Use of algae as an energy source

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Presentation of algae

Classification

Algae are a large and diverse group of simple organisms that are typically autotrophic: it means that those organisms produce complex organic compounds from simple inorganic molecules using energy from light or inorganic chemical reactions.

Algae can be unicellular to multicellular. The largest and most complex marine forms are called seaweeds.

Algae can be classified in many different ways in accordance with classical classification or phylogenetic classification. Here are 2 examples of classification representation:

We can see here that green algae were classified in “plantae” with plants. Furthermore, we can see that “Cyanobacteria”, better known as “blue-green algae”, is classified in “Prokaryota”. Though cyanobacteria were traditionally included in algae in the past, many modern sources regard this as outdated and restrict the term “algae” to eukaryotic organisms. All true algae therefore have a nucleus enclosed within a membrane and chloroplasts bound in one or more membranes.

Furthermore, among algae, we distinguish microalgae from seaweeds. Cyanobacteria are microalgae but there are also a lot of microalgae “Eukaryota”.

Picture 2: Phylogenetic classification

Picture 3: Microalgae

Picture 4: Seaweed
Algae are photosynthetic, like plants, but they lack the various structures that characterize land plants such as leaves and roots.

Algae are a polyphyletic group, as they do not all descend from a common algal ancestor, although their chloroplasts seem to have a single origin.

Algae are photosynthetic, like plants, but they lack the various structures that characterize land plants such as leaves and roots.

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<td><img src="Image" alt="Algae Diagram" /></td>
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**Picture 5: The 3 main types of seaweed**

**Picture 6: Comparison of plant and algae**

Algae can be composed of a holdfast (like hapteron), stipes and lamina, such as the laminaria saccharina.

Algae use the holdfast to hold on to the rocks, to avoid being washed away by waves.
**Photosynthesis**

Algae, such as plants, are capable of photosynthesis. This is to produce oxygen and sugar from light, water and carbon dioxide.

![Photosynthesis diagram](image)

**Algaculture**

Algaculture concerns mainly microalgae. Seaweeds also have many commercial and industrial uses but due to their size and the specific requirements of the environment in which they need to grow, they don’t lend themselves as readily to cultivation.

![Open pond Spirulina farm](image)

Algae are cultivated for many uses as we will see in the next part.

**Growing factors**

To grow algae, many factors have to be taken into account and different algae have different requirements. Of course, there are 4 essential factors: water, light, carbon dioxide and minerals.
Moreover, the water has to be in a temperature range that will support the specific algal species being grown.

About the light, it must not be too strong or too weak. Algae only need one tenth the amount of light they receive from direct sunlight. Direct sunlight is often too strong for algae.

In most algal-cultivation systems, light only penetrates the top 8 to 10 cm of the water because as the algae grow and multiply, they become so dense that they block light from reaching deeper into the pond or tank. That is why algae growers use various methods to agitate the water in their ponds and to make algae circulating in the water: they can use paddle wheels or compressed air, introduced into the bottom of a pond.

Apart from agitation, another means of supplying light to algae is to place the light in the system: glow plates that means sheets of plastic or glass are then used and submerged into the pond or the tank, providing light directly to the algae at the right concentration.

Finally, nutrients must be controlled so algae will not be “starved” and nutrients will not be wasted.

**Growing methods**

Algae can be mainly cultured in open-ponds, such as raceway ponds and lakes, and in photo-bioreactors.

**Open-ponds**

Raceway ponds and lakes are open to the elements and so much more vulnerable to contamination by other microorganisms, such as invasive algal species or bacteria. Furthermore, there is no control over water temperature and lighting conditions. The growing season is largely dependent on location. Because of these factors, the number of species successfully cultivated in an open pond system for a specific purpose is relatively limited.

![Picture 9: Raceway ponds](image)

**Photo-bioreactors**

Algae can also be grown in a photo-bioreactor (PBR). A PBR is a close bioreactor which incorporates some type of light source. A variation on the basic open-pond system is to enclose it with a transparent or translucent barrier. Like this, a pond covered with a greenhouse could be considered as a PBR.
While those systems are usually smaller, for economic reasons, the problems raised previously are not presents here. Indeed, it allows more species to be grown, it allows the species that are being grown to stay dominant and it extends the growing season (only slightly if unheated and during all year if it is heated).

