

**Report**

**Coastal biomass to energy**

*Algae to energy - overview*

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# Algae to energy - overview

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## Renewable energy and sustainability

Facing decline of fossil, non-renewable energy sources accessibility, renewable sources have been explored and increasingly used worldwide. Besides water and wind energy, utilization of solar energy belongs to promising renewable sources, with biomass being one of the forms of solar energy utilization – green plants build biomass from basic nutrients by capturing solar light. For energy retrieval can be then used either newly grown biomass such as wood, maize, rapeseed, or waste biomass, such as agricultural or municipal organic waste. The energy acquired from biomass can be in a form of fuel (biogas, oils) or heat.

## Algae as a source of renewable energy

Sustainability, defined as a capacity to endure, belong to crucial criteria for evaluation and optimization of various energy sources. While it is obvious that utilization of non-renewable energy sources cannot be on a long-term sustainable, big hopes have been put in this respect into renewable sources, including biomass. Unfortunately, by far not all of renewable energy sources are sustainable either 1,2. For example, production of so called first generation biofuels, manufactured from plants otherwise commonly used as human food and feed for farmed animals (such as corn, soya, maize, sugar beet) led to increase of food prices and subsequent starvation in many areas around the world.

Besides that, the net energy and carbon balance are in case of these biofuels often negative 3, and their mass monoculture production have caused many serious environmental damages 4. The second generation of biofuels, utilizing non-food energy crops such as switch grass or willow coppice, together with agricultural and forestry waste, overcomes some of the disadvantages of the previous group, however, their net energy yield and high downstream processing costs are often beyond economical sustainability 5.

## Algae as a source of renewable energy

Recently, increased attention has been paid to algae as a promising energy source of future, and they became called due to their unique properties the third generation of biofuels 6. Algae seem to have several advantages in comparison to other, previously mentioned sources of bio-energy, such as: algae do not require arable land;

* for algae growth is not necessarily needed fresh water, many species can grow in sewage water as well, marine species in salt water;
* algae can under certain conditions grow faster than terrestrial plants, and have larger per area productivity;
* algae cultures can be harvested batch-wise nearly all-year round;
* algae can be turned to various forms of energy and tackle both energy and fuel market.

Some algae species have the ability to store relatively large amount of lipids that can be than relatively easily extracted to fuel. The list of metabolic products that can be further utilized as an energy source and that have been extracted from algae cultures/biomass include: hydrogen, ethanol, butanol, hydrogen peroxide. And, as any biomass, also algae biomass can be fermented to biogas or pyrolysed to charcoal.

## Algae biomass

Algae is a very diverse group of organisms, containing several hundreds of thousands of known species, differing in size, morphology, physiology, life cycle, occurrence. For example algae size ranges from single micrometers to several tens of meters. The small, typically unicellular algae not observable by naked eye are called microalgae, the large ones that can be seen without the aid of microscope are called macroalgae and they are typically multicellular. While microalgae occur in any water environment, vast majority of macroalgae species can be found only in marine habitats. Different groups of algae have capabilities to utilize different parts of light spectra; the specific light capturing pigments contribute to different color of the algae.

Algae have been utilized by humans since centuries for number of purposes: food, livestock feed, food industry, fertilizers, pharmaceuticals, cosmetics, and the overall demand in these fields are increasing 7, 8. Algal biomass for downstream processing can come essentially from three sources: harvesting live algae directly from nature, collecting dead algae biomass washed ashore by waves or tides (seaweed wrack), or culturing of selected species and strains.

### Harvesting from nature

Harvesting macroalgae (known as seaweeds as well) has a long tradition in many coastal lands. Seaweeds have been used as direct fertilizers to fields, as source of soda, potash and iodine for various industrial and agricultural applications, later as a source of alginates used in food industry 7. Intense mechanical harvesting diminished in some places macroalgae considerably, with negative consequences to marine ecosystems 9. However, in other areas can removal of proliferated macroalgae growth be beneficial as a mean of removing of excessive nutrients from environment 10. Harvesting of microalgae blooms has been tested on several places worldwide, but as currently is far from being economically feasible 11.

### Collecting seaweed wrack

In the seaweed wrack usually prevail macroalgae together with small invertebrates and animal carcasses; nevertheless various human wastes and debris, such as plastic, ropes etc., can form a significant portion too. Its quantity depends primarily on amount of macroalgae growing in nearby marine areas, but is dependent on exposure of a particular shore stretch to wind and water currents as well. This marine biomass normally sooner or later decays and serves as an important source of nutrients, enhancing biodiversity 12. However, on coastlines close to human settlements and/or touristic areas may larger amount of decaying seaweed wrack implicate a significant nuisance 13. Before mass introduction of industrial fertilizers, seaweed wrack used to be gathered by farmers and spread to nearby fields. Nowadays, seaweed wrack gets often removed on beaches in touristic areas.

### Culturing of algae

Culturing of algae allows for more or less controlled conditions of algae growth and harvesting, and enables therefore higher productivity and efficiency than nature growth. Culturing of both macro- and microalgae for non-energy usage (such as food) as in some places around the world long tradition 7, 8. Macroalgae are typically cultured offshore directly in seawater on constructions of anchored ropes and can be potentially combined with other aquacultures 14. Microalgae can be cultured either in air-open ponds and raceways, which are relatively cheap to build and maintain, but are connected with limited control and higher risk of contamination, whereas closed culturing systems – photobioreactors – are more costly, yet enable better growth conditions, higher productivity and better overall control 15.

