LEVEL 3 DIPLOMA

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DIPLOMA IN ENVIRONMENTAL SCIENCE

EXTENDED DIPLOMA IN ENVIRONMENTAL SCIENCE
UNIT 4: Scientific principles and the environment

Pre-release Article

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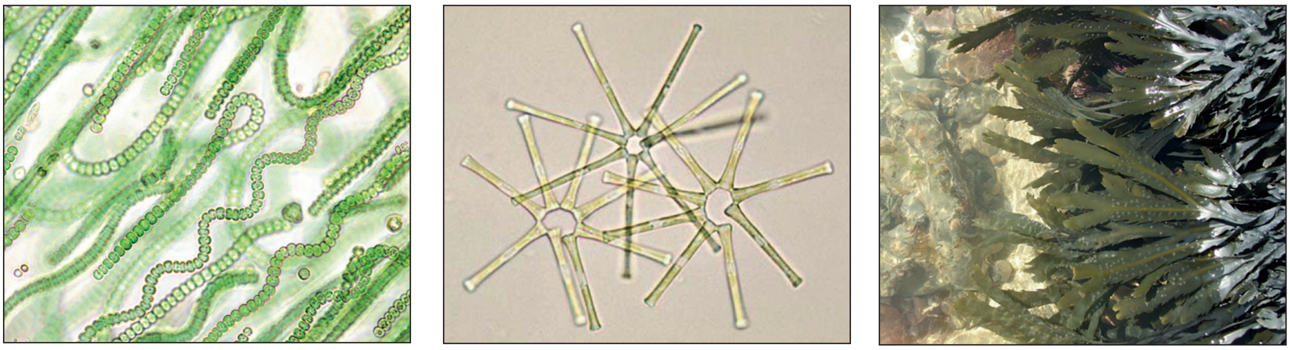
Algae and Sustainable Air Travel

Introduction

Air transport requires a great deal of power. An airliner uses about 240 000 dm^3 of fuel to fly 400 passengers about 14 000 km. Such travel accounts for a substantial part of the human carbon footprint. Most fuel for aircraft comes from petroleum and, unlike surface transport, aircraft fuel cannot be replaced by electrical energy. There has therefore been increasing research seeking to replace petroleum based diesel fuel with oils synthesised by plants and algae. Such biofuels may seem to be carbon neutral but the processes required for their manufacture use a lot of energy. Algal biofuel for aircraft is only sustainable if, overall, the energy input to produce the fuel is substantially less than the energy present in the fuel.

Algae

There are many different species of algae, that make their own food by photosynthesis. Some of these live in extreme habitats. They include prokaryotic cyanobacteria, diatoms and the larger, multicellular seaweeds **(Figure 1)**.



Filamentous colonies of a cyanobacterium *(Nostoc sp)*

Diatom colonies *(Asterionella sp)*

Brown seaweed *(Fucus serratus)*

Figure 1 – examples of algae

Biologists need to know much more about this genetic diversity if they are to find the best species to cultivate. Even closely related species may synthesise different biochemicals and are likely to have individual requirements e.g. an optimum salinity, to achieve their highest productivity.

Effect of salinity on algal growth

One research group cultured several species from an estuary. In an experiment, five repeats for each species in pure culture were used for each salinity. All the repeat cultures had the same concentrations of nutrient ions, such as phosphate when first established. The results for two of the species are shown in **Figures 2** and **3**. These graphs show that species isolated from the same community behave differently when cultured by themselves. Water that is too saline for crop irrigation is often freely available in desert regions and could be used for industrial-scale algal cultures.

