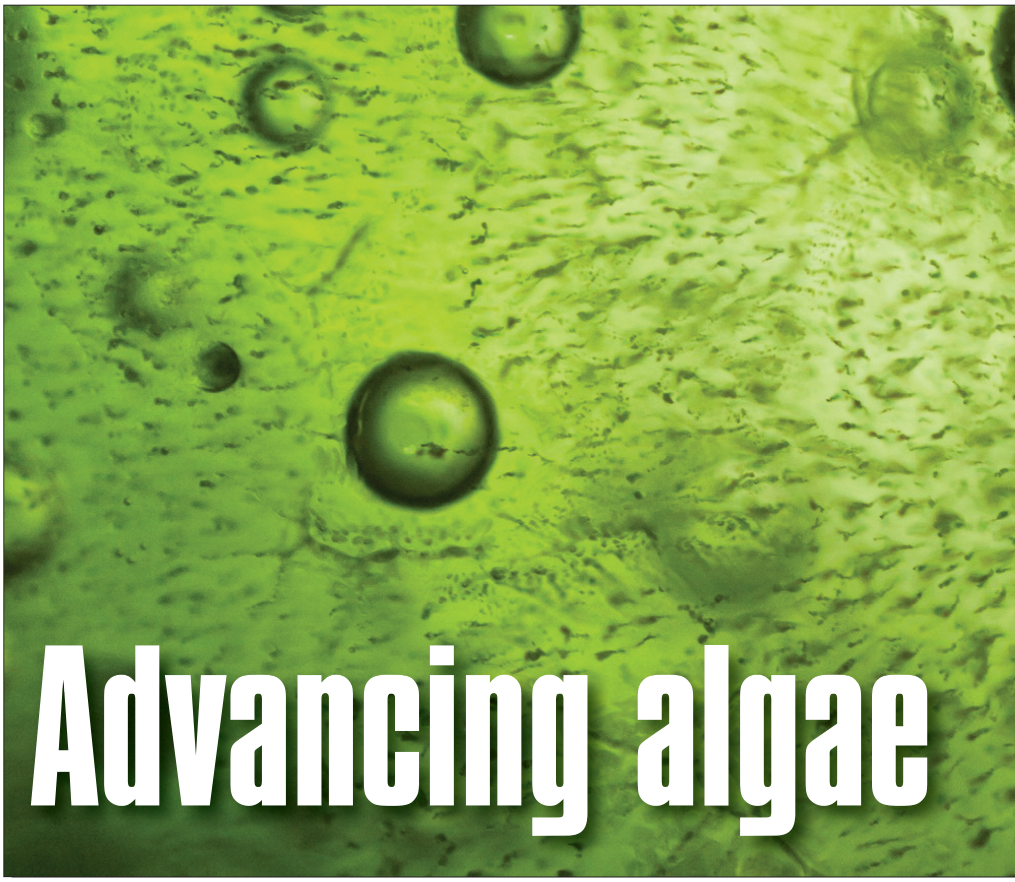
Advancing algae



Commercial-scale production of algae is not yet feasible as it places an unsustainable demand on energy, water and nutrients. Further research and development is needed to develop higher yielding strains and better energy returns. Charlotte Niemiec writes

Despite extensive research and development since *Oils and Fats International* last featured algae (*see 'The algal challenge', OFI June 2009, Vol 25 No 5, p16*), algae-derived biofuels are still not a commercial reality.

This was highlighted at the 'Developing a Successful Algae Business Model' seminar at the World Biofuels Markets conference and exhibition, held in Rotterdam, the Netherlands in March 2013. In the seminar, three algae companies explained why their system was the best, how they could improve yields and reduce costs. On stage, the possibilities seemed endless; off-stage, arguments were brewing. One thing was clear – there is still no accurate science available to prove which method produces the highest algae yield.

Algae's potential, however, is huge. The United States Department of Agriculture (USDA) estimates that algae can produce up to 300 times more oil/unit area than conventional crops such as rapeseed, palm, soya or jatropha (*see Table 1*).

In 2012, the National Research Council (NRC) commissioned a sustainability assessment report, titled 'Sustainable Development of Algal Biofuels in the United States', which featured contributions from the Board on Agriculture and Natural Resources, the Division on Earth and Life Sciences, the Board on Energy and Environmental Systems and the Division on Engineering and Physical Sciences, known collectively as the 'Committee on the Sustainable Development of Algal Biofuels'.

The committee's conclusion was: "The scale-up of algal biofuel production sufficient to meet at least five percent of US demand for transportation fuels would place unsustainable demands on energy, water, and nutrients with current technologies and knowledge. However, the potential to shift this dynamic through improvements in biological and engineering variables exists."

The NRC explains that algae can be seen as a more favourable feedstock for biofuels than land-based plants because of their faster biomass doubling cycle, their more accessible forms of stored carbon than the lignocelluloses used for cellulosic biofuels, and their ability to thrive on water sources and on land sites that are unsuitable for terrestrial farming.

