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A RENEWABLE BIO-DIESEL FROM MICRO-ALGAE (A FUTURE'S NEED)

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ABSTRACT

Biodiesels (fatty acid methyl esters) derived from oleaginous microbes (microalgae, yeast, and bacteria) are being actively pursued as potential renewable substitutes for petroleum diesel. Continued use of petroleum sourced fuels is now widely recognized as unsustainable because of depleting supplies and the contribution of these fuels to the accumulation of carbon dioxide in the environment. Renewable, carbon neutral, transport fuels are necessary for environmental and economic sustainability. Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels. Unfortunately, biodiesel from oil crops, waste cooking oil and animal fat cannot realistically satisfy even a small fraction of the existing demand for transport fuels. As demonstrated here, microalgae appear to be the only source of renewable biodiesel that is capable of meeting the global demand for transport fuels. Like plants, microalgae use sunlight to produce oils but they do so more efficiently than crop plants. Oil productivity of many microalgae greatly exceeds the oil productivity of the best producing oil crops. Approaches for making micro-algal biodiesel economically competitive with petro-diesel are discussed.

Keywords: Bio-diesel, Microbes, Oil Crops, Micro-algae.

INTRODUCTION

Algae have recently received a lot of attention as a new biomass source for the production of renewable energy. Some of the main characteristics which set algae apart from other biomass sources are that algae (can) have a high biomass yield per unit of light and area, can have a high oil or starch content, do not require agricultural land, fresh water is not essential and nutrients can be supplied by waste water and CO2 by combustion gas. The first distinction that needs to be made is between macro-algae (or sea-weed) versus microalgae. Microalgae have many different species with widely varying compositions and live as single cells or colonies without any specialization. Although this makes their cultivation easier and more controllable, their small size makes subsequent harvesting more complicated. Macro-algae are less versatile, there are far fewer options of species to cultivate and there is only one main viable technology for producing renewable energy: anaerobic digestion to produce biogas. Microalgae are sunlight-driven cell factories that convert carbon dioxide to potential bio fuels, foods, feeds and high-value bio actives. Micro-algae can provide several different types of renewable bio fuels. These include methane produced byan aerobic digestion of the algal biomass biodiesel derived from micro algal oil and photo biologically produced bio hydrogen. The idea of using micro-algae as a source of fuel is not new, but it is now being taken seriously because of the escalating price of petroleum and, more significantly, the emerging concern about global warming that is associated with burning fossil fuels. Biodiesel is produced currently from plant and animal oils, but not from microalgae. This is likely to change as several companies are attempting to commercialize micro-algal biodiesel. Biodiesel is a proven fuel. Technology for producing and using biodiesel has been known for more than 50 years. In the United States, biodiesel is produced mainly from soybeans. Other sources of commercial biodiesel include canola oil, animal fat, palm oil, corn oil, waste cooking oil.

Algae fuel or Algal bio-fuel is an alternative to fossil fuel that uses algae as its source of natural deposits. Several companies and government agencies are funding efforts to reduce capital and operating costs and make algae fuel production commercially viable. Harvested algae, like fossil fuel, release CO_2 when burnt but unlike fossil fuel the CO_2 is taken out of the atmosphere by the growing of algae and other bio-fuel sources, and the world food crisis, have ignited interest in alga culture (farming algae) for making vegetable oil, biodiesel, bio-ethanol, bio-gasoline, bio-methanol, bio-butanol and other bio-fuels, using land that is not suitable for agriculture. Among algal

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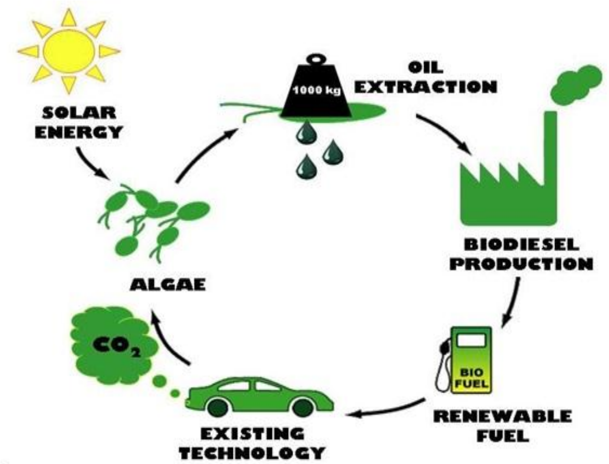
fuels' attractive characteristics: they can be grown with minimal impact on fresh water resources, can be produced using ocean and wastewater, and are biodegradable and relatively harmless to the environment if spilled. Algae cost more per unit mass (as of 2010, food grade algae costs ~$5000/tonne), due to high capital and operating costs, yet are claimed to yield between 10 and 100 times more fuel per unit area than other second-generation bio-fuel crops. The United States Department of Energy estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require 15,000 square miles (39,000 km^2) which is only 0.42% of the U.S. map, or about half of the land area of Maine. This is less than 1⁄7 the area of corn harvested in the United States in 2000.[11] However, these claims remain unrealized commercially. According to the head of the Algal Biomass Organization algae fuel can reach price parity with oil in 2018 if granted production tax credits.



