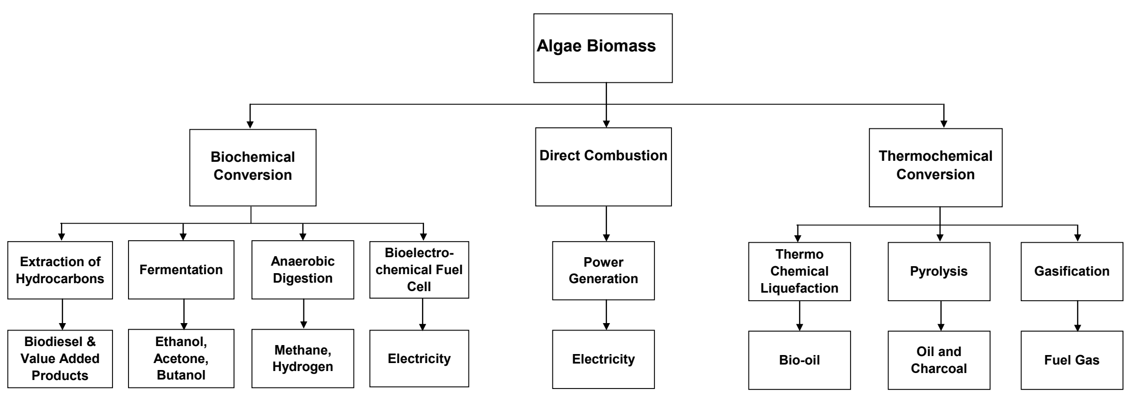
The Choice of Next-Generation Biofuels (Algae Excerpt)

The following is excerpted from Sam Kanes's industry report titled "The Choice of Next-Generation Biofuels," published January 2009.

ALGAE

Algae cultures are processed into lipids, also known as fatty acid methylesters (FAME), and residual biomass made up of plant fibres. Algae lipids are further processed into biodiesel while the residual biomass can be used in pharmaceuticals, biochar, or other applications. Algae biomass is a potential source of second-generation biofuel **that could surpass all others** due to its rapid growth and extremely high yield potential. Other traditional biofuel feedstock must be slowly grown or developed and can only be harvested at certain times of the year. **Algae can double in volume overnight** and can be continuously harvested on a daily basis. The production process mainly requires some sunlight or photo-bioreactor light, lots of carbon dioxide (CO_2) with some nitrogen, phosphorus, and other nutrient requirements. Algae can help produce biodiesel, ethanol, hydrogen, methanol, and biopower, along with other by-products used in the pharmaceutical industry and for bioplastics (Exhibit 1).

Exhibit 1: Algae Biomass Transformation to Energy



Source: DOE.

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Materials – Chemicals

For Reg AC Certification and important disclosures see Appendix A of this report.

Best by Far CO_2 Advantage

It takes 2 tonnes of CO_2 to produce 1 tonne of algae (1.7 tonnes net after processing) and 1 tonne of oxygen. This in turn can make approximately 3.5 barrels of biodiesel, assuming 50% oil-based algae content. According to NREL, the typical coal-fired power plant emits flue gas containing up to 13% CO_2, **which can be used** to enhance algae production. Certain acid oriented algae also consume hazardous NO_x and SO_x emissions. This has sparked **strong interest** from the coal-fired electric utilities and oil and gas companies. Once commercial, it could make algae growth **one of the world's largest industries as it addresses peak oil, climate change, food prices, soil depletion, and water shortages.**

There are currently 50 million tonnes of excess CO_2 emissions per day that are **not** absorbed by oceans or forests, growing at an alarming rate. Partial CO_2 capture and usage by algae facilities could lead to 10% of the total biodiesel demand of 100 million tonnes per year by 2020 being algae-based. In 2007, the total world production of algae biomass was only 10,000 tons. Almost half of algae production is from China, with most of the rest from Japan, Taiwan, United States, Australia, and India.

Numerous Algae Species

There are over 30,000 identified species of microalgae, with up to an estimated 1 million that are mostly unexplored for biofuel production. Researchers have categorized microalgae in a variety of classes based on their life cycle and basic cellular structure. The four most important classes are:

1. **Diatoms (Bacillariophyceae)**: This unicellular class of algae is mainly found in the oceans, but can also be found in fresh and brackish water. Its size varies from 5 micrometres to 5 millimetres so that up to 10 million algae bodies can be grown in only one millimetre of water (10% of water volume). There are approximately 100,000 species assumed to exist, with more than 400 new species discovered each year. Diatoms store carbon in the form of natural oils or as a polymer of carbohydrates known as chyrsolaminarin.

