REALITY OF ALGAL FUELS!

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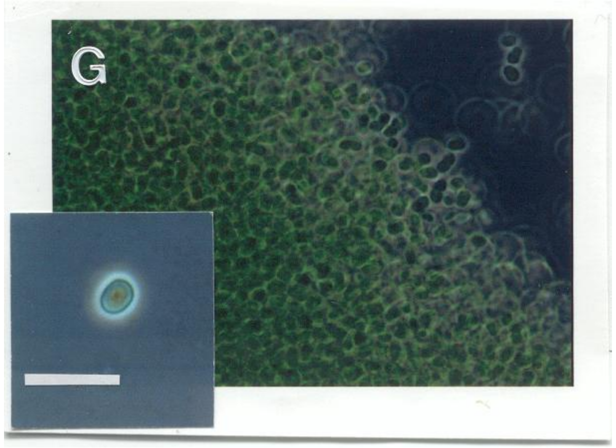
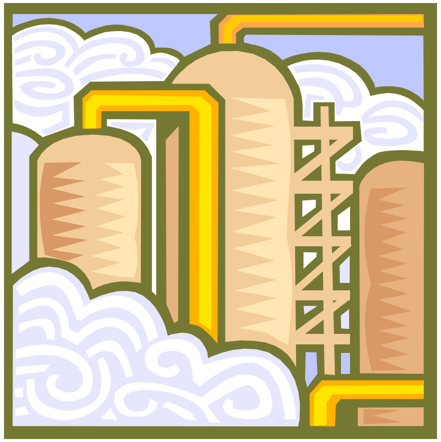
September 1, 2011

Biofuels: what we know and what we don’t



Replacing a feedstock into algae brings a number of challenges

We know which crops/feedstocks are currently used and how to process those



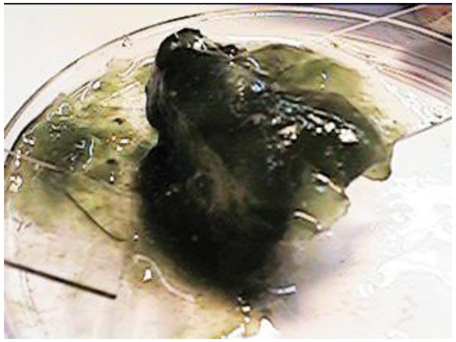
We know how to grow algae and how to operate refineries

We know which quality of oil is needed for transportation fuels

Algae is a new fuel feedstock, and we need to define

- **What to grow**
- **Where to grow**
- **How to grow <u>economically</u>**
- **How to process biomass <u>economically</u>**

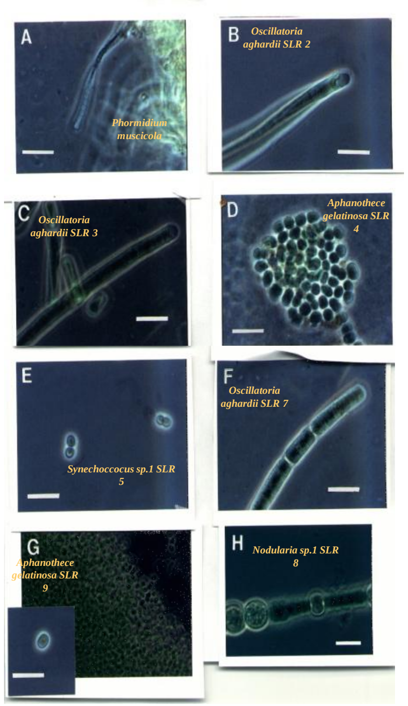
What to grow

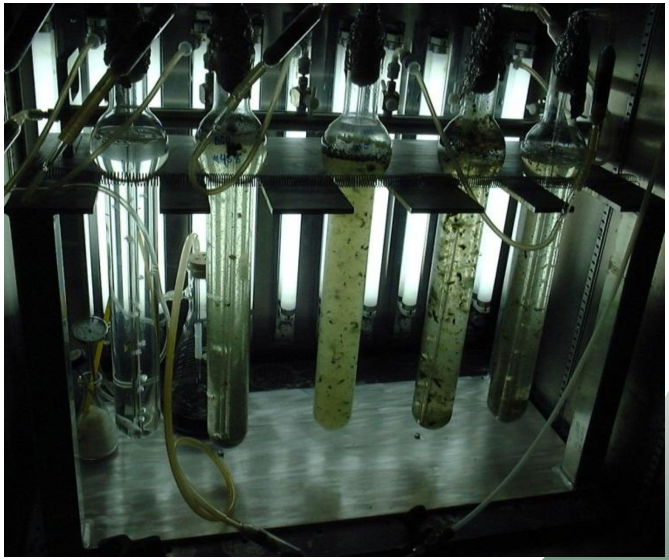


CRITERIA:

Need to make oil efficiently
Oil needs to meet fuel requirements
Need to be adaptable to the conditions of the site

