dr. Michael Huesemann
  - Dr. Blaine Metting



Pacific Northwest National Laboratory  
Operated by Battelle for the U.S. Department of Energy



**Ethanol**  
PRODUCER MAGAZINE

**Inventure Chemical  
completes cellulosic  
feasibility studies**

In the fourth quarter of 2007, Inventure Chemical, a Seattle-based biofuels technology developer, completed 20 feasibility studies to identify the highest-yielding and most cost-effective second-generation feedstocks for use in the company's patent-pending biofuel conversion process. Fourteen of the studies were completed for companies growing algae, while the remaining studies consisted of analyses and market studies for agricultural waste streams. In the wake of these studies, Inventure is continuing to expand its biodiesel and ethanol research and development production facility.

---

**4. | Challenges**

---

## Challenges

### • **Technology Obstacles and Risk**

- Growth/Propagation: “The efficient and stable mass culture of microalgae and low cost harvesting are the main issues in microalgae biofuels production” (J. Weissman, Algae Biomass Summit).
  - Selection of proper algal strain for the growing conditions and maintaining strain stability for monoculture (resistance to invasion / “mongrel” algae).
  - Efficient sunlight conversion.
    - Theoretical maximum solar conversion efficiency is 10%.
    - Converting 10% of total solar energy translates to a mean annual productivity of 100 grams per square meter per day (J. Weissman).
  - Exposure of microalgae to sunlight. Light scattering/inhibition reduces exposure to sunlight for microalgae suspended deeper in the media.
  - Controlling growth rates to prevent “crashes”
  - Temperature control
  - CO<sub>2</sub> availability and transport (CO<sub>2</sub> must be “scrubbed” – Sulfur dioxide and hydrogen sulfate toxic to algae!)
  - Water chemistries, make-up water (evaporation)
  - “The problem is not making oil from algae, the problem is making algae.” (Benemann).

## Challenges

### ASP Productivity Results

(Source: J. Weissman, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007))

Principal and Location	gm/m <sup>2</sup> /d	% PAR	Days	Scale, m <sup>2</sup>	Alga
	Ave (Max)	Ave (Max)			
Laws, Hawaii, 1984-5	37 (65)	9 (15+)	78	48	TETRA
Laws, Hawaii, 1985-6	30 (35)	9.6	400	48	CYCLO
Laws, Hawaii, 1990	15	3.5	variable	24	TETRA
Ben Amotz, Israel, 1986	27 (40)	9.5	90	0.35	CHAET
Richmond, Israel, 1985-6	25		60	2.5	NANNO
	28		14	2.5	ISO
Weissman, CA, 1986	32 (40)	7 (10)	125	1.4	CHAET
	32 (40)	6.8 (9)	43	1.4	CYCLO
Weissman, CA, 1983	16	3.6	240	100	SCENE
Weissman, NM, 1988	30(50)	6.8	50	3	AMPHO
	18.4	4.8	180	3	TETRA
	20	7	40	3	CYCLO
Weissman, NM, 1989	20(24)	5	100	1000	CYCLO MONOR
Weissman, NM, 1988-90	10(24)	3	730	1000	CYCLO MONOR

