



Tomorrow's Diesel is Yesterday's Slime

moore_a@denison.edu

Amanda Moore

Denison University

The current situation

There is a scientific consensus that **climate change is inevitable**. If we do not cut our emissions fast enough, we'll have the following effects:

- Flooding of coastal regions
- Increase in length and severity of storms
- Destruction of sensitive ecosystems
- 20-30% of species could face extinction

Why biodiesel?

- Biodiesel (when blended with some amount of petroleum diesel) can be used in **existing diesel engines**.
- Plants need CO₂ to grow. Thus, when they are burned as biodiesel, there is less net growth in the amount of CO₂ in the atmosphere.

•However, traditional farming has many drawbacks. (See other posters for details)

Crop	US gal/acre
Corn	18
Soybean	48
Chinese tallow	699
Algae (Test Yield)	819
Algae (Theoretical Yield)	5,000

Algae is the most efficient plant at producing oil. Some algae species are **45% oil!**

Fig. 1 Average yield of biodiesel from some crops

Three reasons for algae

1. Algae can be **grown on the waste** from sewage systems and the exhaust from power plant smokestacks.
2. **It's not food!** It can also be grown in locations that are not traditionally farmland and with fewer resources than are used for conventional biodiesel crops.
3. Algae produces **40 times** as much biofuel per acre as corn, and has the potential to produce **250 times** more than corn!

Annual Greenhouse Gas Emissions by Sector

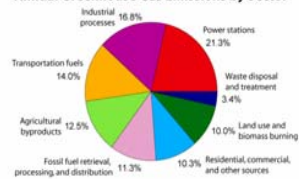


Fig. 2 Annual US greenhouse gas emissions by sector

Source: Emission Database for Global Atmospheric Research, v3.2, 2000

Biodiesel from algae could potentially eliminate the 14% of our annual greenhouse gas emissions from transportation fuels. It would also reduce many of the **point source CO₂ emissions** from power stations by turning them into biodiesel.

How it works

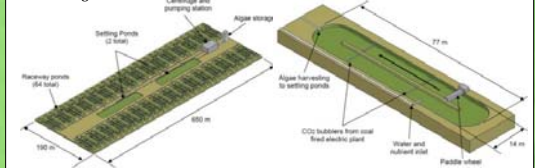
Ways to industrially grow algae:

Raceway, or open-pond:

- Paddlewheels circulate the algae around a racetrack
- Ponds are shallow because light only penetrates first 3-4 inches
- Open to the elements**, so vulnerable to contamination
- Large production capacity during warmer months, but possibly no production during colder months
- Cheaper to construct**, but harder and more expensive to maintain



Figs. 3,4,5: Top: New Mexico State University researchers examine one of their ponds. Bottom: Diagram of full operation (left), diagram of one pond (right) Source: AlgaeLink



Bioreactor:

- Any type of **closed system**
- Can be exposed to sunlight or artificially lit
- Can be heated for year-round production
- More expensive**, but more control

Fig. 6: Right: Vertigo, developed by Global Green Solutions. Consists of racks of plastic tubing.



Fig. 7: Below: GreenFuel technologies' bioreactor in AZ, which uses power plant emissions.



Success story:

MIT built an algae bioreactor on top of its 20 MW power plant in 2004. It since has reduced CO₂ emissions by **82%** on sunny days and **50%** on cloudy days. The bioreactor also filters out **85%** of the nitrogen oxides produced.

Turning algae into oil:

Three methods: chemical (right), physical (bottom), and supercritical fluid extraction (text below). Oil extracted under any method can then be processed into biodiesel.

Supercritical fluid extraction: CO₂ is put under high pressure, liquefied, and then heated until it has the properties of both a liquid and a gas. This supercritical fluid is then used as a solvent to extract the oil.