At this time: Need to be a source of valuable co-products



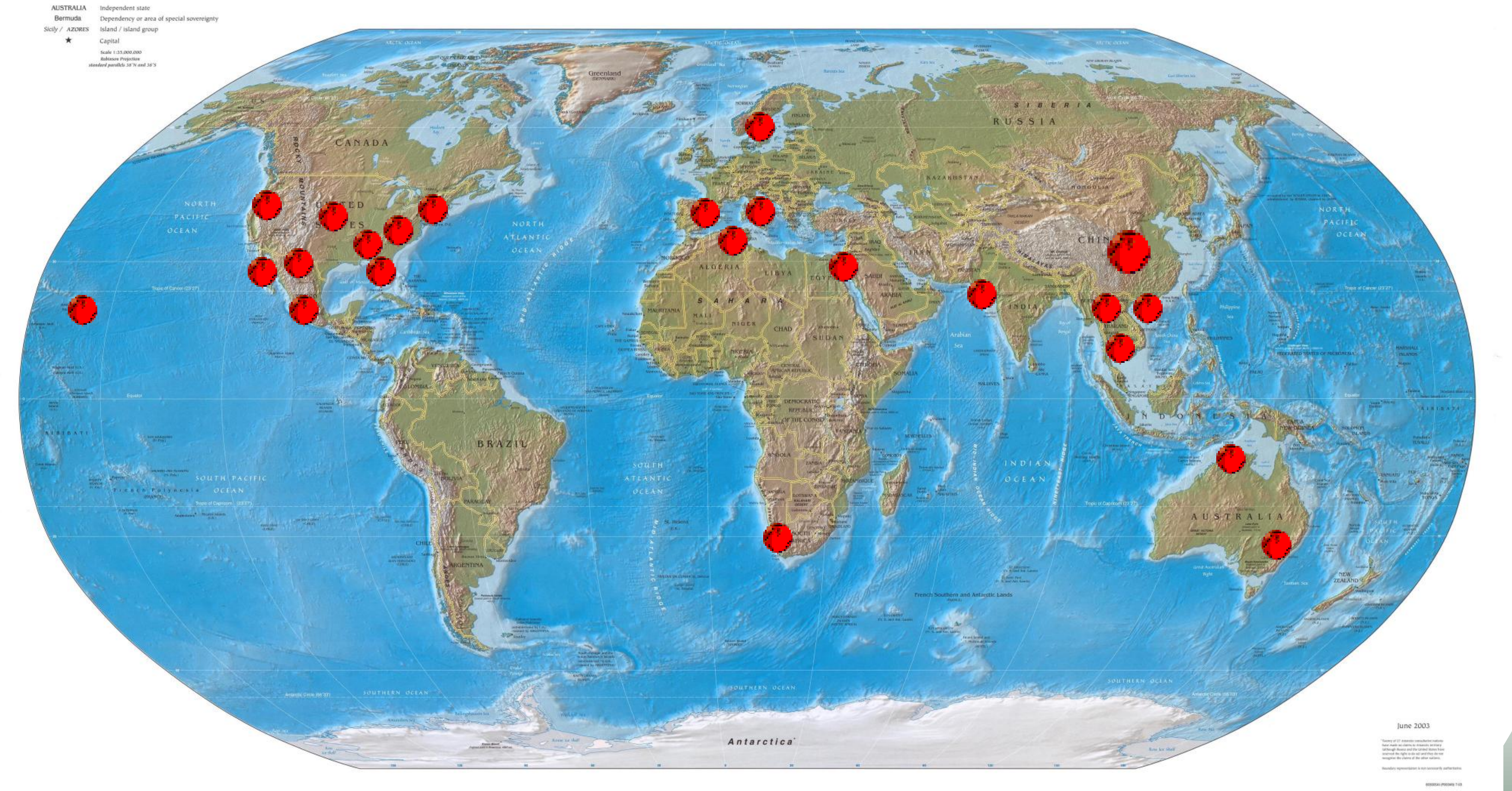


Oil content in selected algal species

Species	Oil content (% dw)	Reference (cited after Carlsson et al, 2007)
Ankistrodesmus TR-87	28-40	Ben-Amotz and Tornabene (1985)
Botryococcus braunii	29-75	Sheehan et al. (1998); Banerjee et al. (2002); Metzger & Largeau (2005)
Chlorella sp.	29	Sheehan et al. (1998)
Chlorella protothecoides (autotrophic/ heterothrophic)	15-55	Xu et al. (2006)
Cyclotella DI-35	42	Sheehan et al. (1998)
Dunaliella tertiolecta	36-42	Kishimoto et al. (1994); Tsukahara & Sawayama (2005)
Hantzschia DI-160	66	Sheehan et al. (1998)
Isochrysis sp.	7-33	Sheehan et al. (1998); Valenzuela-Espinoza et al. (2002)
Nannochloris	31 (6-63)	Ben-Amotz & Tornabene (1985); Negoro et al. (1991); Sheehan et al. (1998)
Nannochloropsis	46 (31-68)	Sheehan et al. (1998); Hu et al. (2006)
Nitzschia TR-114	28-50	Kyle DJ, Gladue RM (1991) Patent Application, PCT WO 91/14427, 3 Oct 1991
Phaeodactylum tricornutum	31	Sheehan et al. (1998)
Scenedesmus TR-84	45	Sheehan et al. (1998)
Stichococcus	33 (9-59)	Sheehan et al. (1998)
Tetraselmis suecica	15-32	Sheehan et al. (1998); Zittelli et al. (2006); Chisti (2007)
Thalassiosira pseudonana	(21-31)	Brown et al. (1996)
Crpythecodinium cohnii	20	www.oilgae.com
Neochloris oleoabundans	35-54	www.oilgae.com
Schisochytrium	50-77	www.oilgae.com