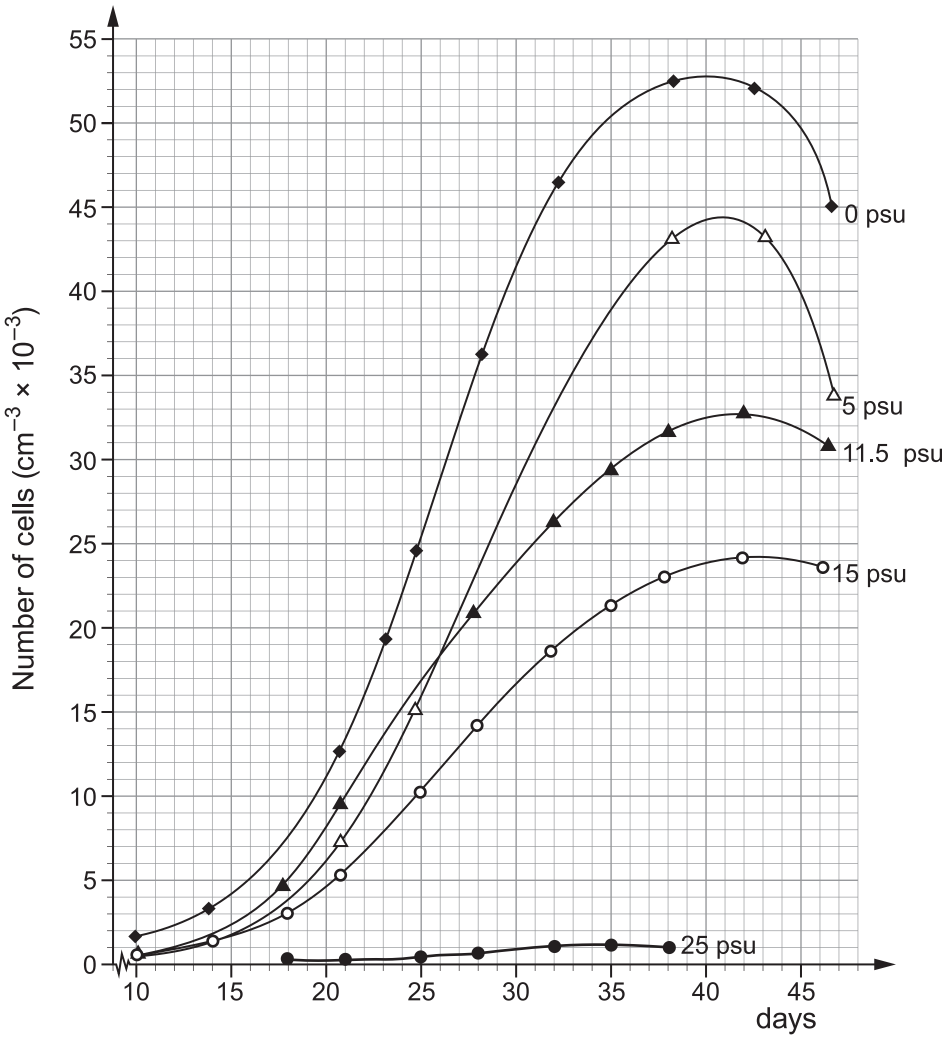


Figure 2 – *Scenedesmus amartus*

(psu = practical salinity units which are measured with a conductivity meter. Ocean water has a psu of 35.)

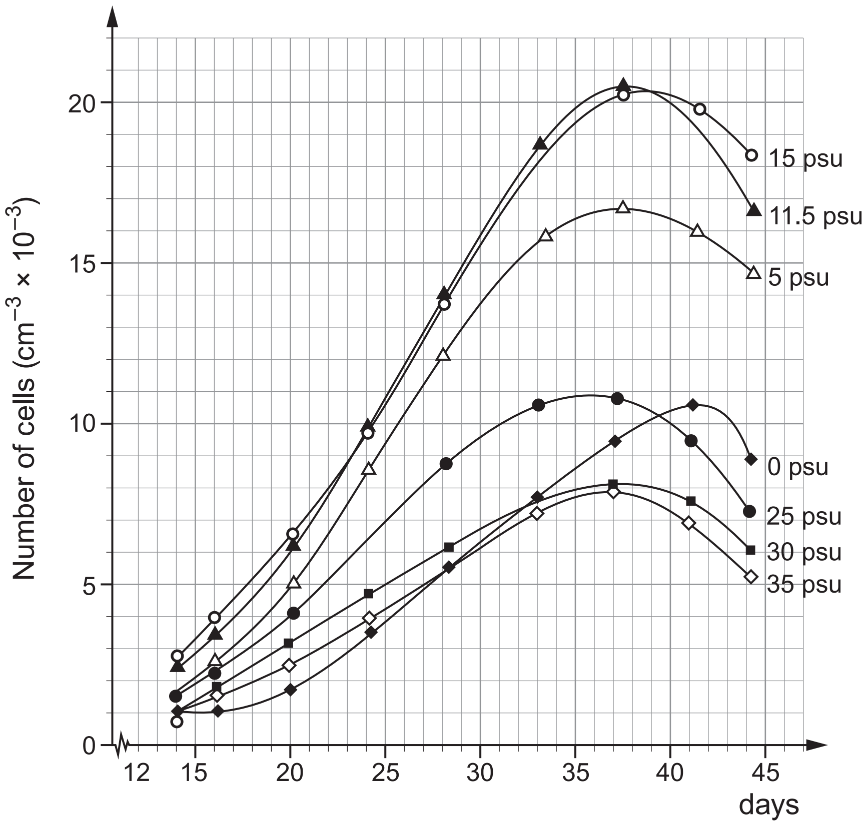


Figure 3 – *Oocystis submarina*

Turn over.