The report states that "microalgae have been reported to reach short-term maximum productivities of 50-60kg dry weight/m^2/day in CO_2-enriched open ponds in Hawaii and California."

Additionally, "some authors have extrapolated values of maximal biomass productivity and combined them with maximal oil content to predict oil yields of 100 tonnes/ha/year. However, such high productivity projections have yet to be obtained in large-scale, long-term experiments."

TABLE 1: RANKED COMPARISON OF OIL YIELD WITH COMMON AGRICULTURAL CROP-BASED BIODIESEL FEEDSTOCKS

Plant Source	Seed Oil Content (% oil by weight in biomass)	Oil Yield (L oil/ha year)	Land Use (m^2 yr/kg biodiesel)	Biodiesel Productivity (kg biodiesel/ha year)
Soyabean (*Glycene max L.*)	18	636	18	592
Camelina (*Camelina sativa L.*)	42	915	12	809
Canola/rapeseed (*Brassica napus L.*)	41	974	12	862
Sunflower (*Helianthus annuus L.*)	40	1,070	11	946
Microalgae (low oil content)	30	58,700	0.2	51,927
Microalgae (medium oil)	50	97,800	0.1	86,515
Microalgae (high oil content)	70	136,900	0.1	121,104

Source: Report 'Sustainable Development of Algal Biofuels in the United States'

What is algae?

The term algae includes micro- and macro-algae. Seaweed is a common macroalgae, larger and cheaper to produce than microalgae. Nevertheless, macroalgae are seen as a lower priority than microalgae, says the NRC.

Microalgae (including cyanobacteria) are small, aquatic organisms that carry out oxygen-evolving photosynthesis and lack the stems, roots, leaves and embryos of plants. More than 40,000 species are recognised.

Algae have a harvesting cycle of 1-10 days, unlike other yearly food crops, as they can grow 20 to 30 times faster than food crops.

Commercial production of microalgae began in the 1960s in Japan, using the species *Chlorella*. The following decade saw the harvesting of *Spirulina* from Lake Texcoco in Mexico, but production was carried out in Thailand. By 1980, 46 large-scale facilities operated in Asia, producing more than 1,000kg of microalgae each month, mostly as a feedstock for the aquaculture market. By 2008, the global production of microalgal biomass was estimated at 9,000 tonnes/year.

Algae cultivation methods

Cultivation generally takes place in one of two ways: in an open-pond system or in a closed photobioreactor. In 2009, open pond systems dominated the market, at 98%, but current cultivation methods are more balanced.

Both methods have advantages and disadvan-

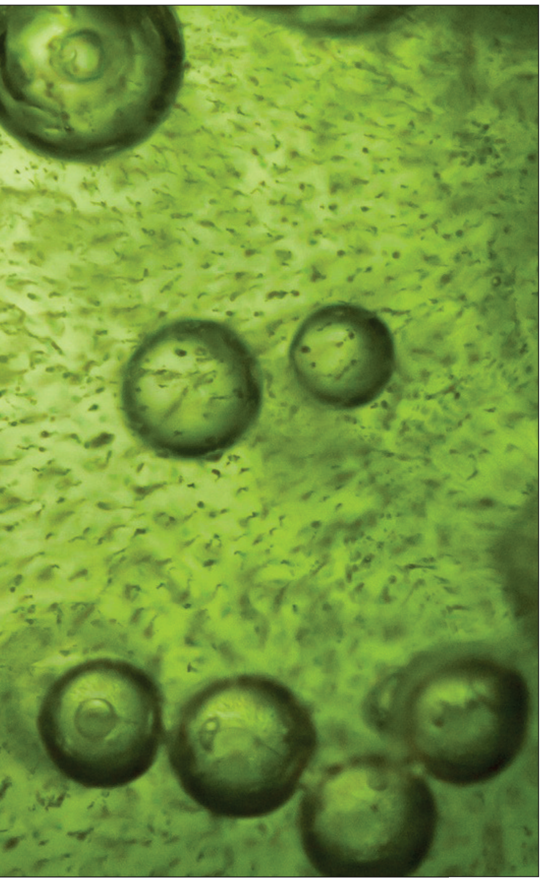


PHOTO: LAURENT DAMBIES/FOTOLIA.COM

MICROALGAE CAN PRODUCE UP TO 300 TIMES MORE OIL/UNIT AREA THAN CONVENTIONAL CROPS SUCH AS RAPESEED, PALM, SOYA OR JATROPHA

tages, as the committee explains. Open-pond systems allow for larger scale units at lower capital investments, lower operating costs, and lower energy demands than closed photobioreactors. However, the open nature of such ponds makes them vulnerable to the natural elements, such as water loss through evaporation (as much as 10 litres/m²/day) and invasion of undesirable species.