Because PBR systems are closed, all essential nutrients must be introduced into the system to allow algae to grow and be cultivated. It is possible to introduce a continuous stream of sterilized water containing nutrients, air and carbon dioxide. As algae grows, excess culture overflows and is harvested. If sufficient care is not taken, continuous bioreactors often collapse very quickly. However, once they are successfully started, they can continue operating for long periods.

An advantage of this type of algae culture is that algae produced has a higher nutrient content than the one produced in open ponds. It can be shown that the maximum productivity for a bio-reactor occurs when the “exchange rate” (time to exchange one volume of liquid) is equal to the “doubling time” (in mass or volume) of the algae.

There are many types of PRBs, including tanks provided with a light source, polyethylene bags or glass or plastics tubes.

**Harvest**

Algae can be harvested by centrifugation, flocculation or froth flotation. Alum and ferric chloride are chemical flocculants used to harvest algae. Water that is brackish or salty requires additional chemical flocculants to induce flocculation. Harvesting by chemical is a method that is often too expensive for large operations. However, interrupting the carbon dioxide supply to an algal system can cause algae to flocculate on its own, which is called “auto-flocculation”.

In froth flotation, the water and algae are aerated into froth and algae in then removed from the water.

Finally, ultrasound based method of algae harvesting are currently under development, like other additional methods.

**Usual uses**

**Fertilizer**

Algae are used by human in many ways: they are used as fertilizer, like seaweeds for centuries, soil conditioners and are a source of livestock feed.

For example, maerl is a deposit consisting of debris of seaweed rich in limestone, often mixed with sand and bits of shells. It forms extensive beds in suitable sub littoral sites and it is commonly used as a soil conditioner because of its important rate of calcium and magnesium. It is dredged from the sea floor
and crushed to form a powder. It is still harvested around the coasts of Brittany in France and Cornwall in Great Britain.

![Picture 11: Maerl](image)

**Nutrition**

Seaweeds are used a lot for food, especially in Asia. They are an excellent source of many vitamins and many nutrients like magnesium, calcium or potassium. In China, at least 70 species of algae are eaten as a Chinese vegetable and roughly 20 species of algae are used in everyday cooking in Japan.

Another example of edible algae is dulse (Palmaria palmata), a red alga which is dried and may be bought in the shops in Ireland. It is eaten raw, fresh, dried or cooked like spinach.

![Picture 12: Dulse](image)

Microalgae can also be cultivated to be used as a nutritional supplement, such as Chlorella and Dunaliella (green algae), which is high in beta-carotene and is used in vitamin C supplements. One of the most popular microalgae species is Spirulina, which is a Cyanobacterium also cultivated for its nutritional value, and which is sometimes nicknamed “superfood”.

![Picture 13: Nutritional supplement](image)
Finally, algae can be used as stabilizing substances or thickener in milk products (it reacts with the milk protein) such as ice cream, processed foods including lunch meat, beer or wine. Indeed, Chondrus crispus and tropical seaweeds of the genera Kappaphycus and Eucheuma are a source of “carrageen” which has a stabilizer and thickener power.

Carrageen and agar-agar are also used in Asia for gelatin-like deserts.

**Wastewater treatment**

Algae can also be used in wastewater treatment facilities, reducing the need for amounts of toxic chemicals products than are already used. It can also capture some fertilizer in runoff of farms and thus, reduce the pollution with surplus nitrogen or phosphorus.

![Picture 14: Sewage treatment using algae](image)

This system of sewage treatment is quite the same that the one used in Folkecenter. The waste water goes to different tanks, where the nutrient salts are absorbed by the algae and other microorganisms. The water then flows until the environment, free from the majority of pollutants.

**Other uses**

The natural pigments produced by algae can be used as an alternative to chemical dyes and coloring agents. Many of the paper products used today are not recyclable because of the chemical inks that are used and paper recyclers have found that inks made from algae are much easier to break down.