2. **Green Algae (Chlorophyceae)**: This type of algae is abundant mainly in fresh water and can occur as single cells or as colonies. Studies of this algae's production show that the maximum temperature for growth of common strains of green algae is 32°C. Green algae store carbon in the form of starch, although oils can be produced under certain conditions.

3. **Blue-green Algae (Cyanophyceae)**: This class of algae is closer to bacteria in structure and organization. It plays an important role in fixing nitrogen from the atmosphere. Blue-green algae can live in extreme temperatures (-60°C to 85°C) and can grow in full sunlight and in almost complete darkness. There are approximately 2,000 known species found in a variety of habitats, mostly freshwater-based.

4. **Golden Algae (Chrysophyceae)**: This type of algae is similar to the diatoms except they have more complex pigment systems. Golden algae can appear yellow, brown, or orange in colour. They are found primarily in freshwater systems and produce natural oils and carbohydrates as storage compounds. There are approximately 1,000 known species of this algae class.

A majority of the algae used in biofuel production tests to date fall into the first two classes. The four algae genomes listed above are the only ones that have been mapped. Each algae strain has particular characteristics that determine the type of fuel it could make. Strains high in fat are more suitable for biodiesel feedstock, while strains high in carbohydrates are more suitable for ethanol feedstock. Strains high in heat content would be more suitable for biopower, while strains high in nutrients are used for nutraceuticals, dyes, beta-kerotene, and health food.

Algae Growth

Exhibit 2: Parameters for Algae Growth and Production

What affects algae growth and oil production?

- Algae selected
- Light levels
- Temperature
- Water flow rates
- Carbon dioxide (CO_2)
- Macronutrients: carbon, nitrogen, phosphorus, magnesium, calcium, potassium, sodium, chloride
- Micronutrients (trace metals): iron, boron, zinc, manganese, molybdenum, copper, sulfate, cobalt, cadmium, vanadium, aluminum, nickel, chromium, bromine, iodine, tungsten, …
- Vitamins

Source: Global Green Solutions Inc.

The key factors that affect algae growth and metabolism are sunlight, CO_2, water, nutrients, and temperature. Cold temperatures and overcast weather will reduce algae's oil production potential. Other factors that need to be considered are what nutrients aid in cell wall production and cell division. Starving algae of their appropriate nutrients (sodium nitrate and potassium phosphate) at the appropriate time will reduce the rate of algae cell division but optimize the growth in the algae's oil percentage. Exhibit 2 (from Global Green Solutions Inc.) lists parameters for optimum algae growth and production.

Algae's CO_2 consumption and coincident oxygen emission occurs primarily during daylight hours and is dependent on proper light exposure within a certain band of the sun's spectrum. Its ability to consume nitrous oxides (NO_x) or other nitrogen sources occurs at all times of the day. Over a seven-day test period, a steady NO_x removal rate of 86% during both day and night was observed by one algae grower, but CO_2 removal varied from 50% on rainy days to 82% on sunny days.

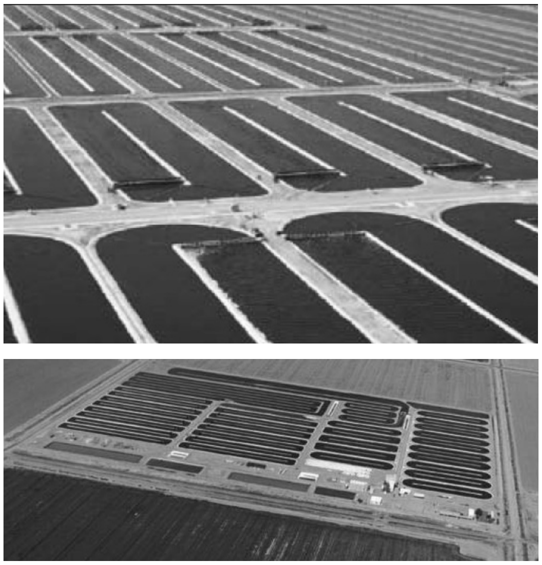
Algae are the most efficient converters of solar energy by a factor of 10 versus other plants and trees due to their simple cellular structure and surface water interface. The cells grow while suspended in water, **so they have more efficient access to dissolved CO_2 in water** and other nutrients. Therefore, according to the DOE, the typical oil yield for algae biomass should be about 15,000 litres of oil per hectare, which is **30 times annualized more oil per acre than soybean yields**.