Fig. 8: Full process of algae production and oil extraction, emphasis on the physical extraction methods. Oil presses collect about 70% of the oil from algae. Source: AlgaeLink

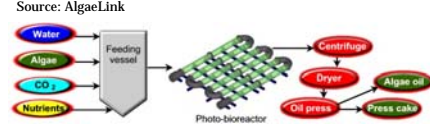
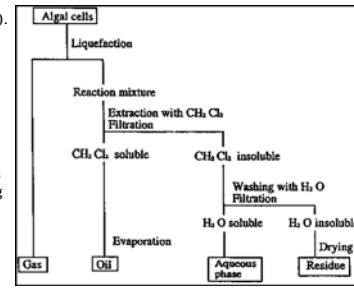


Fig. 9: Chemical process to extract oil from algae using dichloromethane. Source: FAO Agricultural Services Bulletin - 128



Cost Examples

Open pond:

Sonora Desert: It is estimated to cost at least **\$40K per hectare** to start an open pond algae system here. It then costs an additional **\$12K per hectare per year** to operate the farm. (A hectare is about 2.5 acres)

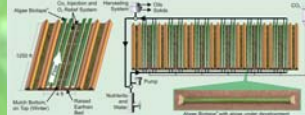


Fig. 10: The Simgae algae system. On the left is a single algae bed, and on the right is a 1 acre plot. Simgae looks to be one of the most promising bioreactors because of it's extremely profitable oil. Source: Simgae

Bioreactors:

AlgaeLink: Prices do not include equipment for extracting oil. The various-sized systems range in cost from **\$821K** for the one-ton-per-day model to **\$14M** for the 100-ton-per-day model.

Simgae: Initial costs are **\$45K - \$60K per acre** and maintenance costs are **\$12K - \$16K per acre**. Profitable oil can be sold to processors for **\$0.60 - \$0.90 per gallon**, which is one-third cheaper for buyers than traditional crops' products, making it significantly more attractive.

Competing Systems: Simgae estimates that systems with more rigid frameworks would have an initial cost of **\$100K - \$1M per acre**.

Is it worth it?

The US consumes 138 billion gallons of fuel (in diesel terms) each year and spends \$100-150 billion on crude oil imports. **What if we built an algae infrastructure to replace all the oil used for transportation?**

Using the numbers from the Sonora Desert:

- We'd need 3.85 million hectares (15,000 miles², or twice the size of New Jersey) of algae.
- Would cost between \$154 billion - \$308 billion to initially construct.
- Would cost \$46 billion per year in maintenance.

Costs over the following four years:

Year	\$ in billions for algae	\$ in billions for oil
1	354	150
2	400	300
3	446	450
4	492	600

Conclusions

While the initial start-up costs of an algae farm can be high, especially in colder climates, they still pay for themselves very quickly. What we need to do now is convince policy makers that laws should favor algae farms over other biodiesel crops, such as ethanol, and also convince investors that it's a safe bet for their money.

We are in the earliest stages of that now: the first commercial biodiesel plant (Simgae) is about to be built. Also, Boeing is investigating the use of algae for bio-jet fuels. An increasing number of people are being informed about the technology, and in order to make progress, we have to ensure that number keeps growing.

Fig. 11: A sample of algae oil to be analyzed. Different types of algae yield oils with different properties that can be used for even more than biodiesel.



For further information:

This poster was developed as an assignment for Honors 295, Fall 2007, Population, Environment, and Sustainability—Ethics for Living into the Future. References can be obtained by contacting the author.

•**Cost estimates:** Michael Briggs, UNH: http://www.unh.edu/p2/biodiesel/article_algae.html

•**Technical details of the algae oil production process:** FAO Agricultural Services Bulletin - 128: <http://www.fao.org/docrep/w7241e/w7241e0h.htm>

•**Simgae:** http://diversified-energy.com/index.cfm?s_webAction=simgae

•**AlgaeLink:** <http://www.algaeLink.com/>

•**General algae-into-oil info:** <http://www.oilgae.com/>