Closed systems offer some protection of the cultivated algae from the natural elements. As they have tubes and pipes, closed photobioreactors are more expensive to construct and require more energy to operate than open-pond systems. But closed photobioreactors can improve the sun exposure and take advantage of specialised species, thereby improving productivity.

Algae not yet sustainable

Despite algae's high oil content, they need large amounts of water, CO_2 and nitrogen to produce significant amounts, which would place unsustainable pressure on the environment. The NRC concludes that "the scale-up of algal biofuels production to yield 37.8bn litres of algal oil (10bn gallons)", is currently unsustainable.

According to the NRC: "At least 123bn litres of water would be needed to produce 39bn litres of algal biofuels or an equivalent of five percent of US demand for transportation fuels. The estimated requirement for nitrogen and phosphorus needed to produce that amount of algal biofuels ranges from six million to 15M tonnes of nitrogen and from one million to two million tonnes of phosphorus if the nutrients are not recycled or included and used in co-products. Those estimated requirements represent 44% to 107% of the total nitrogen use and 20% to 51% of total phosphorus use in the USA."

The USDA estimates that if algae-derived fuel was to replace all petroleum fuel in the USA, it would require 15,000 square miles of land, which is a few thousand square miles larger than Maryland state.

Location is also a problem. Optimal conditions for algae include a large amount of sunshine, minimal rainfall, a source of CO_2, flat land and an abundance of seawater (or freshwater). One advantage of algae is that it could be produced in regions unsuitable for most crops, such as desert land. However, concerns have been raised that utilising such marginal land could carry negative consequences for untouched, natural land.

Algae in practice today

At the conference, the options presented for microalgal production systems were open ponds, floating photobioreactors (PDRs) in a closed system, and the relatively new technology of hanging gardens.

Aurora Algae, USA – formerly Aurora Biofuels – uses salt-water open pond technology. It has a demonstration site in Karratha, western Australia, which produces 15 tonnes/month of algal biomass. The company chose western Australia as the location meets all the environmental requirements of algae and the country has strong government support for the production of sustainable biofuels.

Karratha has space enough to hold a potential 1,000 acres (404ha) of ponds, which would yield 2,400 tonnes/month of biomass. The current system comprises 38 microponds, four 50m² ponds, four 400m² ponds and six one-acre ponds.

Greg Bafalis, CEO of Aurora Algae, explained that CO_2 was one of the biggest cost components of algae, using two to three tonnes/tonne of algae, but Australia has lots of pure CO_2. As Australia has introduced a new carbon tax, Aurora takes a company's CO2 in a symbiotic relationship.

The German Algal Biofuels Company, GmbH, specialises in the production of algae using the hanging garden technique. Its hanging gardens – sheets of hanging glass upon which algae grow – are six metres high, and two metres wide and deep. Janine Bramer, project manager with the company, explained that there is no real growth in the winter, due to lack of light availability, but from March to October production is good.

The advantage of using a hanging garden system is space: sheets placed vertically take up significantly less space than those placed horizontally. Bramer explained that, in the same space that would allow for 41 flat panel reactors, 306 vertical reactors can be placed.

The current system contains two rows of six reactors, and each reactor consists of 12 panels, each with 70 tubes. The total volume produced is 54,432 litres/year. The company claims to have had positive results when cultivating algae under flue gas.

Miguel Verhein from Algasol Renewables, located in Spain, believes his company's system is the lowest cost production method on the market.

The company's closed photobioreactor system consists of bags which float on the water. The bags are made of a flexible, thin, low-cost polymer material. The company claims to require only 3m³ of reactor material where other systems would require one hectare (500m³ volume), equal to a 75% material/cost reduction compared to a tube reactor. Algasol also claims that 70% less water is used in its system compared to tube reactors.

Unlike other PBR designs, there is no need for the PBR to carry the weight of the biomass culture (500 tonnes/ha), and there is limited tension on the corner support profiles. The bags can be used both in the ocean and in ponds on land.

Verhein explained the system reduces capital expenditure as the water body provides a supporting structure using less material and less steel. The operational expenditure is also reduced due to an internal aeration system, efficient temperature control and stirring. The system is modular and industrially scalable.

Making algae sustainable

The NRC report states: "Algal biofuels have the potential to contribute to improving the sustainability of the transportation sector, but the potential is not yet realised. Additional innovations that require research and development are needed to realise the full potential of algal biofuels."

More research and development is required before algae-derived biofuels become a commercial reality. The NRC states that the following avenues of R&D would go some way towards making algae a sustainable feedstock:

- Algal strain selection and improvement to enhance desired characteristics and biofuel productivity;
- An energy return on investment (EROI) that is comparable to other transportation fuels, or at least improving and approaching the EROIs of other transportation fuels;
- The use of wastewater for cultivating algae for fuels or the recycling of harvest water, particularly if freshwater algae is used. ●

Charlotte Niemiec is OFI's editorial assistant. This feature is based on a 2012 report issued by the National Research Council and conducted by the Committee on the Sustainable Development of Algal Biofuels