There is also much interest in the food industry into replacing the coloring agents that are currently used with coloring derived from algal pigments.

Algae can finally be used to make pharmaceutics or cosmetics (microalgae).

All these ways to use algae in life must be complemented by the use of algae as an energy source, studied more deeply in the next part.
Use of algae as an energy source

Biofuels production

Context

With the record oil price increases since 2003, competing demands between foods and other biofuel sources and the world food crisis, there is much interest in algaiculture for making biodiesel, bioethanol and many other biofuels.

One of the biggest advantages of biodiesel compared to many other alternative transportation fuels is that it can be used in existing diesel engines, which relieves manufacturers of having to make costly engine modifications. Biodiesel can also be mixed, at any ratio, with conventional petroleum diesel. As a result, the alternative fuel can be used in the current distribution infrastructure, replacing petroleum diesel either wholly, or as a diesel fuel blend with minimal integration costs.

Extensive research was conducted to determine the utilization of microalgae as an energy source, with applications being developed for production of biodiesel, bioethanol, and bioplastics.

Plants such as soybeans and sunflowers produce oil that can be used to make biofuel. Although these crops have received a lot of media attention in the last several years, they require intensive management and may not be sustainable in the long term due to rising development and production costs.

Furthermore, the fact remains that microalgae can outperform the current feedstocks utilized for conversion to biodiesel and ethanol, yet do not impact the consumable food markets or fresh water resources.

![Image](Image)

**Picture 15 : Cycle of biofuel produced by algae**

Presentation

Algae can be used to produce biofuel, called algae fuel, algal fuel or even third generation biofuel. Compared with second generation biofuels, algal fuels have a higher yield: they can produce 30 to 100 times more energy per hectare compared to terrestrial crops. To better realize, since the whole organism converts sunlight into oil, algae can produce more oil in an area the size of a two-car garage than an entire football field of soybeans.
However, biofuel from algae is quite expensive (it costs 5 to 10 $ per kg) and there are some active researches to reduce both capital and operating costs of production so that it could be commercially viable.

On an ecological point of view, algal fuels do not impact fresh water resources because algae can grow in ocean or even in waste water (which in fact is a good environment for algae because they can find nutrients). Moreover, biofuels are biodegradable and so relatively harmless to the environment if spilled, contrary to all other fuel types.

The United States Department of Energy estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require 40,000 square kilometers which a few thousand square miles larger than Maryland or 1.3 Belgium. This is less than 1/7th the area of corn harvested in the United States in 2000.

Oil extraction

Algae oil can be extracted through a wide variety of methods:

- The simplest method is **mechanical crushing**. Since different strains of algae vary widely in their physical attributes, various press configurations work better for specific algae types. Mechanical crushing is often used with chemicals.

- Using of **chemical solvents**: benzene, ether and hexane can be used to separate oil from algae. Hexane is widely used in the food industry and is relatively inexpensive. The inconvenient of this method is the danger involved in working with the chemicals. Care must be taken to avoid exposure to vapors and direct contact with the skin, either of which can cause serious damage (benzene is classified as carcinogen and chemicals are can explode easily).

- **Enzymatic extraction** uses enzymes to degrade the cell walls with water acting as a solvent and this makes fractionation of the oil much easier. The costs of this extraction process are estimated to be much greater than hexane extraction. The enzymatic extraction can be supported by ultrasonication: the combination of the two methods causes faster extraction and higher oil yields.

- **Ultrasonic-assisted extraction** can greatly accelerate extraction process. Using an ultrasonic reactor, ultrasonic waves are used to create cavitation bubbles in a solvent material and when these bubbles collapse near the cell walls, it creates shock waves and liquid jets that cause those cells walls to break and release their content into the solvent.
The cost to extract oil from microalgae varies depending on the method used but is around 1.80 $ per kg (compared to 0.50 $ per kg for palm oil).

- Using of an oil press: when algae are dried, it retains its oil content, which then can be “pressed” out with an oil press. Many commercial manufacturers of vegetable oil use a combination of mechanical pressing and chemical solvents in extracting oil.