Photosynthesis

During photosynthesis, light energy is absorbed by photosystems found in phospholipid membranes. Absorbed light energy excites the electrons of the pigment molecules. The energy passes to carrier proteins that are part of the photosynthetic membranes. The energy reaching the carrier proteins allows the active transport of protons (H^+) through the membranes. An electrochemical gradient is thus created which allows the synthesis of both ATP and reduced NADP. The ATP and reduced NADP are used in the Calvin cycle by which carbon dioxide is reduced and sugars are synthesised. Sugars produced by photosynthesis are transported out of chloroplasts and used to supply the needs of the organism. The diagram below summarises processes involved in the growth of plants and algae.

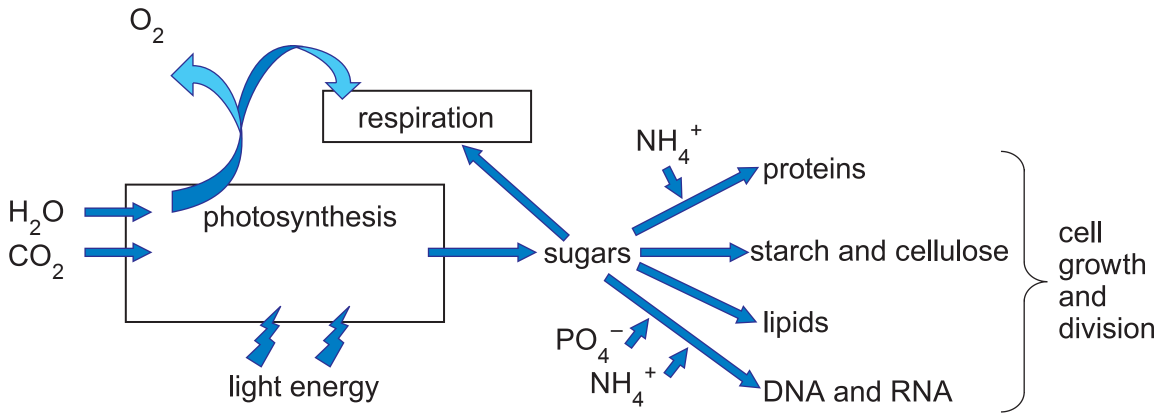


Figure 4 – summary of algal metabolism

Some of the sugar produced by photosynthesis is used in respiration to generate ATP. ATP is essential to drive the endergonic reactions needed to synthesise polysaccharides, proteins, lipids and nucleic acids. Only part of the light energy trapped by photosynthetic pigments is available in storage products such as lipids.

The effect of light intensity on photosynthesis

The overall rate of photosynthesis may be limited by light intensity, however the intensity of full sunlight is far greater than that needed by even the most efficient cells. On a cloudless summer's day in the UK, at noon, this intensity varies between about 100 and 130 kilolux. **Figure 5** shows the relationship between the rate of photosynthesis and light intensity for three different communities of algae living at different depths in the Arctic ocean in summer. The rates are given as percentages of the highest rate of oxygen production that was observed in all three communities.