## Challenges

### • **Technology Obstacles and Risk (Cont.)**

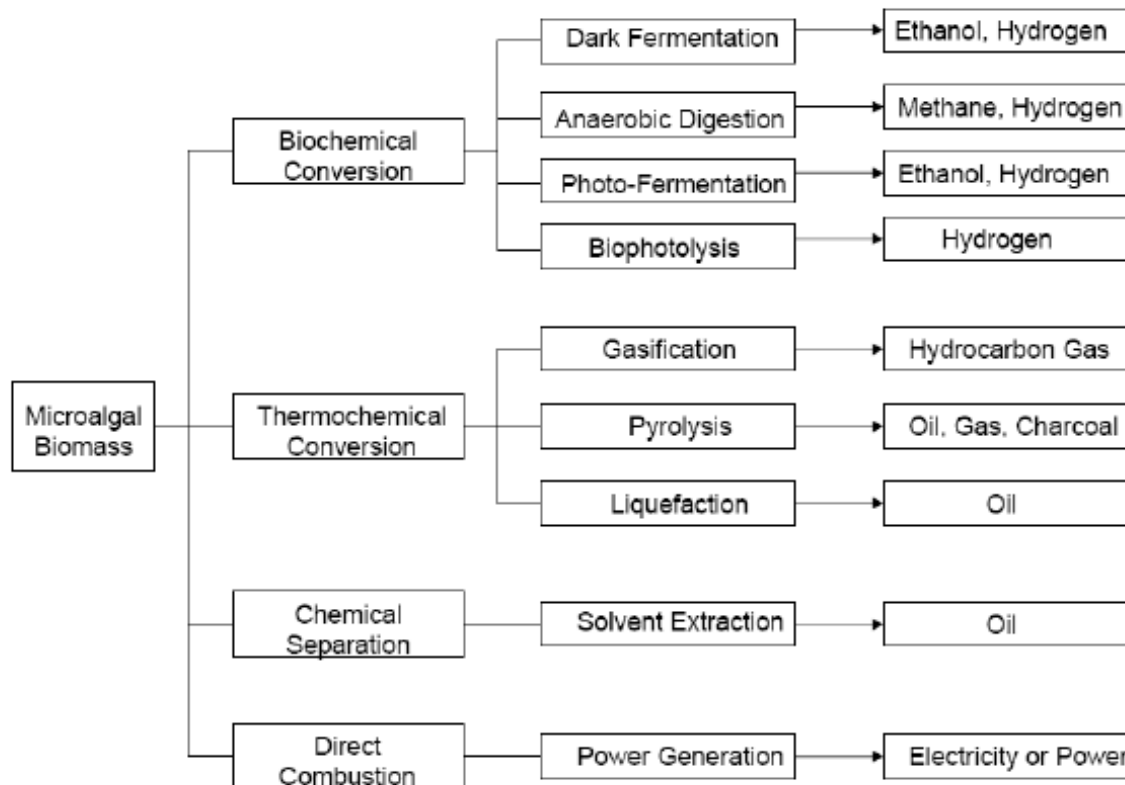
- Harvesting/Dewatering: Harvesting must generally occur on a daily basis in order to reach maximum growth and propagation potentials; however, harvesting involves separating a few hundred pounds of microscopic particles from hundreds of thousands of gallons of media. We're talking a 1000-fold concentration. Drying is expensive (unless natural drying used).
- Harvesting Methods (From relative high cost to low cost):
  - Foam fractionation
  - Ozone flocculation
  - Centrifugation
  - Electrofloatation
  - Inorganic Chemical Flocculation
  - Filtration or Microstrainers
  - Discrete Sedimentation
  - Autoflocculation
  - Bioflocculation
  - Tilapia Enhanced Sedimentation / Brine Shrimp

## Challenges

- **Technology Obstacles and Risk (Cont.)**
  - Extraction: Efficient lipid extraction and oil purification processes
    - Physical pulverization (expeller/press)
    - Chemical treatment (hexane, benzene – potential environmental issue); solvent recovery is expensive.
    - Enzymatic
    - Sonication/Ultrasonic (sound waves)
  - Conversion: Conversion of algal oil to JP-8, JET-A, Green Diesel, etc.
    - Process optimization to increase efficiencies
    - Achieving fuel characteristics
      - Energy density
      - Carbon numbers
      - Cloud point
      - Stability
      - Consistency

## Challenges

- **Technology Obstacles and Risk (Cont.)**



## General Microalgal Biomass Conversion Technologies

**Source:** M. Huesemann, Pacific Northwest National Laboratories, *Biofuels from Microalgae: Products, Processes and Potential*, Presentation at Algae Biomass Summit, San Francisco, CA (Nov. 15, 2007).



## Challenges

- **Technology Obstacles and Risk**

- Photobioreactor designs:

- Leakage
- Fouling
- Contamination
- Overheating
- Expensive
- Some studies (Rudolfi et al, 2007) suggest energy balance may be 1:1 or even negative for photobioreactor approach.

## Challenges

- **Markets**

- Certifications/Qualifications: Standards organizations must develop certification and qualification processes before companies are comfortable using the fuel.
- Coproducts:
  - Efforts will be required to break into Coproduct markets
  - Markets may not materialize (e.g., price points aren't right, local needs, etc.)

- **Cost**

- The lack of any mass/commercial production of algal oil means its cost is unknown and high (\$20+ per gallon). Scaling up will reduce this cost over time.
- Getting to \$1/gallon for algal oil is considered “DARPA Hard”
- Capital and Operating Costs. First 150mmgy algal oil facility may be upwards of \$500 million to \$1 billion. This would produce approximately 50mmgy JP-8 (3:1 conversion rate).