BIODIESEL

The U.S. Department of Energy's Aquatic Species Program, 1978–1996, focused on biodiesel from microalgae. The final report suggested that biodiesel could be the only viable method by which to produce enough fuel to replace current world diesel usage. If algae-derived biodiesel were to replace the annual global production of 1.1bn tons of conventional diesel then a land mass of 57.3 million hectares would be required, which would be highly favorable compared to other bio-fuels. As they do not have to produce structural compounds such as cellulose for leaves, stems, or roots, and because they can be grown floating in a rich nutritional medium, micro-algae can have faster growth rates than terrestrial crops. Also, they can convert a much higher fraction of their biomass to oil than conventional crops, e.g. 60% versus 2-3% for soybeans. The per unit area yield of oil from algae is estimated to be from between 1,000 to 6,500 US gallons per acre per year (4,700 to 18,000 $m^3/km^2 \cdot a$). This is 7 to 30 times greater than the next best crop, Chinese tallow (700 US gal/acre or 650 $m^3/km^2 \cdot a$). Studies show that some species of algae can produce up to 60% of their dry weight in the form of oil. Because the cells grow in aqueous suspension, where they have more efficient access to water, CO_2 and dissolved nutrients, microalgae are capable of producing large amounts of biomass and usable oil in either high rate algal ponds or photo bioreactors. This oil can then be turned into biodiesel which could be sold for use in automobiles. Regional production of microalgae and processing into bio-fuels will provide economic benefits to rural communities.

ALGAE CULTIVATION

Algae can produce up to 300 times more oil per acre than conventional crops such as rapeseed, palms, and soybeans. As algae have a harvesting cycle of 1–10 days, their cultivation permits several harvests in a very short time-frame, a strategy differing from that associated with yearly crops. Algae can grow on land unsuitable for other established crops, for instance: arid land, land with excessively saline soil, and drought-stricken land. This minimizes the issue of taking away pieces of land from the cultivation of food crops Algae can grow 20 to 30 times faster than food crops.

Photo Bio-Reactors

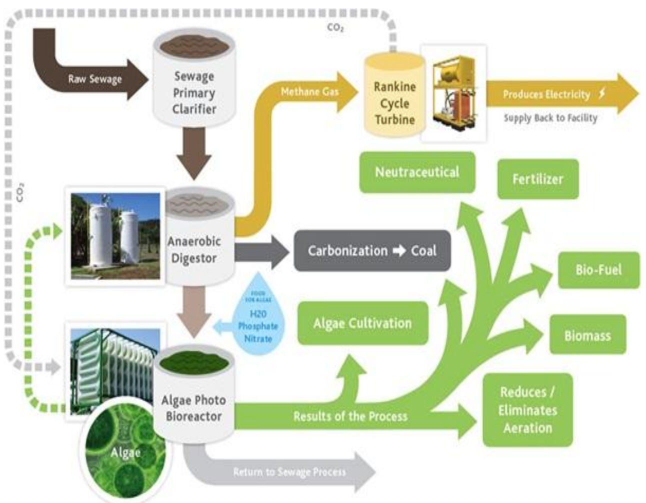
Most companies pursuing algae as a source of bio-fuels pump nutrient-rich water through plastic or borosilicate glass tubes (called "bioreactors") that are exposed to sunlight (and so-called photo bioreactors or PBR).Running a PBR is more difficult than using an open pond, and more costly, but may provide a higher level of control and productivity. Algae farms can also operate on marginal lands, such as in desert areas where the groundwater is saline, rather than utilizing fresh water. Algae can also grow on the surface of the ocean. Because algae strains with lower lipid content may grow as much as 30 times faster than those with high lipid content, the challenges in efficient biodiesel production from algae lie in finding an algal strain with a combination of high lipid-content and fast growth-rate, not too difficult to harvest; and with a cost-effective cultivation system (i.e., type of photo bioreactor) best suited to that strain. There is also a need to provide concentrated CO_2 to increase the rate of production.