Where to grow

Physical Map of the World, June 2003



How to grow and to make the process economically viable

1. Closed vs. open system (bioreactor vs. pond)

2. CO_2 is the most expensive feedstock - drives OpEx

3. Biofuels are cheap and do not drive economics

Bioreactor vs. open system:

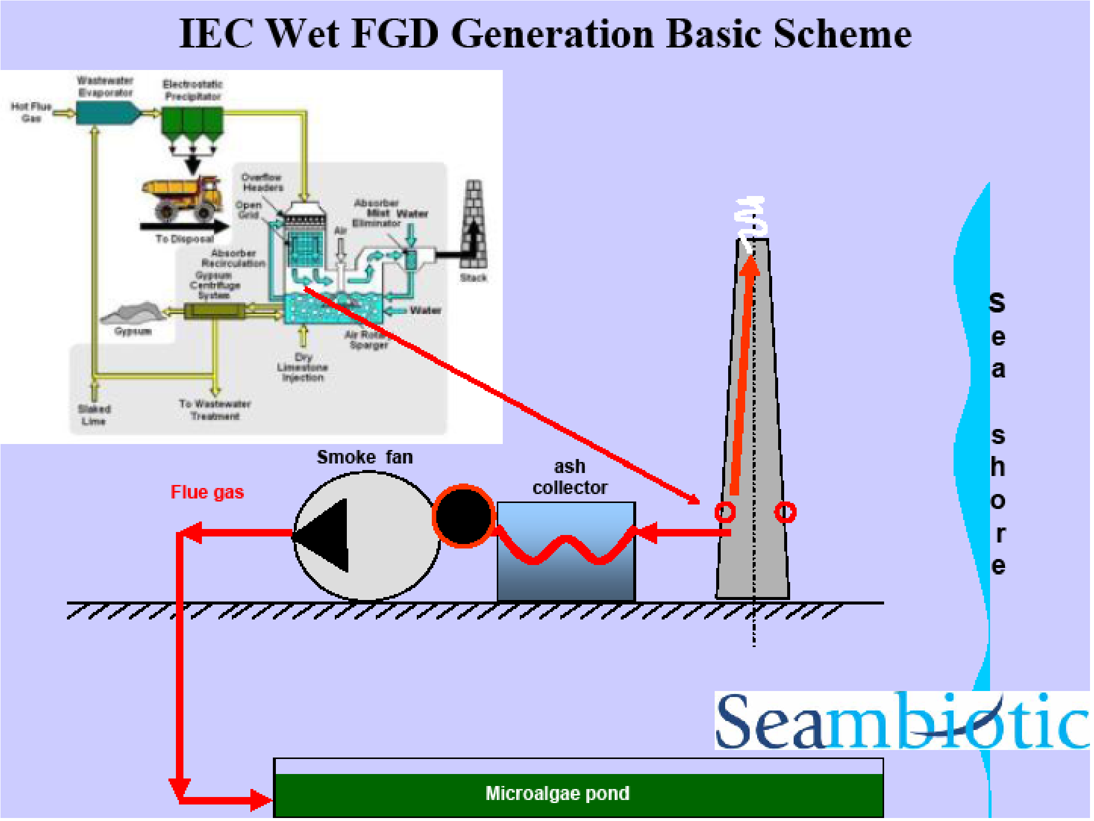
a number off-the-shelf solutions is available for phototrophic….

or heterotrophic cultivation:

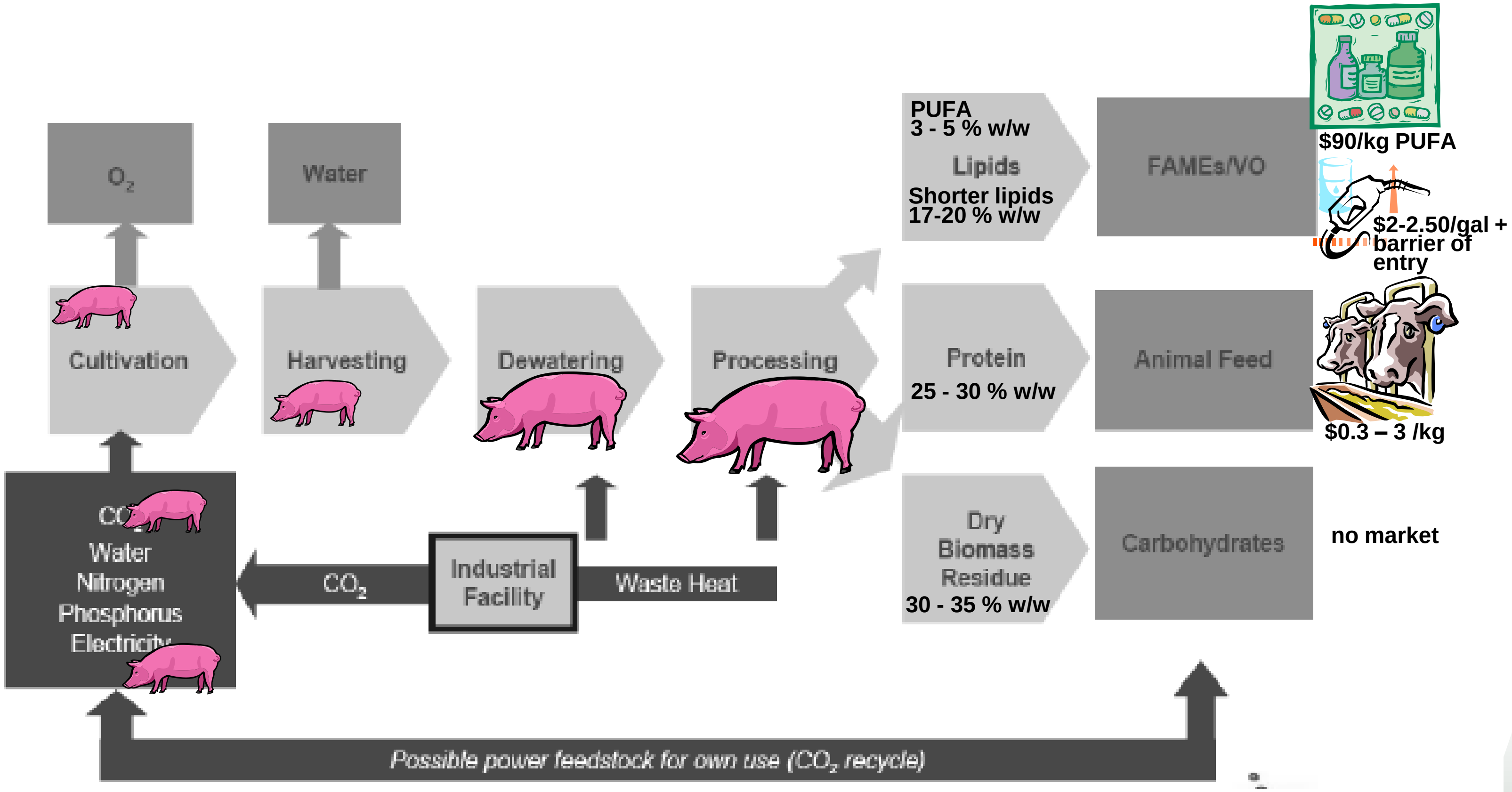
“Algal bioreactors”: from 23,200 images by Google

CO_2 is the most expensive feedstock in algal cultivation which drives OpEx

Solution: use flue gas from a stack. Demonstrated in Ashekelon, Israel, in process by US companies



Algae Production Process Flow: Energy Hogs and Revenue Sources



O$_2$

Water

Cultivation

Harvesting

Dewatering

Processing

CO$_2$
Water
Nitrogen
Phosphorus
Electricity

CO$_2$

Industrial Facility

Waste Heat

PUFA
3 - 5 % w/w
Lipids
Shorter lipids
17-20 % w/w

FAMEs/VO

$90/kg PUFA

$2-2.50/gal + barrier of entry

Protein
25 - 30 % w/w

Animal Feed

$0.3 – 3 /kg

Dry
Biomass
Residue
30 - 35 % w/w

Carbohydrates

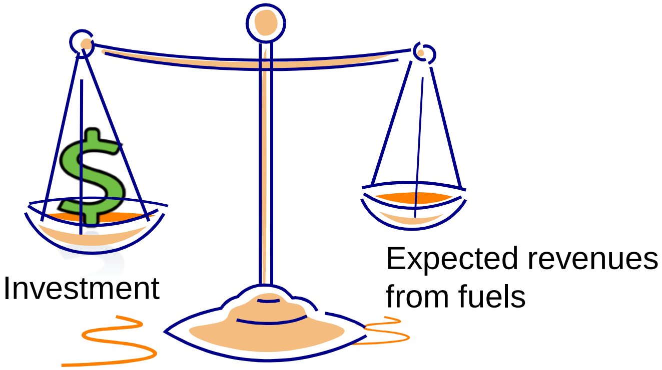
no market

Possible power feedstock for own use (CO$_2$ recycle)

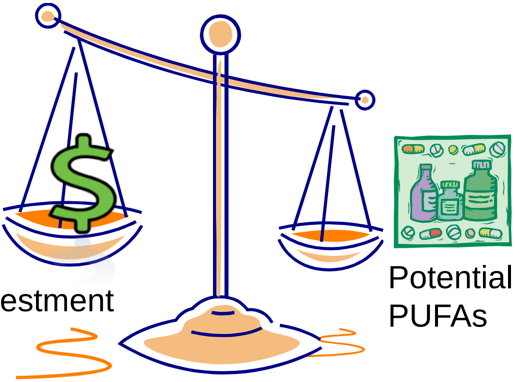
Source: Cellana Group.