## Challenges

- **Permitting/Environmental**

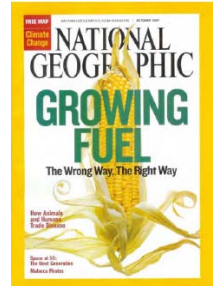
- Land requirements for open ponds
- CO<sub>2</sub> from coal plants provide a necessary input but also NO<sub>x</sub> and Hg (mercury)
- GMO issue. DARPA is specifically excluding GMO research as part of BAA08-07

- **Research**

- No U.S. university offers a program dedicated to or degrees in phycology, the study of algae and a subdiscipline of botany.
- Small cadre of researchers constitute the “experts”, and most were in the room at the Algae Biomass Summit.

## CONCLUSIONS

- No Magic Bullet: “There is no magic-bullet fuel crop that can solve our energy woes without harming the environment, says virtually every scientist studying the issue. But most say that algae ...comes closer than any other plant...” (*National Geographic*, October, 2007).
- Increased Interest: Scrutiny of “First Generation”/Terrestrial biofuels, the carbon debate, ambitious renewable fuel standards, growing acceptance of “peak oil” and other macro-level catalysts have catapulted algae to the forefront of biofuels and as a high-impact contributor to solving global problems.
- Timeframes:
  - **DARPA**: Wants 50mmgy JP-8 contract within 48 months.
  - **Sempra Utilities**: Projects market readiness at 5 years.
  - **Network on Biofixation**: Longer period 10-20 years.
- Significant Hurdles: Major technical and economic hurdles. Fewer political hurdles at this point, but the “first” facility will likely face significant scrutiny for a variety of reasons.
- **THANK YOU!!**



## Andrew T. Braff



### CONTACT:

701 Fifth Avenue  
Suite 5100  
Seattle, WA 98104  
Phone | 206-883-2500  
Fax | 206-883-2699  
abraff@wsgr.com

Andrew Braff is an associate in the Seattle office at Wilson Sonsini Goodrich & Rosati, where his practice focuses on renewable energy project development. His experience includes drafting and reviewing engineering, procurement, and construction agreements, operation and maintenance agreements, energy supply agreements, and equipment supply agreements for the wind, solar, biomass, and biofuels industries. Andrew also has advised on federal and state legislative and regulatory process, including the Environmental Protection Agency's implementation of the federal Renewable Fuel Standard mandated by the Energy Policy Act and various state renewable portfolio standards.

Andrew previously served as an extern for Justice Mary E. Fairhurst of the Washington State Supreme Court and as director for policy and public affairs for California State Assemblyman, now State Senator, Mark Wyland. In addition, he served as a legislative assistant to Congressman George R. Nethercutt, Jr. where he handled appropriations for multiple subcommittees.

### EDUCATION:

- J.D., University of Washington School of Law, 2006  
*External Affairs Editor, Shidler Journal for Law, Commerce & Technology; Recipient, CALI Excellence for the Future Award, Criminal Law; Berman Environmental Law Clinic*
- B.A., Whitman College, 2000  
*With Honors; Magna Cum Laude; Phi Beta Kappa; Recipient, Chester C. Maxey Politics Award*

### ASSOCIATIONS AND MEMBERSHIPS:

- Steering Committee, Algae Biomass Summit
- Member, Energy Bar Association
- Member, Washington State Bar Association
- Member, American Bar Association

### SELECT PUBLICATIONS:

- "RFS Rulemaking: EPA Proposes Implementation of Renewable Fuels Standard," *Biofuels Journal*, 2006
- "The Spy Act: Ditching Damages as an Element of Liability for On-Line Conduct between Private Parties," 2 *Shidler Journal of Law, Commerce & Technology* 17, 2006
- "Defining Spyware: Necessary or Dangerous," 2 *Shidler Journal of Law, Commerce & Technology*, 2005
- Co-author with The Honorable Mary E. Fairhurst, "William O. Douglas: The Gadfly of Washington," 40 *Gonzaga Law Review* 259, 2005

*Algae for Energy*

**W&G R** Wilson Sonsini Goodrich & Rosati  
PROFESSIONAL CORPORATION

Wilson Sonsini Goodrich & Rosati  
PROFESSIONAL CORPORATION