Microalgal Biosequestration & Biofuel Production

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EXECUTIVE SUMMARY

Microalgal cultivation for biofuel is evaluated as strategy to mitigate climate change from a scientific, environmental and economic perspective.

The science is based on microalgae's ability to photosynthesize and to sequester CO_2 in algal biomass. The microorganisms can thrive on marginal land and in saline environments. In addition microalgae have the ability to grow rapidly and produces large quantities of triacyglycerols (TAGs) that through a process of transesterfication can be converted into biodiesel. A conceptual model of a carbon neutral plant and photobioreactor is described and shown diagrammatically.

Algal biosequestration and biofuel production is scientifically sound and technically feasible. It is an effective strategy to mitigate climate change because it removes CO_2 from the atmosphere, sequesters CO_2 emitted from coal fired power stations, replaces fossil fuel emissions with carbon neutral biofuel and has the potential to displace other biofuel crops that destroy rainforests. Because microalgae are only cultivated on otherwise non-arable land they do not displace food production and other forms of biosequestration such as forestry. However to make the biotechnology economically sustainable in Australia will require government intervention through the implementation of an effective emissions trading scheme and the provision of research funds in the early stages.

Introduction

Australia has long been at the leading edge of applied biological sciences and the research being done by Australian scientists on algal biotechnology is particularly suitable to Australia's vast arid landscape with limited freshwater resources (Garnaut 2008).

This report aims to evaluate algal biosequestration, in particular the mass cultivation of microalgae for biofuel, as a strategy to mitigate climate change. To achieve this aim it is necessary to examine how sustainable algal biosequestration is from a scientific, environmental and economic point of view. These issues will be considered in the context of the future development of a viable algal biosequestration and biofuel export industry in Australia.

The Science of Microalgae Cultivation for Biofuel

The Garnaut Climate Change Review defines biosequestration as 'the removal from the atmosphere and storage of greenhouse gases through biological processes' (Garnaut 2008 609). Like terrestrial plants, photosynthetic microalgae have the ability to process water, sunlight and carbon dioxide and sequester them in algal biomass (Christi 2008). Numerous microalgae species thrive on marginal land unfit for agriculture, need only brackish or saline water and the emissions of coal- fired power stations can provide a ready source of carbon dioxide (Griffiths & Harrison 2009).

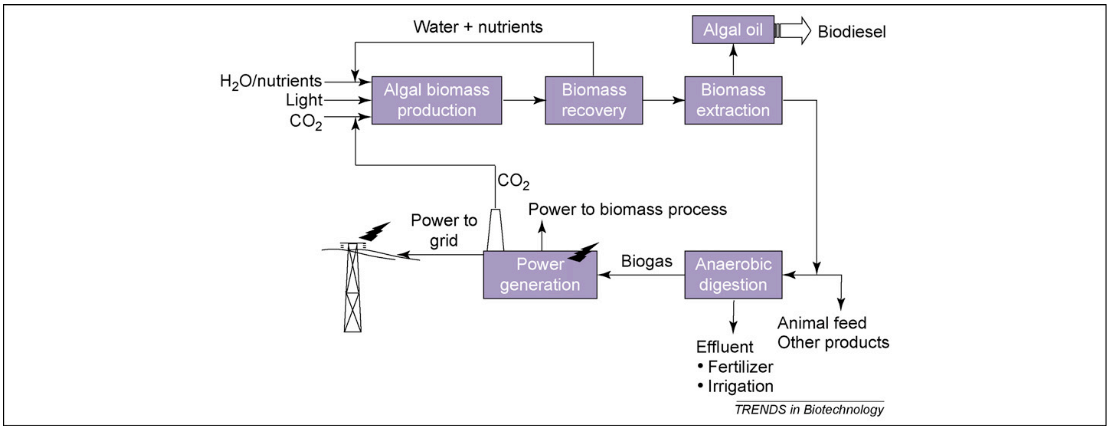
These carbon removal and storage capabilities of microalgae cultivation as strategy to mitigate climate change have excited international interest (Fluentes-Grunewald et al 2009). However that is far from the end of the story because many species of microalgae produce large amounts of oil that can be used as feedstocks for the production of biofuel (Hu et al 2008) that further assists climate change mitigation.