“A critical gap is the energy requirements of these processes are not only largely unknown but unbounded”. (DOE Algal Fuels Roadmap, 2010)

From the investor's perspective: expectations



From the investor's perspective: why should one invest more, at risk, when a marketable product is available?



Investment

Potential revenues from PUFAs

Making algal fuels an attractive product:

Lowering costs of inputs and process through new technologies and system engineering

Removing regulatory barriers (ASTM)

Finding incentives and new revenue streams (from carbon capture to new products)

Menu of available technology options

Available technologies

- Mature cultivation technologies & strains
- A number of harvesting technologies
- Limited choice of dewatering technologies
- Mature processing technologies for plant biomass

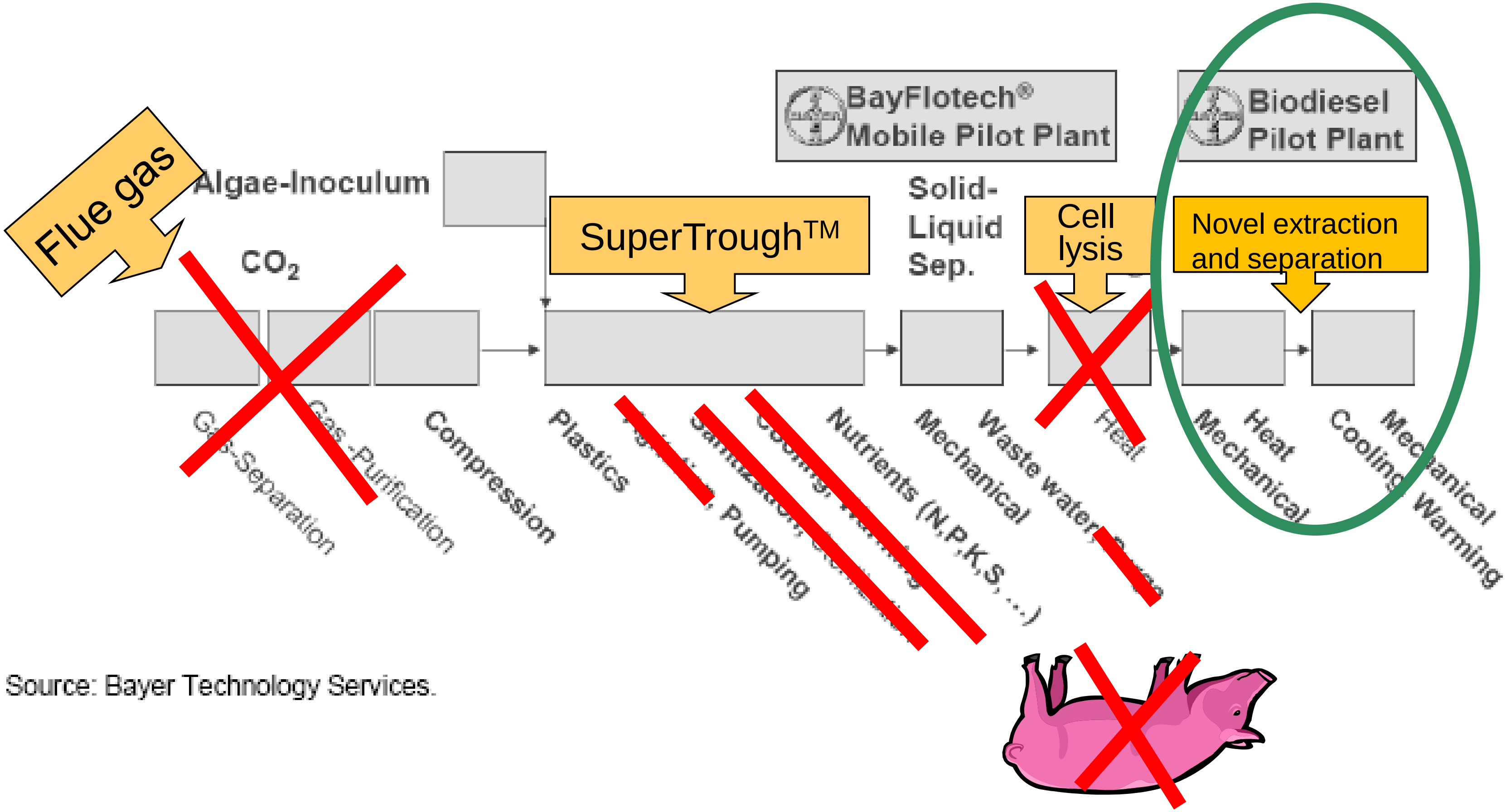
Finding incentives through partnerships

- Algae use CO_2 as food – to grow. Feeding them CO_2 from industrial emissions saves money
- The energy for carbon capture comes from sunlight – free
- Operational cost of CO_2 capture by algae is 7% (based on flue-gas blower and algal harvesting power requirements) as compared to 30% used in the amine capture process
- CO_2 capture by algae eliminates waste disposal and regeneration costs associated with spent amine
- Biomass from the process is a commodity

Benefits of CO2 capture by algae:

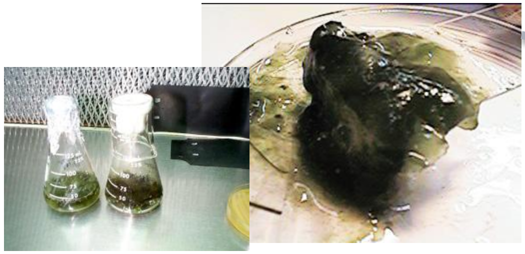
Conversion cost	0
CO2 capture OpEx	7%
Amine WM and regeneration cost	0
Carbon Credit	Yes
Income from biomass sales	Yes
Total:	*Win-Win*

Proposed approach will lower process costs



Source: Bayer Technology Services.