Closed-Loop System

The lack of equipment and structures needed to begin growing algae in large quantities has inhibited widespread mass-production of algae for bio-fuel production. Maximum use of existing agriculture processes and hardware is the goal. Closed systems (not exposed to open air) avoid the problem of contamination by other organisms blown in by the air. The problem for a closed system is finding a cheap source of sterile CO_2. Several experimenters have found the CO_2 from a smokestack works well for growing algae. For reasons of economy, some experts think that algae farming for bio-fuels will have to be done as part of cogeneration, where it can make use of waste heat and help soak up pollution.

Open-Pond System

Open-pond systems for the most part have been given up for the cultivation of algae with high-oil content. Many believe that a major flaw of the Aquatic Species Program was the decision to focus their efforts exclusively on open-ponds; this makes the entire effort dependent upon the hardiness of the strain chosen, requiring it to be unnecessarily resilient in order to withstand wide swings in temperature and pH, and competition from invasive algae and bacteria. Open systems using a monoculture are also vulnerable to viral infection. The energy that a high-oil strain invests into the production of oil is energy that is not invested into the production of proteins or carbohydrates, usually resulting in the species being less hardy, or having a slower growth rate. Algal species with a lower oil content, not having to divert their energies away from growth, have an easier time in the harsher conditions of an open system.



Alternative Applications

Algae used as a source of bio-fuels are a relatively newly discovered use, but algae have been used in numerous other applications for many years. The other components in algae, including carbohydrates, natural dyes and pigments, antioxidants and other bio-active compounds, can all be used in various processes ranging from the industrial to pharmaceutical sectors. Many of the byproducts produced in the processing of microalgae can be used in various applications. Some of the products not used in the production of bio-fuel include natural dyes and pigments, antioxidants, and other high-value bio-active compounds. These chemicals and excess biomass have found numerous use in other industries. For example, the dyes and oils have found a place in cosmetics, commonly as a thickening and water-binding agent. Due to its vitamin rich nature, algae conditions and hydrates the skin while it nourishes, rejuvenates, and detoxifies. Two common algal species in use are Irish moss and carrageenan which contain proteins, vitamin A, sugar, starch, vitamin B1, iron, sodium, phosphorous, magnesium, copper and calcium. These are all useful as sources for skin care, either as emollients or antioxidants.[93] Discoveries within the pharmaceutical industry include certain antibiotics and anti fungals that have been derived from microalgae. They have also been used in natural health products, which have been growing in popularity in the past few decades. The cyano bacteria microalgae Spirulina, provides numerous polyunsaturated fats (Omega 3 and 6), amino acids and vitamins,[94] as well as pigments that may be beneficial, such as beta-carotene and chlorophyll.

ADVANTAGES

- **Ease of Growth**

One of the main advantages that using microalgae as the feedstock when compared to more traditional crops is that it can be grown much more easily. Algae can be grown in land that would not be considered suitable for the growth of the regularly used crops. In addition to this, wastewater that would normally hinder plant growth has been shown to be very effective in growing algae. Because of this, algae can be grown without taking up arable land that would otherwise be used for producing food crops, and the better resources can be reserved for normal crop production. Microalgae also require fewer resources to grow and little attention is needed, allowing the growth and cultivation of algae to be a very passive process.

- **Impact on Food**

Many traditional feed stocks for biodiesel, such as corn and palm, are also used as feed for livestock on farms, as well as a valuable source of food for humans. Because of this, using them as bio-fuel reduces the amount of food available for both, resulting in an increased cost for both the food and the fuel produced. Using algae as a source of biodiesel can alleviate this problem in a number of ways. First, algae is not used as a primary food source for humans, meaning that it can be used solely for fuel and there would be little impact in the food industry. Second, many of the waste-product extracts produced during the processing of algae for bio-fuel can be used as a sufficient animal feed. This is an effective way to minimize waste and a much cheaper alternative to the more traditional corn or grain based feeds.