Algae Production Systems

There are two main types of algae biomass production systems: open and closed. Open systems are typically set up as algae ponds or raceways shaped like horse racetracks, and closed systems are mainly in the form of closed tubular systems that can be horizontal, vertical, something in between pyramidical or in other shapes. Either production technique will result in algae oil being processed in the same way as soybean or palm oil is processed in biodiesel plants. **Therefore, no changes to the existing biodiesel infrastructure are required for algae oil.**

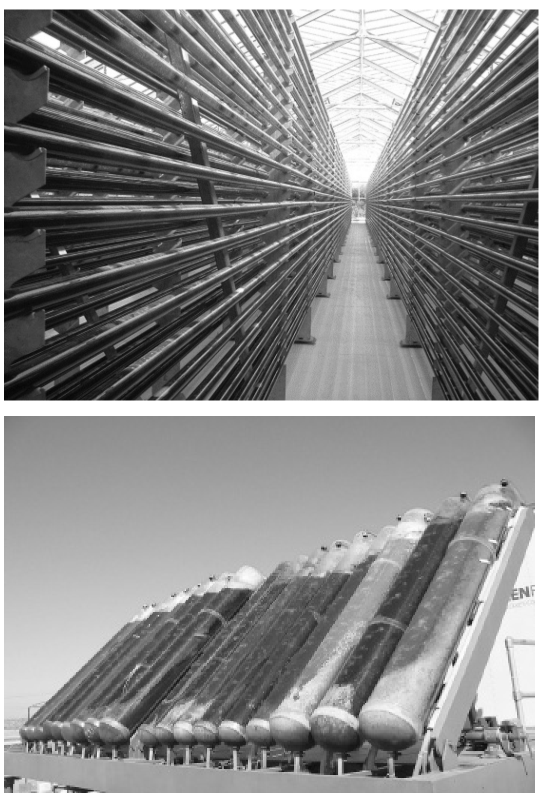
The algae harvesting process starts with dewatering the algae into a thick green paste. The paste is then processed through an extraction system (via centrifuge or other techniques) that splits the cells and separates the oil and water from the meal by-product. Typically, the process can retrieve 70% of the oil from algae cultures, with the additional use of an organic solvent like hexane taking the oil extraction level to 99%. The resulting oil-based feedstock is then shipped to a biodiesel processing plant, and the meal by-product can be sold as organic fertilizer, animal or fish food, or for other uses such as biopower feed.

Exhibit 3: Raceways



Source: Soley Institute.

Exhibit 4: Algae Tubular Systems



Source: CalPoly; DeSmet.

Algae Open Systems

The most common open algae systems are shallow raceways (Exhibit 3). Typically, these ponds are about 15-35 cm deep to ensure sufficient exposure to sunlight. Paddlewheels provide circular flow around the raceway, keeping the algae suspended in the water. Most are lined with plastic or cement, and are between 0.2 and 0.5 hectares in size. The ponds are continually fed with water and nutrients, while mature algae are continually removed at one end. The **productivity of raceways is almost 10 times higher than unmixed algae ponds**. Unmixed open systems are not true algae production ponds because production is not maximized and the biomass produced is rarely harvested. Even when the biomass from unmixed ponds is harvested, their chemical by-products interfere with utilization for biofuels.

Open ponds do have some limitations, including contamination that can cause salinity and pH imbalances, inhibiting algae growth. There are other limitations to algae growth in colder and hot, humid climates. Open systems can be easily scaled up to several acres for individual ponds, while open raceway ponds are much cheaper to build and operate compared to closed bioreactors. Currently, **98% of commercial algae is produced in open systems**. An NREL algae study concluded that the open pond design is the most economic choice for future development.

Algae Closed Systems

A closed algae system consists of photo-bioreactors with either small diameter (5 cm) plastic tubes (Exhibit 4) or larger diameter (greater than 10 cm) flexible bags. Other designs have been used in pilot scale, including flat plate reactors and hanging bag reactors.