Filling in technology gaps & our model



Technology gap - strain selection based on requirements to fuels and to reduce processing steps (Kuritz)

Biomass cultivation – technology gap - system engineering and controls (Varma, in cooperation with industry). Source of field data: PhycoBiosciences, Inc.

For 1 dry ton of algae/day we need 15 acres and 1.6 tons of CO_2

One MW power plant produces 20 tons of CO_2 per day

One 1 ton of dry algae per day yields 1200 gallons of diesel per acre per year

Biomass harvesting/dewatering – technology gap – membrane technologies (Bhave)

Cell breaking – technology gap – lysis (Kuritz)

Extraction/separation of lipids from biomass – technology gap (in cooperation with industry)

JP-8
Diesel

$

CO_2 capture (or carbon credits when available)

$

High-value, specialty or regulated products

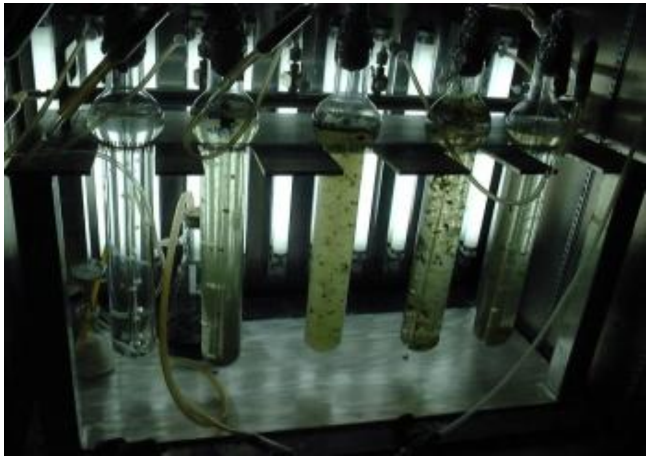
Fuel design & testing– technology gap

Yields of oils

Crop	Yield	
	L/ha	US gal/acre/year
Algae	~3,000	1,200 (our model); 1,500-3,000[1], 5,000-15,000[2]
Chinese tallow	907	97[3,4]
Palm oil	4752	508[4], 635[5]
Coconut	2151	230[4]
Rapeseed	954	102[4], 127[5]
Soy (Indiana)	554-922	59.2-98.6[6]
Soy (average)		48[5]
Peanut	842	90[4]
Sunflower	767	82[4], 102[5]
Hemp	242	26[4]
Corn		18[5]
Safflower		83[5]

1. DOE Algal Biofuels Roadmap, 2010
2. Sheehan et al.,.
3. Kitani, Osamu, "Volume V: Energy and Biomass Engineering, CIGR Handbook of Agricultural Engineering", Amer Society of Agricultural, 1999; Klass, Donald, "Biomass for Renewable Energy, Fuels, and Chemicals", Academic Press, 1998.
4. http://www.grist.org/article/biofuel-some-numbers
5. www.oilgae.org
6. www.ces.purdue.edu/extmedia/ID/ID-337.pdf

