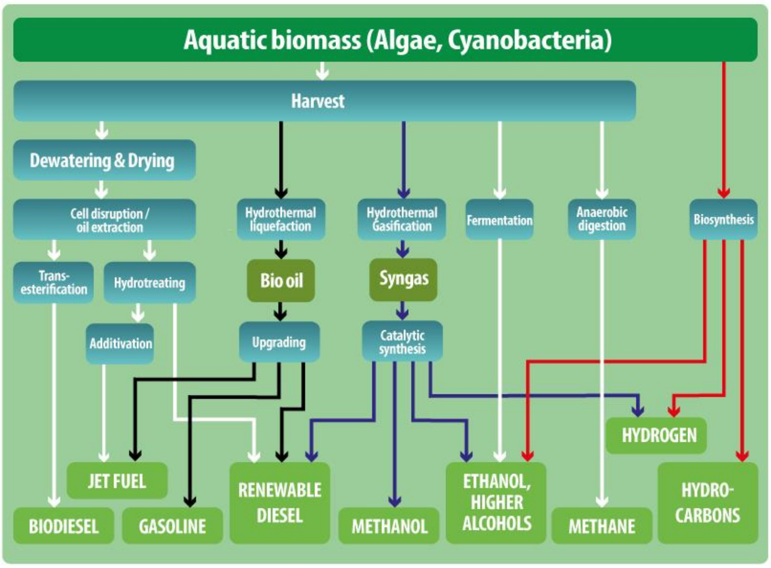
Bioenergy value chain 7: aquatic biomass

Aquatic vs. terrestrial biomass

Photosynthetic algae (including macro- and micro-algae) and photosynthetic cyanobacteria have the potential to produce considerably greater amounts of biomass per hectare than terrestrial crops; some species directly produce fuel (hydrogen, ethanol or alkanes). Advantages of such aquatic biomass are that non- arable land or even off-shore can be used for cultivation; sea or brackish water can be used, as well as industrial carbon dioxide as carbon source or wastewater as nutrient input (nitrogen and phosphorus). Aquatic biomass are energy crops that do not compete with food crops for land or other resources.

Figure 1: Aquatic biomass value chains



There are many parameters that influence aquatic biomass productivity and composition like irradiance levels, dark/light cycles, CO_2 and O_2 concentration, temperature, pH, salinity and nutrients. The maximum theoretical biomass productivity of algae can reach 100 g/m^2/d, but real productivities in good locations are around 15-20 g/m^2/d at present. There are intensive R&D activities at lab and pilot scale to improve these results.

Algae biomass composition consists of carbohydrates, proteins, lipids and other products such as pigments, vitamins, etc., being lipids the most interesting fraction for conversion into biofuels. Oleaginous strains (at least 20% lipid content on Dry Weight (DW) basis) can overproduce lipids (up to 70% lipids on DW basis) under selected severe stress conditions such as N and/or Si starvation.

Cultivation

Major distinctions of cultivation methods are between micro- and macroalgae. Macroalgae are mainly cultivated off-shore in open systems, whereas microalgae can be cultivated on-shore in either open or closed systems.

Large scale cultivation of microalgae in on-shore outdoor open pond systems is well established. Cultivation in open systems is only suitable for a few algal species which can tolerate extreme environmental conditions.

Closed cultivation systems for microalgae, usually on-shore, utilize photobioreactors made of transparent tubes, plates, bags or domes, which permit culture of single species. Either biomass or lipid productivities in photobioreactors can nearly be twice as high as for open ponds.

Final energy products

Biodiesel (FAME)
Renewable diesel
Straight vegetable oil (SVO)
Biokerosene (jet fuel)
Gasoline
Ethanol
Methanol
Methane
Hydrogen
Syngas

Non-energy co-products

Proteins, special oils (omega-3), vitamins, pigments, nutraceuticals

The scale of photobioreactors is yet limited by the build up of oxygen which would rapidly reach inhibitor levels. Besides, the larger a photobioreactor the more difficult it is to keep the monoculture free of parasites or other species.