- Osmotic shock is a sudden reduction in osmotic pressure. It is sometimes used to release cellular components, such as oil.

- Finally, in supercritical fluid (= CO₂ extraction), CO₂ is liquefied under pressure and heated to the point that it has the properties of both a liquid and a gas. This liquefied fluid then acts as the solvent in extracting the oil.

Other methods are still being developed, including ones to extract specific types of oils.
Types of biofuel produced

Algae can be used to produce many types of biofuels. Among them:

- Biodiesel, by transesterification of algal oil. Transesterification means that a reaction is made between algal oil and alcohol.
- Bioethanol (C₂H₆O) by fermentation and distillation of sugars
- Biobutanol (C₄H₁₀O), which can be produced from the green waste left over from the oil extraction.
- SVO (Straight Vegetable Oil), which is algal oil directly used as a fuel. It requires modifications to a normal diesel engine.

Algal Biomass Organization

First, the Algal Biomass Organization (ABO) is a not-for-profit organization dedicated to the advancement through research and education of the field of algal biomass production technologies. The ABO promotes the development of viable commercial markets for renewable and sustainable commodities derived from algae and has 4 “platinum members”.

The different purposes of the Algal Biomass Organization are to:

- Facilitate commercialization and market development of microalgae biomasses, specifically for biofuels production
- Deliver information to the public on initiatives, funding opportunities and industry development
- Provide networking and collaboration opportunities
- Develop a high quality interactive repository of information on algae biomass technology, science, products, processes, economics...

Algal fuel producers

The majority of algal fuel producers are in the USA, where we can find at least 25 producers.

Just for information, here is a list (non-exhaustive) of some producers in the USA:

- Algae Floating Systems, Inc
- AlgaeFuel (California)
- Algae Fuel System (California)
- AlgalOilDiesel, LLP (Oregon)
- Algoil Industries, Inc
- Cellana (Shell & HR BioPetroleum)
- Chevron Corporation (in collaboration with US-DOE NREL)
- Diversified Energy Corporation
• Global Green Solutions
• GreenFuel Technologies Corporation
• PetroSun (Arizona)
• Sapphire Energy (financed by Bill Gates)
• Solix Biofuels (Colorado)
• Valcent (Texas)

Furthermore, we can find some other producers all around the world. For example:

• In Canada: Algae Fuel Systems and International Energy, Inc
• In Spain: Bio Fuel Systems
• In The Netherlands: AlgaeLink
• In New Zealand: Aquaflow Bionomic Corporation (ABC)

Examples

PetroSun

The first algae biofuel plant which had been realized is a plant of PetroSun, a diversified energy company specializing in the discovery and development of both traditional fossil fuels and renewable energy resources. PetroSun has initiated this project of algae-to-biofuel facility on April, 2008, through PetroSun Biofuels, a wholly owned subsidiary of PetroSun.

The facility, located in Rio Hondo Texas, is to use microalgae to produce biofuel. The estimated production will be about 16.7 million liters of algal oil and 50 millions kilograms per year, produced on saltwater ponds spanning 445 hectares (94 ponds of 2 hectares and 63 ponds of 10 hectares). 8 hectares will be reserved for research and development about experimental production of a renewable jet-fuel.

The company will extract the algal oil on-site and transport the raw product via barge, rail or truck to company owned or joint ventured biodiesel refineries. The residual algae biomass will be converted into ethanol or other products.

PetroSun has chosen to work on microalgae to produce biofuel because of many reasons:

• It can produce 30 times more oil per hectare than corn and soybean crops
• The production can be made on marginal land or in brackish water
• Biodiesel produced from algae contain no sulfur, is non-toxic and highly biodegradable
• The biomass left-over from oil-pressing can be fed to cattle as a protein supplement or fermented into ethanol
Furthermore, PetroSun seems to have figure out the major problems about microalgae that are the difficulties to collect and press the algae and also to prevent contamination by invasive species in the case of open pounds.