- **Minimization of Waste**

Growing algae as a source of bio-fuel has also been shown to have numerous environmental benefits, and has presented itself as a much more environmentally friendly alternative to current bio-fuels. For one, it is able to utilize run-off, water contaminated with fertilizers and other nutrients that are a by-product of farming, as its primary source of water and nutrients. Because of this, it prevents this contaminated water from mixing with the lakes and rivers that currently supply our drinking water. In addition to this, the ammonia, nitrates, and phosphates that would normally render the water unsafe actually serve as excellent nutrients for the algae, meaning that fewer resources are needed to grow the algae. Many algae species used in biodiesel production are excellent bio-fixers, meaning they are able to remove carbon dioxide from the atmosphere to use as a form of energy for themselves. Because of this, they have found use in industry as a way to treat flue gases and reduce GHG emissions.

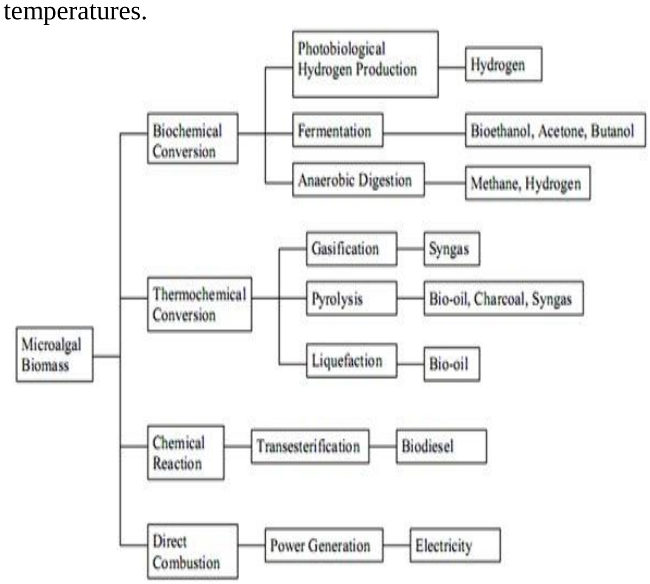
DISADVANTAGES

- **New Technology**

Algae biodiesel is still a fairly new technology. Despite the fact that research began over 30 years ago, it was put on hold during the mid 1990s, mainly due to a lack of funding and a relatively low petroleum cost.[99] For the next few years algae bio-fuels saw little attention, and it was only until the gas peak of the early 2000s that it eventually had revitalization in the search for alternative fuel sources. While the technology exists to harvest and convert algae into a usable source of biodiesel, it still hasn't been implemented into a large enough scale to support the current energy needs. Further research will be required to make the production of algae bio-fuels more efficient, and at this point it is currently being held back by lobbyists in support of alternative bio-fuels, like those produced from corn and grain.

- **Stability**

The biodiesel produced from the processing of microalgae differs from other forms of biodiesel in the content of polyunsaturated fats.[96] Polyunsaturated fats are known for their ability to retain fluidity at lower temperatures. While this may seem like an advantage in production during the colder temperatures of the winter, the polyunsaturated fats result in lower stability during regular seasonal temperatures.



i. Conversion processes for bio-fuel production from micro-algae biomass

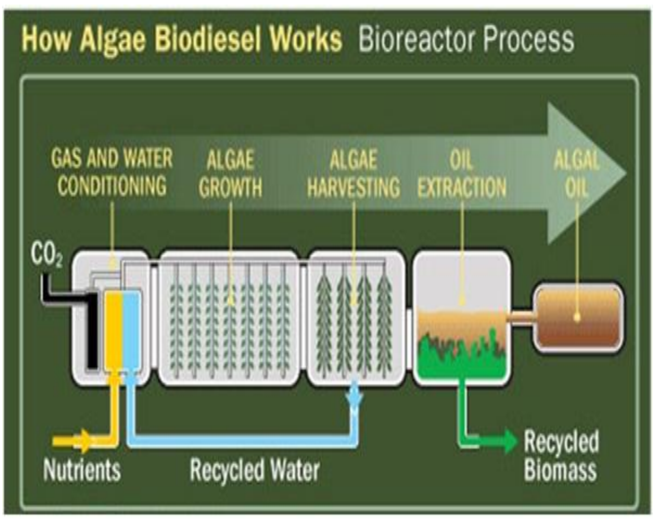
CHARACTERISTICS OF MICRO-ALGAE

Microalgae, recognized as one of the oldest living organisms, are thallophytes (plants lacking roots, stems, and leaves) that have chlorophyll a as their primary photosynthetic pigment and lack a sterile covering of cells around the reproductive cells. While the mechanism of photosynthesis in these microorganisms is similar to that of higher plants, they are generally more efficient converters of solar energy because of their simple cellular structure. In addition, because the cells grow in aqueous suspension, they have more efficient access to water, CO2, and other nutrients.