## Energy production & efficiency

The overall energy production from algae and efficiency of this process depends on costs and efficiency of algae harvesting and/or culturing, together with costs and efficiency of downstream processing. Although algae have been earlier predicted to be a panacea for future energy production with huge potential, it became soon obvious that many of these claims were quite exaggerated 16, 17.

### Efficiency of photosynthesis

As already mentioned above, the utilization of algae for energy is in principal one of the forms of capturing solar energy, and in fact, by far not the most efficient one. Whereas efficiency of photosynthesis at capturing solar light is around 1-2%, efficiency of contemporary photovoltaic panels can achieve efficiency of solar energy capture of 10-20%, with devices under development reaching up to 40% 1,17. In the light-capturing systems of any photosynthetic organism, including algae, are inherent limits given by laws of physics, that won’t enable increase of light capturing efficiency above 10 %, which is rather the theoretical limit to aspire to, the more realistic value being 3-6% 18, 19.

### Algae productivity

The productivity of algae can be indeed higher than of other plants, but only if enough nutrients (and in a right ratio), extra carbon dioxide, optimal light and temperature conditions are supplied 8. These measures inevitably increase production costs beyond economic feasibility for energy production 17. Without providing the optimal conditions is the overall productivity of algae actually lower than at higher plants commonly grown as crops for food 16. Utilization of waste water and waste fumes seems to be a solution to this problem. However, then less than maximal growth and production have to be expected as non-optimal ratio of nutrients as well as growth hindrance due to likely present toxic elements 20, 21.

### Scaling

Scaling from laboratory experimental conditions (where often impressive yields are achieved) to large economically feasible commercial production is been a major stumbling block that won’t be easy to overcome 22, 23. So far, despite many trials, only handful of proposed approaches and technologies has been proved viable and sustainable on a long time base when scaled up beyond laboratory conditions and even less make currently a notable economical profit. In other words, yields gained in economically meaningful scales do not usually match high expectations based on laboratory research, since it is difficult if not impossible to achieve on a large scale the very optimal conditions needed for sustainable algae growth.

### Downstream processing

The two most promising downstream pathways from algae biomass is a lipid extractions for biodiesel (specific algae cultures) and fermentation to biogas (any algae biomass). The technology of turning algae lipids to biodiesel is in principal relatively easy 24,25, however, the algae culture must be first thoroughly dewatered. Numerous methods have been described and tested, unfortunately microalgae dewatering is still very costly and remains a major obstruction to industrial-scale processing of microalgae for biofuel production 20, 26.

Anaerobic digestion of algae biomass yields typically between 0,2 -0,5 m3 CH4/kg VS, which is in the range of the methane production from cattle manure and land based energy crops 27,28,29. The net economical profit is nevertheless typically lower than these, given higher costs connected with culturing, harvesting and necessity of pretreatment, such as washing out salt and sand, drying, hydrolysis or removal of heavy metals that macroalgae easily absorb from seawater and that may hinder fermentation process 30, 31,32.

Recently, potential of gaining energy from algae via combustion or pyrolysis have been investigated as well 33. It is technically possible, but appears to be rather unsuitable for (fresh) algae due to its high water content and therefore necessity of drying 34. Similarly as with biogas fermentation, presence of heavy metals in algae is for this technology very problematic 33.

### Sustainability of algae to energy production

Several years ago were algae proposed to be sustainable energy source of future, with huge potential to cover significant portion of energy consumption, including fuel demands 2435. However, numerous studies based on intense research and published in recent years documented that this very likely won’t happen, or at least not in a near future. Energy production from algae in general seems to be neither ecologically nor economically sustainable.

Recent papers have suggested that large-scale deployment of algae bioenergy systems could have unexpectedly high environmental burdens. Thorough life-cycle analyses of algae to energy production have shown that algae-to-energy systems are not necessarily net-energy positive, more often the opposite is actually true 36, 37,21. The often proposed environmental benefits of CO2 mitigation of algae production has been shown to be questionable as well 38,39, 37. According to some studies only scavenging of dead biomass, including algae, can be on a long term environmentally sustainable 40.

Whereas environmental sustainability of algae energy production can be under certain conditions achieved, the economical sustainability is obviously as yet very far from that goal. Current costs of algae production and processing are about ten times higher than costs of conventional fuels on the market 8,17,5. Furthermore, even process strains sustainable environmentally, may not be necessarily sustainable economically, such as collecting and processing seaweed wrack 41. Therefore, it is obvious that culturing and/or harvesting algae only for energy is currently not yet sustainable and it is questionable if ever will be.

### Perspectives – is there any hope?

Recently, a lot of effort has been put worldwide in improving overall technology of culturing in order to achieve high and stable algae production while keeping costs low. For example numerous novel setups of culturing facilities have been developed and tested, such as vertically placed tubes, micro-layers etc. Thousands of algae species and strains have been screened and their properties studied. Another potential way of increasing algae culture productivity might be application of observations gained in ecological research, such as that multiple species culture has on a long term scale higher, more stable productivity and better resource utilization than monocultures 42, 43.

Algae have been successfully harvested cultured for number of other, profitable purposes (see above). Since usually only certain target substances get extracted in these processing chains, it has been suggested that the rest of algae biomass could be then used for energy production, in a complex processing technology called bio-refinery 8,44,45. However, if the only economical way of turning algae to energy is to use rests from ‘high value’ production, then the quantity of algae biomass available for energy production will be necessarily driven by demand on high value products and production of energy can’t be expected to contribute substantially to overall energy demands.

Coupling algae production with waste water remediation or mitigation of eutrophication seems to be another promising approach 46,47,48,49,50, though here apply of course the same algae energy production limits as above.

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