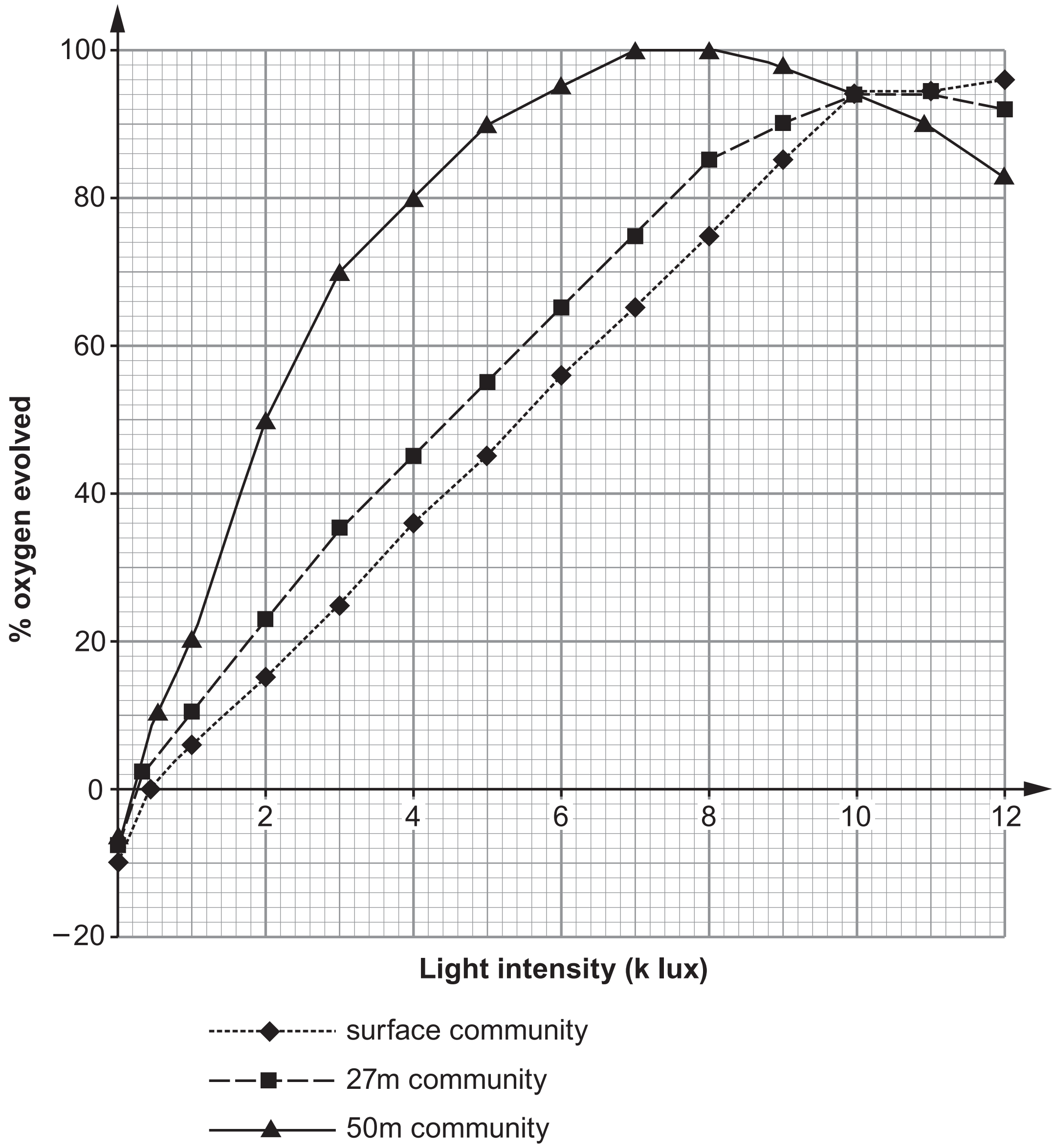


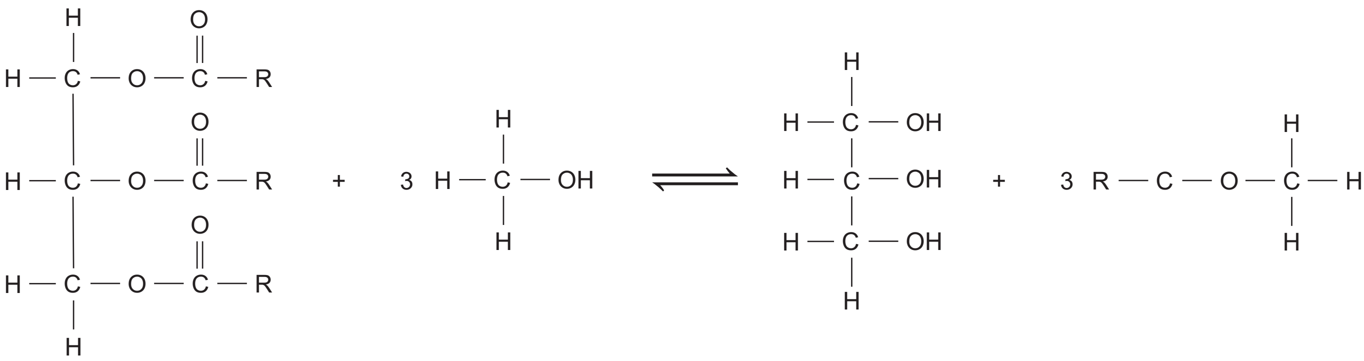
Figure 5 – Rate of photosynthesis as light intensity changes

Excess light energy may damage photosynthetic pigments. When more energy is absorbed than can be used in the Calvin cycle, it is released as heat. Only very small amounts of ATP and reduced NADP can accumulate. Algae near the surface of water are often saturated by light while those a few centimetres below the surface are light-limited. They are shaded by the algae in the water above them. High productivity can be achieved if there is rapid mixing so that cells spend time at the surface absorbing light and time in the shade using their small accumulation of ATP and reduced NADP. The cells must effectively be in rapidly flashing light. Rapidly mixing an algal culture requires a big input of mechanical energy.