The production of biodiesel from algal oil can be carbon neutral because the carbon released into the atmosphere through combustion of biodiesel is offset by carbon sequestration in the photosynthetic process (Durrett et al 2008, Koh & Ghazoul 2008). Unlike burning fossil fuels there is no net addition in carbon emissions. Based on terrestrial crop data, replacing diesel with biodiesel reduces greenhouse gas emissions by an average of 54%, taking into account life cycle analysis (Koh & Ghazoul 2008). In principle a similar reduction is possible with algal- derived biodiesel because the latter process can be carbon neutral (see below).

Algal oil consists of triacylglycerols (TAG) that is a form of reduced carbon very common in nature and which is extremely energy-rich (Durrett 2008, Hu et al 2008). However TAGs are too viscous to be used directly in diesel engines and need to be converted to biodiesel through a process of transesterfication (Durrett 2008). The latter reaction transforms TAGs into fatty acid methyl esters (FAMEs) in the presence of an acidic or alkaline catalyst and an alcohol (Fluentes-Grunewald et al 2009)

Figure 1 shows an integrated oil-production process from marine algae which results in the sequestration of about 183 tons of $C0_2$ per 100 tons of algal biomass (Christi 2008).

Figure1: Production of Biodiesel from Algal Oil
Source:Christi (2008)

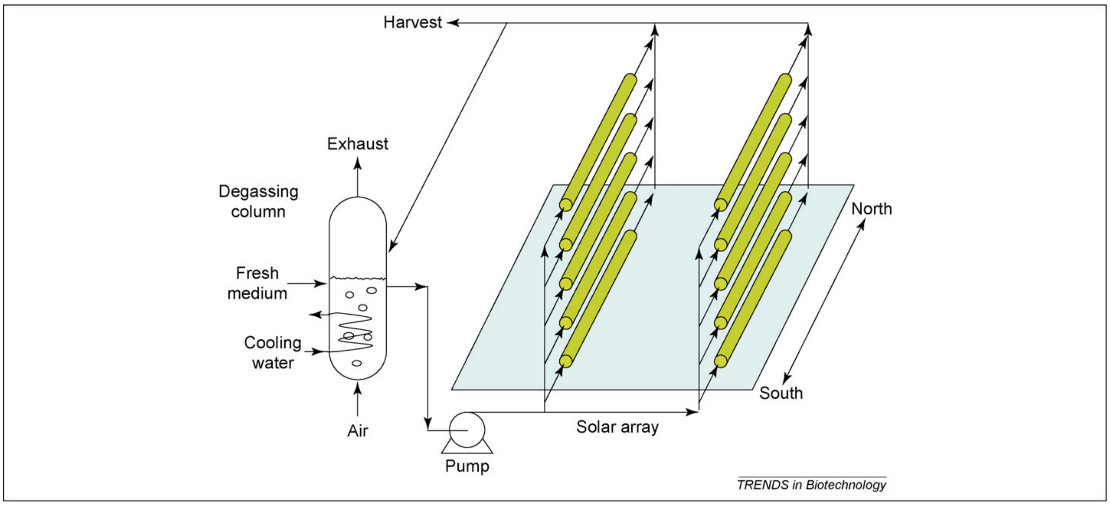


The above process is carbon neutral because all the power used to produce and process the algae comes from a combination of the biodiesel primary product and the biogas manufactured by the anaerobic digestion of what remains of the biomass after the oil has been extracted (Christi 2008).

There is considerable debate in biotechnology circles about the best way to produce algal biomass. Open ponds have the advantage of being relatively economical, easy to maintain and suitable for mass cultivation but suffer from a lack of productivity, contamination and poor control over culture conditions. Photobioreactors afford much better control, reduce evaporation and improve productivity. Some such as tubular photobioreactors are also relatively cheap and are very suitable for outdoor cultures (Ugwu et al 2008).

An example of the latter type of photobioreactor is shown in Figure 2 below.

Figure 2 A Tubular Photobioreactor
Source:Christi (2008)



In the above photobioreactor the algal broth absorbs sunlight as it is pumped continuously through the solar array and degassing column. Water is used to cool the degassing column that is constantly aerated to remove oxygen produced through photosynthesis. An exhaust system removes the oxygen- rich gas from the degassing column. The amount of fresh culture medium fed into the degassing column is balanced by an equal amount of algal broth harvested from the stream before it makes it way back to degassing column as shown in Figure 2 (Christi 2008).