Pilot-scale cultivation at ORNL



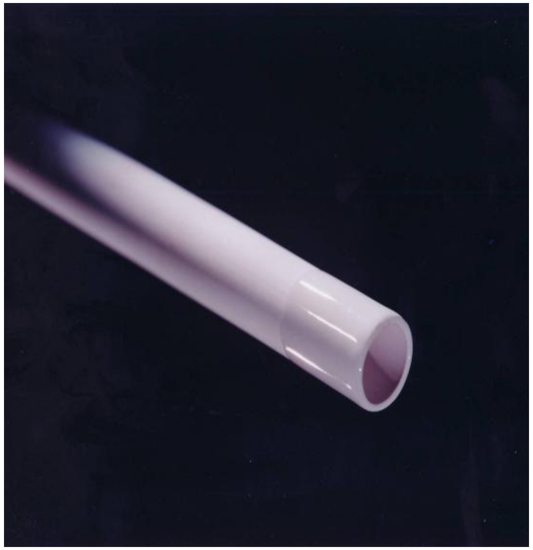
- Research photobioreactor of a unique design for cultivation of up to 5 L algal culture
- Collection of algal strains

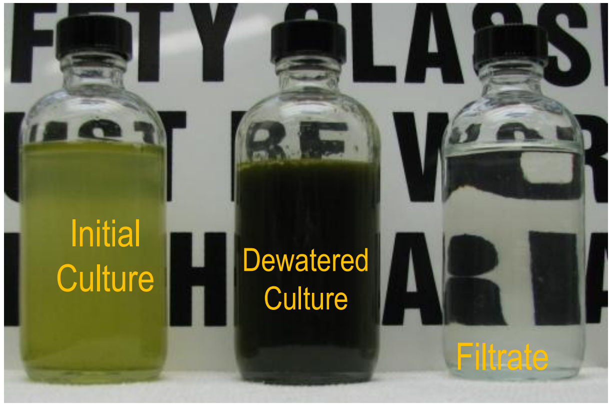
- Facility for batch cultivation of algae up to 200 L (pilot scale)
- Culture densities up to 3 g/L dw
- Media recycling

Cultivation of oil-producing algae

ORNL research on algal fuels: harvesting and dewatering by membrane separations

- Membranes and device were fabricated at ORNL
- Pore diameters of 0.5 nm to 20,000 nm
- Support structure and layer made of variety of metals and ceramics



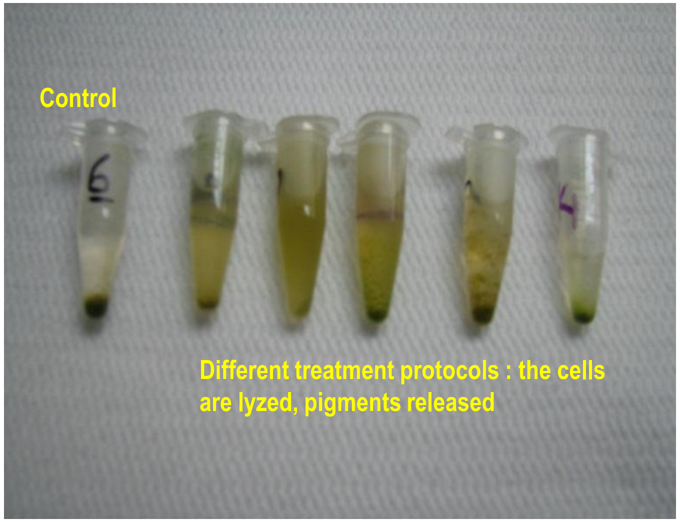


We have achieved 200-fold volumetric dewatering of oil-producing algal cultures using a novel membrane separation system

- Mechanical, thermal, and chemical stability can be tailored by choice of materials of construction
- Membrane layer thickness can be 2µm or less yielding a high permeance at low pressure drop
- Proven at many scales

ORNL research on algal fuels: algal cell lysis

- Most algal strains-producers are resistant to rupture by conventional methods
- We have identified enzymes effective in lysis of oil-producing strains
- Use of enzymes reduces costs of cell breakage by mechanical or chemical treatment
- The lysis allows increased oil yields by separations and extraction



Different treatment protocols : the cells are lyzed, pigments released

ORNL research on algal fuels: engineering R&D and systems development

- Developed models for assessment of engineering solutions for carbon capture and biomass processing
- Proposed processes based on combining algal technologies; systems engineering
- Developing a closed loop system with controls and sensors for maintaining critical cultivation parameters
- Identified technology gaps and provided energy and feasibility analysis of algal technologies

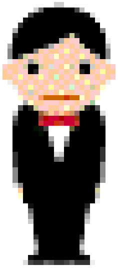
Acknowledgments

Venu Varma

Ramesh Bhave
Bart Smith
Robert Andersen
Costas Tsouris
Jeff Muhs
Our industrial partners

GO ALGAE!

Thank you!