Photo-bioreactors allow optimal sunlight to reach the algal cells either by allowing them to float in arrays of thin horizontal tubes or by directing light via a fibre optic matrix through the bioreactor chamber itself. Algae can grow in a bioreactor even in cold climates, but it takes energy to prevent the pipes and pumps from freezing, increasing operating costs. Another key photo-bioreactor advantage is that closed algae systems are not subject to contamination with airborne particles.

Disadvantages are that closed systems are much more expensive than open systems, with other operating challenges such as overheating and fouling. Also, due to gas exchange limitations, closed systems cannot be scaled up, so far, beyond about a hundred square metres for an individual growth unit. A large-scale closed production system would therefore require **thousands** of repeating units.

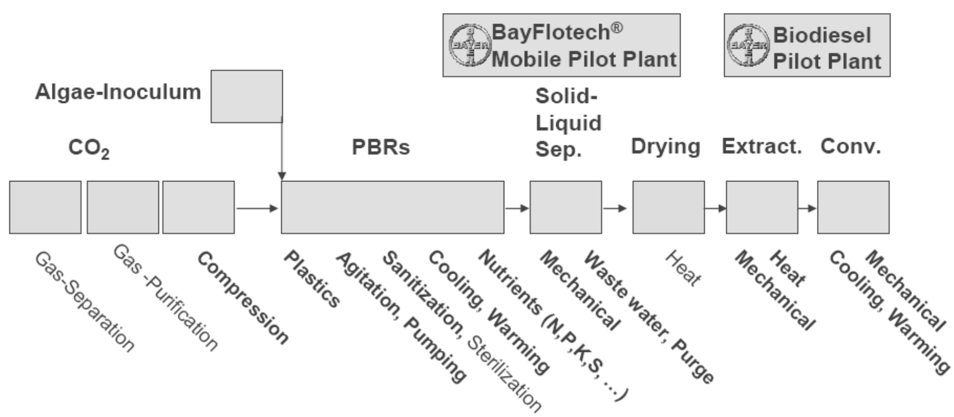
The optimal algae growth technology may wind up using both open and closed systems. First, a small bioreactor could be used to produce a modest amount of "inoculum" culture (approximately 1%-2% of total biomass). This can then be used to seed a much larger, 100-acre, open algae ponds.

Algae Cost Estimates

Successful algae production depends mainly on three parameters: (1) the availability, suitability, and cost of land used for the algae production facility, (2) the type of algae used for harvesting biomass with the highest oil content, and (3) the value of the algae by-products. Companies that choose the right algae species to use in production for their revenue streams are at an advantage over competition that chooses poorly. Some companies choose to focus on one strain of algae and perfect it, while others such as **Solazyme** and **PetroAlgae** are attempting to engineer desirable algae traits.

The energy demand of an algae facility is difficult to predict. Energy consumed must be subtracted from yield estimates, further reducing maximum affordable capital. Exhibit 5 outlines the energy demand of an algae facility.

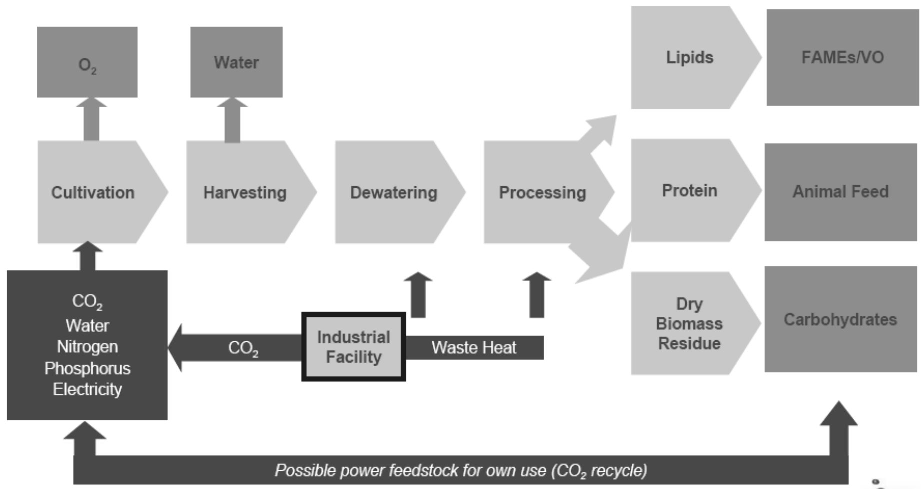
Exhibit 5: Energy Demand of an Algae Facility



Source: Bayer Technology Services.