Traditionally microalgae have been classified according to their color and this characteristic continues to be of a certain importance. The current systems of classification of microalgae are based on the following main criteria: kinds of pigments, chemical nature of storage products and cell wall constituents. Additional criteria take into consideration the following cytological and morphological characters: occurrence of flagellate cells, structure of the flagella, scheme and path of nuclear and cell division, presence of an envelope of endoplasmic reticulum around the chloroplast, and possible connection between the endoplasmic reticulum and the nuclear membrane . There are two basic types of cells in the algae, prokaryotic and eukaryotic. Prokaryotic cells lack membrane bounded organelles (plastids, mitochondria, nuclei, Golgi bodies, and flagella) and occur in the cyanobacteria. The remainder of the algae is eukaryotic and has organelles.

Microalgae can be either autotrophic or heterotrophic. If they are autotrophic, they use inorganic compounds as a source of carbon. Autotrophs can be photoautotrophic, using light as a source of energy, or chemoautotrophic, oxidizing inorganic compounds for energy. If they are heterotrophic, microalgae use organic compounds for growth. Heterotrophs can be photo heterotrophs, using light as a source of energy, or chemo heterotrophs, oxidizing organic compounds for energy. Some photosynthetic microalgae are mixotrophic, combining heterotrophy and autotrophy by photosynthesis. For autotrophic algae, photosynthesis is a key component of their survival, whereby they convert solar radiation and CO2 absorbed by chloroplasts into adenosine triphosphate (ATP) and O2, the usable energy currency at cellular level, which is then used in respiration to produce energy to support growth.

Microalgae are able to fix CO2 efficiently from different sources, including the atmosphere, industrial exhaust gases, and soluble carbonate salts. Fixation of CO2 from atmosphere is probably the most basic method to sink carbon, and relies on the mass transfer from the air to the microalgae in their aquatic growth environments during photosynthesis. However, because of the relatively small percentage of CO2 in the atmosphere (approximately 0.036 %), the use of terrestrial plants is not an economically feasible option. On the other hand, industrial exhaust gases such as flue gas contains up to 15 % CO2, providing a CO2rich source for microalgal cultivation and a potentially more efficient route for CO2 biofixation. Many micro-algal species have also been able to utilize carbonates such as Na2CO3 and NaHCO3 for cell growth. Some of these species typically have high extracellular carbo anhydrase activities, which is responsible for the conversion of carbonate to free CO_2 to facilitate CO_2 assimilation. In addition, the direct uptake of bicarbonate by an active transport system has also been found in several species. Growth medium must provide the inorganic elements that constitute the algal cell. Essential elements include nitrogen (N) and phosphorus (P). Minimal nutritional requirements can be estimated using the approximate molecular formula of the micro-algal biomass, which is $CO_{0.48}H_{1.83}N_{0.11}P_{0.01}$. Nitrogen is mostly supplied as nitrate (NO_3), but often ammonia (NH_4^+) and urea are also used. Urea is most favourable as the nitrogen source because, for an equivalent nitrogen concentration, it gives higher yields and causes smaller pH fluctuations in the medium during algal growth. On the other hand, nutrients such as P must be supplied in significant excess because the phosphates added complex with metal ions, therefore, not all the added P is bio-available. Furthermore, microalgae growth depends not only on an adequate supply of essential macronutrient elements (carbon, nitrogen, phosphorus, silicon) and major ions (Mg^{2+}, Ca^{2+}, Cl, and SO_4^2) but also on a number of micronutrient metals such as iron, manganese, zinc, cobalt, copper, and molybdenum.



Microalgae as a Potential Source of Biofuel:

There are several ways to convert micro-algal biomass to energy sources, which can be classified into biochemical conversion, chemical reaction, direct combustion, and thermo chemical conversion, Thus, microalgae can provide feedstock for renewable liquid fuels such as biodiesel and bio-ethanol.