"Our business model has been focused on proving the commercial feasibility of the firms' algae-to-biofuels technology during the past eighteen months," stated Gordon LeBlanc Jr, Chief Executive Officer of PetroSun. "Whether we have arrived at this point in time by a superior technological approach, sheer luck or a redneck can-do attitude, the fact remains that microalgae can outperform the current feedstocks utilized for conversion to biodiesel and ethanol, yet do not impact the consumable food markets or fresh water resources."

The Rio Hondo algae farm will be expanded in the future to provide the feedstock required by present or proposed company owned or joint ventured biodiesel and ethanol refineries.

The Company plans to construct or acquire additional plants in the Gulf Coast region that are reachable via barge up the Mississippi River and its tributaries including the Red River. Bridgeport, Alabama refinery will receive algal oil feedstock from this distribution program.

PetroSun is also engaged in Australia: negotiations to establish a commercial scale algae farm system in New South Wales, Australia are ongoing. The company will produce algae and extract the algal oil as a biofuel feedstock. A local refiner will process the algal oil into biodiesel for the regional marketplace. PetroSun and Icon Energy are also negotiating a new agreement that would create a joint venture between the parties for the development of an algae-to-biofuels commercial farm system in Queensland, Australia.

As you can see, PetroSun is developing very fast its activity in the production of biodiesel from algae. I therefore advise you to consult their website and especially the news at: http://www.petrosuninc.com/in-the-news.html.

Valcent

Valcent Products Inc. is a US public traded company with offices in Vancouver and El Paso, Texas. Valcent Products Inc. researches and develops life enhancing industrial, commercial and consumer products and processes that have mass consumer appeal.

Vertigo Energy is a joint venture established with Global Green Solutions Inc. to market world wide Valcent’s patent-pending Vertigo bioreactor technology developed to provide a profitable and viable renewable energy resource which is algae and to reduce greenhouse gas emissions.

Like this, Vertigo is a High Density Vertical Bioreactor (HDVB) where microalgae are mass grown to collect oil to produce biofuels.

Valcent has commissioned the world’s first commercial-scale bioreactor pilot project at its test facility in El Paso, Texas.

The Vertigo bioreactor can be developed on non-arable land. It requires very little water due to its closed circuit process. Apparently, it doesn’t incur significant labor costs and it doesn’t employ fossil fuel burning equipment.

The HDVB technology was developed by Valcent in recognition and response to a huge unsatisfied demand for vegetable oil feedstock by biodiesel refineries and marketers.
AlgaeLink, in Nethelands, design, build, own, operate and market Algae growing plants and AlgaeLink algae photo-bioreactors.

They sell pilot plants with a production of 2 to 4 kg dry biomass per day which includes:
- 36 meters of transparent synthetic tubes (diameter : 300 mm, volume : 3.5 m³)
- All pumps and valves
- Feeding tanks
- Sensors
- Computer with AlgaeLink’s monitoring software

This pilot plant costs 69,000 € and is made for firms or people who want to test some algae strains, to test the algae growing conditions in their area, to learn how to collect, dry and press oil out of the algae...

This installation just requires an area of 50 m², 10 kg of carbon dioxide per day and some nutrients for algae (Ca, Cu, Fe, Mg, Mn, Mo, K and Zn).
Biohydrogen production

Introduction

To introduce this part, we have to notice that hydrogen gas is the most efficient and cleanest burning fuel known to man. Currently, hydrogen is produced from many sources of energy, including fossil fuels such as natural gas and coal, via industrial processes including coal gasification and steam reforming. Both currently used industrial hydrogen production processes require high energy inputs, and are accompanied with the release of greenhouse gases and other noxious byproducts, such as carbon monoxide.

Renewable energy resources, such as solar radiation, wind and biomass, can also be utilized to produce hydrogen gas either via electrolysis or other reforming processes.

As I said, hydrogen gas has the highest energy content per unit of weight: 120 MJ/kg, against 40 MJ/kg for oil.

![](image)

**Picture 23 : Heating value of hydrogen**

Biohydrogen is hydrogen gas generated with the help of biological organisms. Microorganisms such as algae and bacteria generate hydrogen gas at ambient temperatures, in contrast to high-temperature industrial production.