According to estimates by Michael Briggs of the University of New Hampshire Biodiesel Group, construction costs for an open algae pond are approximately $80,000 per hectare and the operating costs (including power consumption, labour, chemicals, and fixed capital costs) are approximately $12,000 per hectare. Other industry cost estimates for open algae systems range from $50,000-$250,000 per hectare for capital costs and $15,000-$20,000 per hectare for operating costs. The capital cost estimates for closed algae bioreactors are about $1 million per hectare. Operating costs for bioreactors can be reduced by utilizing light-emitting diodes (LED) that use 92% less energy than incandescent bulbs.

Exhibit 6: Algae Production Process



Source: Cellana Group.

The algae production process is illustrated in Exhibit 6. Current algae production development research indicates that biological technologies would be a low-cost harvesting technique, but it has not been tested and confirmed on a large scale. Cost estimates for biological harvesting techniques range from $0.20 per gallon to $1.50 per gallon. Mechanical or chemical harvesting technologies are much more expensive, with cost estimates ranging from $3 per gallon to $50 per gallon. Other factors that increase algae production costs depend on which algae species is used in the system and the type of bioreactor used. In open systems, the main cost factor (15% of total cost) is from centrifuge operations. In closed systems, the main cost factor (46% of total cost) is from the circulation pumps.

Exhibit 7: Algae Operating Costs

Cost Component	Conventional ($/gal)
Algae growth	$15.00 – $20.00
Water and nutrient supply	$0.40 – $0.70
Carbon dioxide supply	$1.20 – $2.40
Harvesting	$0.80 – $1.60
Oil extraction	$1.50 – $2.60
Inoculation	$1.10 – $5.50
Algae oil subtotal	**$20.00 – $32.80**

Source: General Atomics.

Results from the NREL study indicate that algae oil production costs could range from $0.93 to $1.65 per gallon, not including biofuel tax incentives that could apply. Other total algae oil production cost estimates in the past range from $9 per gallon to $16 per gallon, based on research by John Benemann, up to a maximum of $20 per gallon to $33 per gallon based on research by General Atomics. Exhibit 7 breaks out the cost components for the production of algae. The algae growth component accounts for about 75% of the total production costs of algae. If existing algae projects can achieve biodiesel production price targets of less than $1 per gallon, the United States may realize its goal of replacing up to 20% of transport fuels by 2020 by using environmentally and economically sustainable fuels from algae production.

Algae Advantages Ex Cost

Algae biomass has **numerous advantages** as a potential wide-use biofuel because it addresses many of the issues that other biofuel sources face (food prices, soil depletion, and water shortages). Below is a comprehensive list outlining the positive aspects of algae biomass.

Exhibit 8: Agricultural Land Required for Algae

% of Agricultural Land Required to Fuel US Transportation	
CORN	1,700 %
SOYBEANS	650 %
CANOLA	240 %
JATROPHA	154 %
COCONUT	108 %
OIL PALM	50 %
MICROALGAE	2 – 5 %

Source: Virginia Coastal Energy Research Consortium.

- **Rapid growth rates:** Algae biofuel feedstock has the quickest time to harvest compared to other biofuel feedstock. For example, it takes five to seven years to harvest palm oil, three to five years to harvest jatropha, but after only two weeks of algae inoculation, one can harvest algae continuously. Certain species of algae can reach harvest size in **only 48 hours**.
- **Highest yield per hectare:** According to EESI, the typical yield for algae biomass should be approximately 15,000 litres of oil per hectare, 30 times more oil per acre than soybeans yield. Potential scientific estimates of up to 200,000 litres of oil per acre have been made, but no one has yet come close to that due to a variety of practical limitations.
- **Does not compete with food:** Algae for land use do **not** require arable land so they will not compete with food crops. It will qualify for the revised renewable energy standards issued in the United States and the EU. Its high yield per acre/hectare means that algae production requires the **least amount of land** compared to all other biofuel feedstocks such as soybean, palm oil, and jatropha. If only **2% of U.S. farmland was dedicated to algae, enough biodiesel could be produced to fulfill the entire annual U.S. oil demand** (Exhibit 8).
- **Best CO_2 Capture and Use (CCU):** Algae consume CO_2 as they grow by fixing the carbon molecule and emitting the oxygen molecules. The oxygen must be removed, as excess amounts can inhibit algae growth. This **leads to the potential for capturing CO_2 from fossil fuel power stations and other CO_2 emitting industrial plants that would otherwise be vented into the atmosphere**. Algae fuels will be carbon neutral at worst compared to other biofuel feedstocks that are not. Algae will become a CCU strategy versus many trying to store CO_2 underground (CCS).
- **Environmental Benefits:** Algae biofuel is non-toxic, highly biodegradable, and contains no sulphur, meaning it is a clean-burning, safe fuel for general use.
- **Cold Weather:** Algae have a very low cloud point, making algae oil **more ideal for winter use relative to any other biodiesel**.