Lee et al (2009) point out that harvesting marine microalgae biomass to make biodiesel is technically challenging and thus presents an obstacle to economic production. However in experiments on microbial flocculation, a team of scientists from the University of Adelaide were able to achieve 'a significant improvement over other commercial harvesting methods' (Lee et al 2009 565)

Environmental Effectivness

The above discussion has demonstrated algal biosequestration's ability to mitigate climate change through the removal of CO_2 from the atmosphere, the sequestration of CO_2 emitted from fossil fuel-fired power stations and the replacement of fossil-fuels with biodiesel. However another important climate change benefit of cultivating microalgae for biofuel is its potential to replace biofuel production from terrestrial crops such as palm oil.

The cultivation of palm oil has caused the widespread destruction of rainforest in tropical areas. In Malaysia increases in areas under oil palm production between 1990 and 2005 resulted in the loss of 1.1 million hectares of forest while the corresponding loss for Indonesia was 28.1 million hectares (Fitzherbert et al 2008). Rainforests are more effective carbon sinks than monoculture crops and there are substantial net greenhouse gas emission increases associated with clearing forests, peat soil dessication and fossil fuel use in planting, transport and processing (Fitzherbert et al 2008). A worldwide study showed that the conversion of native habitats to cultivate biofuel, together with the associated land-use changes, would lead to a carbon debt of between 333 and 3003 tons of $C0_2$ per hectare and would take between 17 and 423 years to repay (Koh & Ghazoul 2008).

Owing to algae's ability to synthesize and accumulate large quantities of oil, grow at high rates and tolerate degraded environments not suitable for growing anything else (Hu et al 2008) the cultivation of microalgae for biofuel has the potential to displace the environmentally destructive production of biofuel from terrestrial crops such as palm oil. Garnaut (2008) estimates that annual algal oil production could exceed 30 000 litres per hectare, a potential yield more than ten times the next most productive biofuel crop, palm oil that currently yields about 2 400 litres per hectare.

Economics

As discussed above, microalgae cultivation for biofuel is feasible from a scientific point of view (Christi 2008) and the environmental benefits as a strategy for climate change mitigation are considerable. The main obstacles to large- scale commercial production are economic (Griffiths & Harrison 2009).

Algal productivity is a big issue because although researchers attain high yields in the laboratory the results have yet to be replicated in large-scale commercial production (Griffiths & Harrison 2009). As indicated above harvesting of algal biomass is difficult (Lee et al 2008) and constitutes a substantial operating and capital cost (Griffiths & Harrison 2009). Hu et al (2008) observes that more research is needed into the biosynthesis of TAGs and that resources need to be channeled into pilot plants located in appropriate environments.

However these stumbling blocks to economic production should be regarded as short-term. Economic theory holds that countries should specialize in industries in which it has a long-term *comparative advantage* relative to other countries (Frank & Bernanke 2007).

Australia has a comparative advantage in microalgae cultivation for biofuel because it has an abundance of saline environments in which marine algae thrive, has many coal-fired power stations to provide the CO_2 algae require and is at the leading edge of worldwide biotechnology research (Garnaut 2008). However the technology is expensive and left to itself the market will not provide the necessary investment to bring algal bisequestration into commercial production (Garnaut 2008).

The Garnaut Climate Change Review (2008) estimates that a carbon price of at least $100 per tonne would be necessary to stimulate the required innovation and investment to make the technology viable. If and when that happens, microalgal cultivation for biofuel will not only provide many green jobs but lift Australia's export earnings through sale of microalgal feedstocks and biofuel, sale of carbon credits on the international carbon market and sale of algal biotechnology and expertise.

Conclusion

Algal biosequestration and biofuel production is scientifically sound and technically feasible. It is an effective strategy to mitigate climate change because it removes CO_2 from the atmosphere, sequesters CO_2 emitted from coal fired power stations, replaces fossil fuel emissions with carbon neutral biofuel and has the potential to displace other biofuel crops that destroy rainforests. Because microalgae are only cultivated on otherwise non-arable land they do not displace food production and other forms of biosequestration such as forestry. However to make the biotechnology economically sustainable in Australia will require government intervention through the implementation of an effective emissions trading scheme and the provision of research funds in the early stages.

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