History

Algae can be grown to produce biohydrogen. Indeed, in 1939, Hans Gaffron, a German researcher, observed that the algae he was studying, *Chlamydomonas reinhardtii* (a single-cell green algae), would sometimes switch from the production of oxygen to the production of hydrogen. Gaffron never discovered the cause for this change and it’s only in 1997 that a professor from the University of California at Berkeley, Anastasios Melis, discovered that if the algae culture medium is deprived of...
sulfur, it will switch from the production of oxygen (normal photosynthesis) to the production of hydrogen.

He found that the enzyme responsible for this reaction is hydrogenase and that this enzyme loses this function in the presence of oxygen. Furthermore, depleting the amount of sulfur available to the algae interrupt its internal oxygen flow, allowing the hydrogenase an environment in which it can react and causing the algae to produce hydrogen.

*Chlamydomonas moewusii* is also a good strain for the production of hydrogen. Scientists at the US department of Energy’s Argonne National Laboratory are currently trying to find a way to take the part of the hydrogenase enzyme that creates the hydrogen gas and introduce it into the photosynthesis process. The result would be a large amount of hydrogen, perhaps about the same amount of oxygen created.

Chlamydomonas’s size is about 10 micrometers. This alga has two flagellums and that is why it is sometimes nicknamed “the animal algae”.

**Picture 24 : Chlamydomonas reinhardtii**

**Picture 25 : Structure of Chlamydomonas**

**Principle**

Biohydrogen from algae is produced in a bioreactor which respects the conditions necessary to the production of hydrogen by algae.

A lot of issues related to bioreactors design appeared and are gradually solved through bioengineering:

- Restriction of photosynthetic hydrogen production by accumulation of proton gradient.
- Competitive inhibition of photosynthetic hydrogen production by carbon dioxide.
- Competitive drainage of electrons by oxygen in algal hydrogen production.
- Requirement for bicarbonate binding at photosystem II for efficiency photosynthetic activity.
Use of algae as an energy source

Photosystem II is the first protein complex in Light Dependent Photosynthesis. It is a combination of pigments and chlorophyll in chloroplasts of a plant or algae cell. The photosystem uses photons of light to energize electrons.

To be economically feasible, the production of hydrogen from algae should reach energy efficiency (conversion of sunlight into hydrogen) of 7 to 10 %. Now, in their natural forms, algae achieve at most a meager 0.1 %.

Like this, some researches were undertaken and are still underway to improve this rate.

Research

In 2006, researchers from the University of Bielefeld and the University of Queensland have genetically changed the *Chlamydomonas reinhardtii* in such a way that it produces an especially large amount of hydrogen. The product, the Stm6, can, in the long run, produce five times the volume made by the wild form of alga and up to 1.6 to 2 % energy efficiency. By shortening the chlorophyll stacks in the photosynthetic organelles, Anastasios Melis has “probably” passed the threshold of 10 % of efficiency.

Furthermore, at the University of Karlsruhe, a prototype of a bioreactor containing 500 to 1000 liters of algae cultures is being developed. The reactor is to be used to prove the economic feasibility of the system in the next five years.

In 2007, Anastasios Melis has apparently achieved an efficiency of 15 %.

Furthermore, it was discovered that if copper is added to its environment, algae will switch from the production of oxygen to hydrogen.

Addition of copper

Now, a team of biologists including Raymond Surzycki and Jean-David Rochaix from the University of Geneva, and Laurent Cournac and Gilles Peltier, both from the Atomic Energy Commission, the National Center for Scientific Research and the Mediterranean University, have demonstrated a new method for hydrogen production by algae. The team presented a **method using copper to block oxygen generation** in the cells of *Chlamydomonas reinhardtii* that could lead to a consistent cycle of hydrogen production.

In order to induce hydrogen production in the algae, cells must be placed in an environment without oxygen but with access to light. To completely deplete the algae’s oxygen supply, the researchers turned off part of a chloroplast gene required for oxygen evolution by adding copper to the cells in an enclosed
chamber. Specifically, the addition of copper turned off the Cyc6 promoter, which drives the Nac2 gene, which is required for photosystem II synthesis (PSII generates oxygen).