Two contrasting approaches are being adopted by organisations developing algal biofuel technology. One is to grow the algae in shallow open ponds or channels. They are stirred continuously to bring cells repeatedly near to the surface. The advantage of this is the low initial cost but “wild” algal species are able to invade and to compete with the desirable strain of algae that is being used. The alternative is to grow the algae in photobioreactors. These are tubes or chambers through which the algal culture is continuously pumped. A turbulent flow is created so that cells are momentarily in bright light and then pass into the centre of the tube or plate so they are shaded by other cells. Contaminating species are excluded in bioreactors. Carbon dioxide enrichment is more easily provided. Photobioreactor technology on a sufficiently large scale to produce enough aircraft biofuel to meet demand is feasible, but it would not be economically competitive with petroleum fuel at current prices.

Formation of biofuel

Most of the lipid in algae is triglyceride. The technology of converting triglycerides to biodiesel is well established. The reaction is:



Triglyceride Methanol Glycerol Biodiesel

Methanol must be present in excess to ensure a good yield of biodiesel. Glycerol is also a valuable by-product.

Starch and cellulose derived from algae can be hydrolysed and fermented to produce ethanol – a well established alternative to petrol.

Different species of algae store relatively different amounts of lipids and starch. There is also variation in the proportion of saturated and unsaturated fatty acids present in the lipids of different algae. Researchers are investigating the thousands of species available to choose the most favourable and there is the possibility of using recombinant DNA technology to produce improved strains of these species. A laboratory-produced strain that gives high yields of the most suitable fatty acids must be able to grow and compete under the conditions found on an industrial scale.

Biofuel technology

Biofuels are already being produced from plants such as maize, sugar cane and oil palm. These crops grow on valuable agricultural land, often land which was formerly tropical rainforest. Algae are potentially more favourable as a biofuel source for several reasons:

- They can be more productive because they do not need to use any of their energy and nutrients to develop nonphotosynthetic components such as xylem and roots – all algal cells are photosynthetic.
- They lack molecules such as lignin that are difficult and expensive to remove during fuel manufacture.
- The growth of single celled algae is continuous rather than seasonal.
- Unproductive land, including desert areas, can be used to grow algae.
- They can be grown in waste water such as sewage effluent or water contaminated by heavy metal ions – some species are able to absorb heavy metal ions and store them, thus making waste water from mining much safer.
- Algae often synthesise valuable non-fuel by-products such as essential fatty acids.

The carbon footprint and other environmental impacts of any industrial process may be investigated by Life Cycle Analysis (LCA). LCA identifies all the significant inputs and outputs associated with a specified quantity of an industrial product. LCA was carried out for algal biodiesel, assuming the algae are to be grown in open channels.

Table 1 Energy used and CO_2 emitted while producing 24 kg algal biodiesel.

Operation contributing to production	**Energy used (MJ)**	**CO_2 emitted (kg)**
Growth of the cells	15	0
Harvesting cells (by filtration and drying)	2 915	242
Separation of triglycerides from the harvested cells	165	6
Transport of triglycerides for conversion	9	1
Conversion of triglyceride into diesel	36	3
Production and transport of methanol	72	0.1
Distribution of biodiesel to users	10	0.7
Production and transport of natural gas	70	0
Coproducts (eg ethanol, glycerol)	–9 972**	–274 **
Total for all significant operations	–6 680	–21
Negative values indicate a gain in energy or an absorbtion of CO_2 from the environment. **The energy which would be used and the CO_2 produced if these coproducts are manufactured by alternative processes.		

NB The combustion of 24 kg of diesel in an aircraft engine emits about 120 kg of CO_2, and provides 1000 MJ.

Table 2 Net emissions during the production of 24 kg of algal biodiesel

Type of emission		Mass emitted (kg)
VOC		–0.16
CO		–0.92
NO_x		–1.65
Particulate matter	PM 10 μm	–0.15
	PM 2.5 μm	–0.11
SO_x		1.34
CH_4		0.15
CO_2		–20.90
Other air emissions		8.44
Total air emissions		–13.96
Total waterborne emissions		18.60
Total solid emissions		0.28
Total radioactive species emitted		trace

Negative values indicate an absorption of a substance from the environment, eg NO_x may be absorbed from air by algae and used for their protein synthesis.

Tables 1 and **2** show where it is most important to increase efficiency or develop new processes if algal biofuel industries are to develop and replace fossil fuel.