Algae Challenges

There are still many economic and scientific challenges to overcome in the development of commercial algae biofuel. It still appears about five years away from commercialization. The key limiting factor when scaling up from the lab is land cost and availability, especially in open system processes. The optimal required land area for algae open systems is between 300 and 4,000 square metres. The algae facilities should also be located in climatic regions with annual temperatures greater than 15°C and near desert conditions with water access.

Project Development

From 1978 to 1996, the DOE carried out a program known as the Aquatic Species Program (ASP) to develop renewable fuels from algae. The ASP produced a collection of 300 species, mostly from the diatoms and green algae classes that are best suited for biofuels production. They are currently housed at the University of Hawaii for use by all humanity.

Canadian Algae Players

Trident Exploration Corp., a Canadian natural gas exploration company, and **Menova Energy Inc.**, a Canadian solar power company, have signed an agreement to form a company that will develop a new photo-bioreactor system to produce algae biomass by capturing and recycling CO_2 emissions from petroleum refineries. It will use existing sunlight capture technology developed by Menova with Trident's waste stream gas capture initiatives. The partners believe that the new system will permit an increase in the cumulative GHG emissions that can be captured and recycled year round within Canada's climate. Commercialization of the project is expected in 2012.

Exhibit 9: Valcent Products (VCTPF.OTC)

Source: Bloomberg.

Valcent Products, a Vancouver-based algae company, is developing algae cultivation technology to produce feedstocks for ethanol, biodiesel, and jet fuel. Its vertical crop technology uses only 5% of water required by conventional field crops and creates yields 10-20 times more than soybeans. Valcent is traded on the OTC, ticker: VCTPF (Exhibit 9).

U.S. Algae Players

Green Star Products Inc. completed a three-phase demonstration project using a 40,000-litre facility in Montana, one of the world's largest demonstration facilities. In November 2007, Green Star signed a contract with **Biotech Research Inc.** to build a 500-acre commercial algae facility in the U.S. Midwest. Construction began in the summer of 2008 on the facility, which will be adjacent to an existing biodiesel plant. It will use the CO_2 emitted from the biodiesel plant's boilers to feed a portion of the algae facility as needed. The algae oil produced at the facility will be turned into biodiesel through the existing biodiesel plant facilities. Green Star Products trades on the OTC, ticker: GSPI (Exhibit 10).

Exhibit 10: Green Star Products (GSPI.OTC)

Source: Bloomberg.

Algenol Biofuels has several algae test production facilities around the world yielding 6,000 gallons of ethanol per acre per year, rising to 10,000 gallons per acre per year by 2009. In a partnership with **BioFields**, Algenol is targeting its first large-scale ethanol production facility from algae biomass to be in production by late

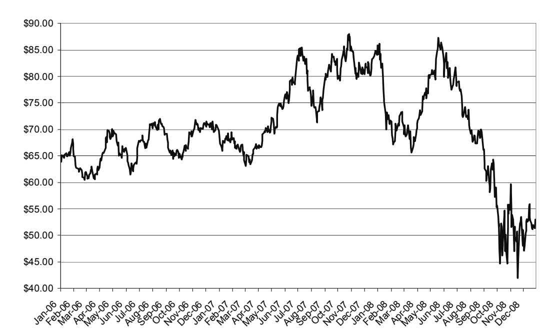
2009. The partnership will build an $850 million, 1 billion gallons per year industrial-scale ethanol facility in Mexico on 102,000 acres of desert near Cabo San Lucas. Algenol will fill each tank with sea water and use its patented algae in the process. As the algae grow, Algenol will funnel CO_2 from a nearby power plant into the tanks.