Within about three hours, nearly all the oxygen was consumed by respiration, and the algae reached an anaerobic state. **Without oxygen, the algae began to synthesize hydrogenase and then produce hydrogen.**

Hydrogenase can be produced only on anaerobic conditions because oxygen is highly toxic to the hydrogenases.

![Picture 27: Behavior of algae without copper](image-url)

![Picture 28: Behavior of algae with copper](image-url)

One of the most significant differences between this method and earlier methods is **using copper addition rather than sulfur depletion** to repress photosynthetic activity. In past experiments, when the cells’ sulfur was depleted, the cells stopped growing and died after a few days. However, when adding copper, the biologists observed that the cells remained healthy. The rate of hydrogen production in the plants with copper was slightly lower than that of sulfur-depleted plants, but comparable.

The scientists also observed that, in healthy cells, the Cyc6 promoter doesn’t stay repressed for long due to “anaerobiosis”—the ability of the cells to survive (and repair) with lack of oxygen. Subsequently, PSII activity is restored, and the cell returns to producing oxygen. However, as the scientists point out, this
apparent limitation may turn out to be an advantage, since the procedure could be repeated over and over again. Through the alternate expression and repression of the Nac2 gene, the researchers have opened up the possibility of establishing a cycling hydrogen producing system.

Several laboratories are making efforts along research lines as:

- Establishing a cycling system in which photosynthesis generates reducing power with starch, which could subsequently be used to feed the hydrogenase once anaerobiosis has been achieved.
- Modifying the hydrogenase by genetic engineering to make it more tolerant toward oxygen

**Interesting figures**

It would take an algae farm the size of the state of Texas to produce enough hydrogen to supply the energy needs of the whole world. It would take about 25 000 square kilometers to be sufficient to replace gasoline in the US: this is less than a tenth of the area devoted to growing soya in the US and equal the size of the state of Vermont.

**Application**

Algae can produce hydrogen that could be used by fuel cells to generate electricity, without expensive process like electrolysis required for splitting water into hydrogen and oxygen.

![Fuel cell](https://example.com/fuel-cell.png)

**Picture 29 : Fuel cell**

A good conclusion for this part would be these quotations from Jean-David Rochaix:

“We are still at a very early stage; we need more basic research for understanding the complex regulation of photosynthesis, respiration and starch metabolism for establishing a more efficient system.”

“The final challenge will be to produce bioreactors in which large amounts of algae can be grown with efficient hydrogen production,” he said. “It is too early to say whether we will be successful, but it is clearly important to undertake research on this problem given its great potential impact for clean energy production.”
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Illustration sources

**Picture 2:**  [http://4e.plantphys.net/article.php?ch=1&id=399](http://4e.plantphys.net/article.php?ch=1&id=399)

**Picture 3:**  [http://www.igb.fraunhofer.de/WWW/Presse/bilder/Download.bis2000/IGB_Alge2.jpg](http://www.igb.fraunhofer.de/WWW/Presse/bilder/Download.bis2000/IGB_Alge2.jpg)


**Picture 6:**  [http://library.thingquest.org/3715/plant1.gif](http://library.thingquest.org/3715/plant1.gif)

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**Picture 7:**  [http://www.geodigm.com/e_img/img_0401_01.gif](http://www.geodigm.com/e_img/img_0401_01.gif)

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**Picture 12:**  [http://www.wholefoodsmarket.com/recipes/images/seaveg_dulse.jpg](http://www.wholefoodsmarket.com/recipes/images/seaveg_dulse.jpg)

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**Picture 14:**  Tina’s Power Point

**Picture 15:**  [http://enviro-energie.blogspot.com/2008/01/biocarburants-partir-dalgues-farce-ou.html](http://enviro-energie.blogspot.com/2008/01/biocarburants-partir-dalgues-farce-ou.html)

**Picture 16:**  [http://www.mapofworld.com/usa/states/maryland/maryland-location-map.html](http://www.mapofworld.com/usa/states/maryland/maryland-location-map.html)


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