The idea of using microalgae as a source of bio-fuel is not new, but it is now being taken seriously because of the rising price of petroleum and, more significantly, the emerging concern about global warming that is associated with burning of fossil fuels. The utilization of microalgae for bio-fuels production offers the following advantages over higher plants:

- microalgae synthesize and accumulate large quantities of neutral lipids (20–50 % dry weight of biomass) and grow at high rates.
- Microalgae are capable of all year round production; therefore, oil yield per area of microalgae cultures could greatly exceed the yield of best oilseed crops.
- Microalgae need less water than terrestrial crops therefore reducing the load on freshwater sources.
- Microalgae cultivation does not require herbicides or pesticides application.
- microalgae sequester CO_2 from flue gases emitted from fossil fuel fired power plants and other sources, thereby reducing emissions of a major greenhouse gas (1 kg of dry algal biomass utilise about 1.83 kg of CO_2).
- wastewater bioremediation by removal of NH_4^+, NO_3, PO_4^3 from a variety of wastewater sources (e.g. agricultural runoff, concentrated animal feed operations, and industrial and municipal wastewaters).
- combined with their ability to grow under harsher conditions and their reduced needs for nutrients, microalgae can be cultivated in saline/brackish water/coastal seawater on non-arable land, and do not compete for resources with conventional agriculture.

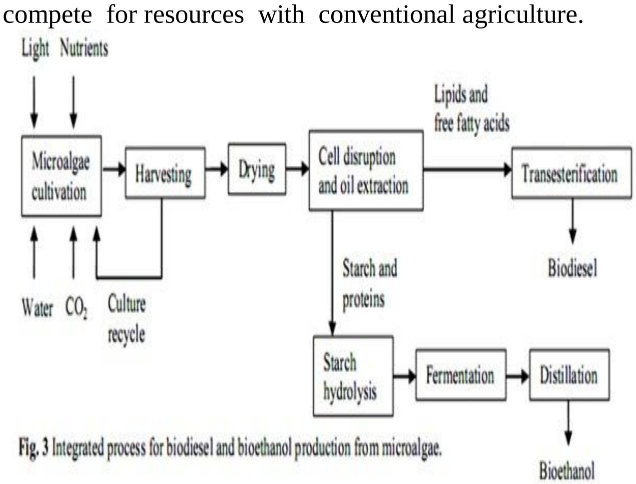


Fig. 3 Integrated process for biodiesel and bioethanol production from microalgae.

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CONCLUSION

Microalgae are a diverse group of prokaryotic and eukaryotic photosynthetic microorganisms that grow rapidly due to their simple structure. They can potentially be employed forth production of bio-fuels in an economically effective and environmentally sustainable manner. Microalgae have been investigated for the production of a number of different bio-fuels including biodiesel, bio-oil, bio-syngas, and bio-hydrogen. The production of these bio-fuels can be coupled with flue gas CO2 mitigation, wastewater treatment, and the production of high value chemicals. Micro-algal farming can also be carried out with seawater using marine micro-algal species as the producers. Developments in micro-algal cultivation and downstream processing (e.g., harvesting, drying, and thermo chemical processing) are expected to further enhance the cost effectiveness of the bio-fuel from microalgae strategy. The choice for the most suitable energy carrier to be produced from algae is most clear in the case of seaweed. As visualized in Figure 3, only the utilization of the entire biomass is an option, because conditions in the open sea cannot be controlled as they can on land, and therefore specifically stimulating the production of e.g. alkanes, lipids or hydrogen are not possible. Using algae for ethanol production is in such an early stage that not much can be concluded yet about its strengths and weaknesses and is therefore not investigated further in this report. Nevertheless, its future development deserves attention. Algae for bio-diesel are generally the favoured algae-for-energy option and have been researched the most. Both open and closed land based cultivation systems appear suitable for this option. The conversion of the extracted lipids to biodiesel is relatively easy, and the product price can easily be compared with fossil fuel prices. Most commercially aimed pilot installations also chose this pathway. Since nutrient-limitation is often used as a lipid stimulation strategy, this technology requires strict nutrient input control, therefore using manure or waste water as a nutrient source may be relatively complicated.

- Future petrol tanks with renewable bio-diesel.

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