Sapphire Energy in June 2008 announced it has produced 91 octane gasoline from algae that meets ASTM certification and is compatible with existing petroleum infrastructure. The company said the product was made **solely from photosynthetic micro-organisms**, sunlight, and CO_2, was carbon neutral and was renewable. The company is still five years away from commercial development. It raised $100 million in February 2008 from investors including Bill Gates.

In December 2007, **Royal Dutch Shell** announced it will fund an algae project in Hawaii to be converted into biodiesel. In collaboration with **HR Biopetroleum**, a government-funded start-up on the Hawaiian island of Kona, Shell has formed a new company called **Cellana** that will build a 2.5-hectare algae demonstration facility. In addition, Shell will build a separate 1,000-hectare site to determine the economics when algae facilities are scaled up to a commercial level. If the results are positive, the company will build a 20,000-hectare site. Royal Dutch Shell trades on the NYSE, ticker: RDS/A (Exhibit 11).

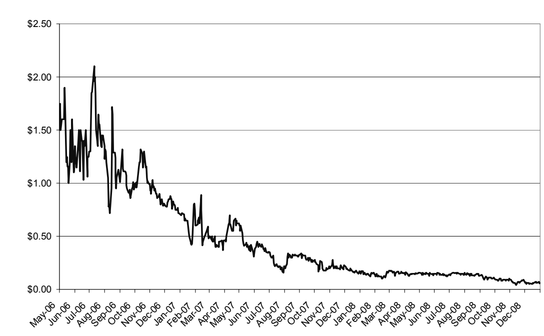
PetroSun Inc. started its algae operations in Texas on April 1, 2008. Its algae farm consists of 1,100 acres of saltwater ponds that the company estimates will produce a minimum of 4.4 million gallons of algal oil and 110 million pounds of biomass per year. PetroSun dedicated 20 acres of ponds for a proposed algae-derived jet fuel research and development program, from which it has since withdrawn. PetroSun's Bridgeport, Alabama, biorefinery will receive the algal oil feedstock from the Texas facility for processing. In September 2008, PetroSun announced an agreement with Shanghai Jun Ya Yan Technology Development Co., Ltd. to establish a commercial-scale algae farm pilot facility in China. The planned $40 million facility will produce algae biomass for conversion to biodiesel, ethanol, and other commercial products. PetroSun trades on the OTC, ticker: PSUD (Exhibit 12).

Exhibit 11: Royal Dutch Shell (RDS/A.NYSE)



Source: Bloomberg.

Exhibit 12: PetroSun Inc. (PSUD.OTC)



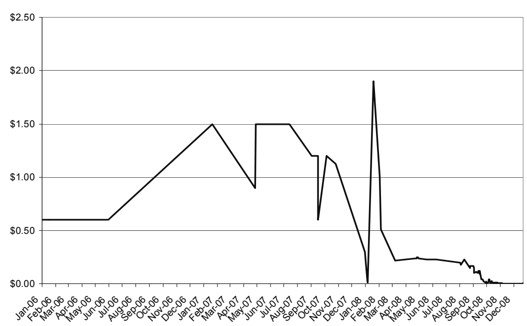
Source: Bloomberg.

In January 2008, **Solazyme Inc.** announced a partnership with Chevron Technology Ventures to explore the commercialization of algal fuel. The Solazyme process grows a special strain of algae in the dark, instead of the traditional photosynthetic process. The company's CEO, Harrison Dillon, claims that by growing them in the dark, algae are 1,000 times more efficient at producing oils compared with growth by sunlight. In February 2008, the company successfully tested all blends of algal biodiesel up to B100 using a Mercedes Benz C320.

In the first half of 2009, **PetroAlgae** will transition its current 20-acre pilot algae facility farm in Melbourne, Florida, into a commercial demonstration farm. Once the company finalizes the bioreactor systems, it will duplicate the small-scale commercial facility into larger units across North America. By the end of 2009, PetroAlgae hopes to make algae oil commercially. It is also working to build up licensees with 10,000 acres to develop, which could produce 100 million gallons of algae oil per year.