Sustainability of algae as feedstock

% of US Agricultural Land Required to meet demand in fuels*

Crop	% requirement
Corn	**1700%**
Soybean	**650%**
Canola	**240%**
Jatropha	**154%**
Coconut	**108%**
Oil Palm	**50%**
Microalgae	**2-5%**

* The Choice of next generation Biofuels January 2009, Scotia Capital. Sam Kanes and David Forster

ASTM approves biojet annex for hydroprocessed esters

By Bryan Sims | July 06, 2011

- Subcommittee D02.J0 on Aviation Fuels in ASTM International Committee D02 on Petroleum Products and Lubricants officially approved the addition of the jet fuel annex to the alternative fuel specification D7566 titled “Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons”, which now allows up to a 50/50 blend of biobased components with conventional Jet-A fuel. The new annex will set fuel properties for what’s called “Hydroprocessed Esters and Fatty Acids” (HEFA) fuel derived from biomass feedstocks such as camelina, jatropha or algae, as well as production control criteria of the fuel for aviation use. The revised standard was approved July 1.

Aviation fuel producers, distributors, airport fuel farms and airlines in the global aviation community will now be able to verify fuel quality and performance by testing according to the D7566 specification requirements. With this new edition, D7566 includes new, specific requirements for the biobased synthetic fuel component such as thermal stability, distillation control and trace material amounts. After blending with conventional jet fuel, new lubricity, distillation and composition requirements in D7566 must also be met. As a result, the blended jet fuel used in airplanes is essentially identical to conventional jet fuel and doesn’t differ in performance or operability, according to Mark Rumizen, lead on the certification-qualification group for the Commercial Aviation Alternative Fuels Initiative (CAAFI) who also helped out on the work to revise the specification.

“Because of the great emphasis on safety when you’re dealing with aviation fuel, the passage of this ballot required a collaborative and cooperative effort between the members of the aviation fuels community,” he said. Representatives from companies across the fuel supply chain, including HEFA fuel producers, aircraft and engine manufacturers and regulatory agencies were involved in the specification development and revision.

The revised specification references numerous other ASTM standards, including tests that measure various properties of the fuel. D7566 fuels also meet the requirements of ASTM D1655, “Specification for Aviation Turbine Fuels”, which has been used by the aviation community for decades for the quality control and distribution of conventional aviation turbine fuel. This allows these new D7566 fuels to be seamlessly integrated into the distribution infrastructure and onto certified aircraft as D1655 fuels.

The newly-revised specification for HEFA blends in Jet-A fuel successfully rides on the coattails of the now widely used Fischer-Tropsch process under the D7566 specification, which was approved by ASTM back in 2009.

Rob Midgley, technology manager of aviation fuels for Shell Aviation, Cheshire Great Britain and a D02 member, noted, “The approval of HEFA as a blending component in jet fuel builds on the great efforts expended by ASTM on approving Fischer-Tropsch components in 2009 and shows that, as a consensus group. ASTM can make great strides while maintaining the safety levels demanded by the aviation sector.”

ASTM’s decision to amend the jet fuel specification was welcomed by various stakeholders within the aviation fuel supply chain, most notably the Air Transport Association of America Inc., the industry trade organization that represents some of the leading U.S. airlines. According to John Heimlich, vice president and chief economist for the ATA, it will likely take time for significant volumes of biojet fuel to enter the U.S. market due to competitive hurdles, petroleum price volatility and scarcity of financing for fuel production facilities and other factors, “but there are reasons to expect up to one billion gallons of biofuel to be in annual production by 2020,” he said in an email correspondence. Heimlich added that the worldwide airline industry is projected to spend approximately $176 billion on conventional jet fuel this year.

Prospective biojet fuel suppliers like San Francisco-based algae fuel biotech outfit Solazyme Inc. lauded ASTM’s decision to revise the D7566 jet fuel specification to include biobased blends.

“We applaud the historic ruling by ASTM International, and the continued work of both ATA and CAAFI, to implement sustainable initiatives for the aviation industry,” said Solazyme CEO Jonathan Wolfson in a statement. “[The ruling] approving the use of algae and other sustainably-derived biofuels in commercial flight is a regulatory breakthrough and provides a critical step in the commercialization of advanced, low-carbon biofuels. Solazyme commends these leading industry organizations for their continued commitment to secure alternative energy supplies.”

In June, Solayzme announced the U.S. Navy successfully demonstrated its algae-derived jet fuel in a MH-60S Seahawk helicopter. The test flight was completed with a 50/50 blend of Solazyme’s algae-based SolajetHRJ-5 fuel and traditional petroleum-derived jet fuel. According to Solazyme, it is the only company to date to provide the U.S. Navy with microbe-derived advanced aviation and marine fuel. The company also noted that Honeywell’s UOP was the refinery partner on the jet fuel delivery, and has been working with Solazyme since 2009 on multiple contracts with the U.S. military.

Also in late June, Dynamic Fuels LLC, a joint venture between Tyson Foods and Syntroleum, supplied a 50 percent blend of its renewable jet fuel produced at its 75 MMgy facility in Geismar, La., in both engines of a Boeing 737-800 aircraft operated by KLM Royal Dutch Airlines. According to Dynamic Fuels, the flight was a preview of more than 200 commercial flights between Amsterdam and Paris KLM plans to make in September using the same fuel.