Heterotrophic and mixotrophic algae cultivation is done in stirred tank bioreactors or in fermenters.

Macroalgae (seaweed) are usually cultivated in off-shore farms but their productivity is much lower than that of microalgae. Their composition is mainly carbohydrates, not lipids.

Harvesting and drying

The typical microalgae concentration in cultivation broths is 0.02 – 0.07% of total suspended solids (open ponds), in photobioreactors it ranges from 0.14 – 0.7% dry matter. The recovery of the microalgae from the algae suspension is affected in two steps. A pre-concentration step or bulk harvesting leads to a concentration of 2 – 7%. Methods are flocculation via thickeners, dissolved air flotation (for small microalgae) and sedimentation (for large microalgae). The second concentration step is the thickening or dewatering and brings the concentration of solid matter up to 15 – 25%. Main methods are centrifugation, filtration and ultrasonic aggregation. In a third step the harvested algal paste needs to be dried. To prevent from degradation the moisture level should be kept below 7%. Methods are solar-drying, drum-drying, freeze-drying and spray-drying. Apart from solar-drying, drying is very energy intensive and accounts for a large part of total energy consumption.

Conversion technologies

Algae and its cellular components have been considered as feedstocks to be processed to create a variety of end-use energy products, which include a wide range of liquid and gaseous transportation fuels.

The most studied and developed bioenergy value chain is the extraction of algal lipids that are either esterified into biodiesel (FAME) or hydrotreated into renewable diesel (HVO or jet fuel). Left unrefined, the algal oil can act as straight vegetable oil. One of the most important R&D challenges in this value chain is to find an effective and non-costly lipid extraction process.

Hydrothermal treatment of aquatic biomass allows for the production of a bio-oil or a syngas, that can be further processed into hydrogen, methanol, ethanol, gasoline, renewable diesel, and jet fuel.

Two other options are fermentation for ethanol production and anaerobic digestion to gain bio-methane. Both ways spare the need of drying the algal culture. Fermentation, hydrothermal liquefaction and anaerobic digestion are also a practical way to treat the residual algal biomass from other conversion routes.

Direct fuel production: In emerging fuel production routes such as microbial biosynthesis, biophotolysis and autofermentation, algae or cyanobacteria are not used as feedstock, but they are the actual producers of the fuels (alkanes, hydrogen or ethanol respectively). These pathways are at pilot scale and huge efforts are being made to improve productivities and recovery technologies.

Example projects on algae production

Pilot projects in Europe

FP7 Algae Cluster	Three projects - BIOFAT, ALL Gas, and InteSusAl – supported by EU, demonstration at industrial scale of algae and its subsequent use in biofuel production, runs from 2011 – 2015/16
fuel4me	4-year project funded by the EU, optimisation of lipid production, 2012 - 2017

Projects in Australia and the USA

Algae.Tec.	Pilot plant in Australia, since 2007
Heliae	Pilot plant in Arizona / USA, since 2008
Sapphire Energy Inc.	First-of-its-kind commercial plant in New Mexico / USA, since 2009
Algenol	Pilot plant in Florida / USA, since 2011
Joule Unlimited	Cyanobacteria demo plant in Massachusetts / USA, since 2011
Biosystems	Demo plant in Florida / USA, since 2013

Synergies between biofuels and other industrial sectors

Microalgae provide dissolved oxygen that can be used by bacteria to break down and oxidize organic matter in wastewaters. This leads to the liberation of CO_2, phosphate, ammonia and other nutrients used by algae. Biofuel production in combination with wastewater treatment and nutrient recycling is thus predicted to be a near-term application.

In any case, the combination of biofuel production with the valorisation of other fractions of the algal biomass (proteins, special oils (omega-3), vitamins, pigments, nutraceuticals) is necessary for the economic sustainability of the process.

Further information

Read up-to-date information about the aquatic biomass on www.biofuelstp.eu.