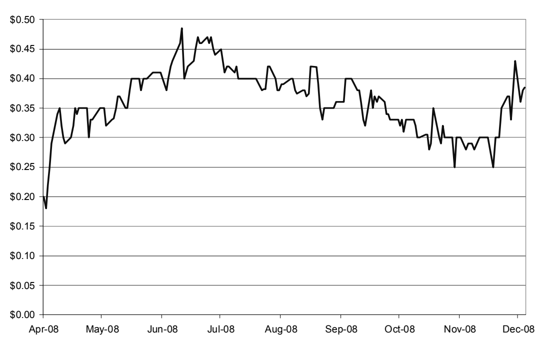
On November 11, 2008, **Solix Biofuels**, a Colorado-based alternative energy technology firm, announced it raised $10.5 million for an algae biofuel facility in Colorado, developed jointly by Solix and **Southern Ute Alternative Energy LLC**. The pilot plant will be located on a 10-acre site on the Southern Ute Indian Reservation in southwest Colorado. The first phase of the project will take 12-18 months and consist of four acres of photo-bioreactors for growing algae, as well as a lab facility. Upon completion of the pilot plant, Solix plans to build an additional five-acre expansion that will allow the pilot facility to produce at commercial scale. Solix's technology is forecast to achieve 30-100 times more yield than soybeans at 150,000 litres of algae oil per hectare per year.

Exhibit 13: BioCentric Energy Inc. (BEHL.OTC)



Source: Bloomberg.

Exhibit 14: OriginOil (OOIL.OTC)



Source: Bloomberg.

BioCentric Energy Inc. announced details of five algae projects that are scheduled to occur over the next three years. (1) BioCentric will partner with Southern Pacific Energy Inc. to deliver its CO_2 reduction and algae growth solution for biodiesel production in Lake Elsinore, California. (2) Through a joint venture, it will implement CO_2 reduction using algae growth at a coal-fired steel mill in China. (3) In Orange County, Texas, BioCentric will work with joint venture partner Petroleum Equipment Institute to implement a two-acre algae facility to produce biodiesel while absorbing CO_2 emissions. (4) In Peru, the company is organizing a farmer co-op to assist in planting, harvesting, sale, and delivery of organic biodiesel feedstock. (5) It will facilitate the sale and delivery of sister company BioCentric Consortium's organic oils, including rapeseed oil, for biodiesel production. BioCentric Energy Inc. is traded on the OTC, ticker: BEHL (Exhibit 13).

OriginOil is looking at several strains of algae that can produce biodiesel feedstock. It addresses typical algae problems that occur in both the growth and extraction stages. OriginOil's algae growth process occurs in its patented Helix BioReactor that achieves total distribution of nutrients to the algae for optimal growth rates. The company plans on shipping standardized containers full of algae, which customers can use to set up their own biofuel refineries. OriginOil is traded on the OTC, ticker: OOIL (Exhibit 14).

Notes

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Appendix A: Important Disclosures

Company	Ticker	Disclosures*
Agrium Inc.	AGU	H3, U
Methanex Corporation	MX	S
NOVA Chemicals Corporation	NCX	S
Potash Corporation of Saskatchewan, Inc.	POT	T

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High financial and/or operational risk, low predictability of financial results, high stock volatility.

Caution Warranted
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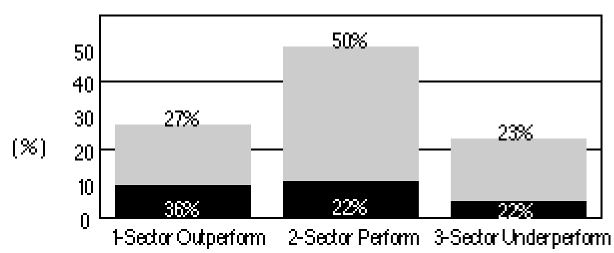

- Percentage of companies covered by Scotia Capital Equity Research within each rating category.
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* As at February 28, 2009.

Source: Scotia Capital.

For the purposes of the ratings distribution disclosure the NASD requires members who use a ratings system with terms different than "buy," "hold/neutral" and "sell," to equate their own ratings into these categories. Our 1-Sector Outperform, 2-Sector Perform, and 3-Sector Underperform ratings are based on the criteria above, but for this purpose could be equated to buy, neutral and sell ratings, respectively.

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