

Project report: Biofuel from microalgae: efficient separation, processing & utilisation of algal biomass



Lead organisation: The University of Melbourne

Project partners: Bio Fuels Pty. Ltd. (A division of the Victor Smorgon Group)

Project commencement and completion date: February 2010 - June 2012

Project summary

Currently, conventional fuels from fossil fuel sources represent 95 per cent of Australia's transport fuel consumption. Of these, diesel is the primary fuel used in the freight transport, mining and agricultural sectors, and is driving the growth in fuel imports. However, Australia has an opportunity to capitalise on its natural comparative advantages and agricultural expertise to develop an advanced biofuels industry, using feedstocks such as algae, to increase fuel security and reduce greenhouse gas emissions.

The aim of this project was to develop an effective, scalable technology to produce biodiesel and other valuable by-products from microalgal biomass harvested from large-scale algal farms. Prior to this project there was no clear method available that was ready for commercial-scale implementation and insufficient information available to evaluate the economics of such a process.

It was supported through the Second Generation Biofuels Research and Development (Gen 2) Program, which supported the research, development and demonstration of new biofuel technologies and feedstocks that address the sustainable development of an advanced biofuels industry in Australia.

The first phases of the project evaluated potential methods for extracting lipids from microalgal biomass and compared different microalgal species to determine the most effective strain to use. Preliminary technical and economic assessments of the shortlisted processes were performed followed by lab-scale experiments of those determined to have the most promise.

From this work, *Nannochloropsis* sp., a marine microalgae, was found to be the most economic strain and a scalable two-step process was developed to break apart the algal cells to allow access to the lipids that can be converted to biodiesel. The process then involves separating the lipids for biodiesel production using a chemical called hexane. The remainder of the 'de-lipidated' algal biomass is then dried in a solar dryer to produce a high-protein animal or aquaculture feed.

An economic assessment to determine the feasibility of the overall process predicted a broad range of potential returns on investment, depending on process and external economic factors (e.g. the price of oil and feed). A small-scale demonstration of the process was performed, which proved that the processes developed were effective for producing high yield, clean lipids for biodiesel production;

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however further refinement and scale-up of the technology would improve its efficiency and economics.

Project scope

The aim of this project was to develop an effective, scalable, economic technology to produce biodiesel and other valuable by-products from microalgal biomass harvested from large-scale algal farms. Microalgae are small aquatic photosynthetic organisms that use solar energy to power conversion of CO₂ into cellular biomass which can be converted to value-added products, including biodiesel. The advantages of microalgae include:

- High productivity - algae grow quickly and offer a high yield of energy per hectare of cultivation;
- No competition with food crops - algae can grow on non-arable land and can sometimes use saline or waste water; and
- Greenhouse gas emissions reduction - algae use CO₂ to grow, which can sometimes be sourced directly from high-emitting industries, and may further reduce emissions by displacing existing fossil fuel sources.

Objectives of the project:

- Assess existing technologies that could be applied to the processing of microalgal biomass.
- Develop a body of experimental data to assess the technical feasibility of the process options and develop process models to evaluate economic feasibility.
- Develop a detailed understanding of how various attributes of different microalgal species affect the efficiency of processing to select a preferred strain of microalgae.
- Optimise the process parameters and demonstrate the process for producing biodiesel and other products at larger scale using the preferred strain of microalgae.

Outcomes

Technical developments and key findings include:

- Development and application of methods for extracting and characterising lipids from microalgal biomass

Methods were developed to allow a more complete understanding of lipids present in microalgal biomass that are required for producing products including biodiesel and co-products.

- Development of an effective, scalable process for extracting lipids from algal biomass

An effective extraction process was developed that can be scaled using readily available processing equipment and has scope for further development and improvement.

- Development of process model and economic assessment tool

The process model developed during this project is a valuable tool that has allowed an assessment of the economics of the process, including the range of returns that can be expected from a commercial scale operation.

- Testing and demonstration of the lipid extraction process

In the final phase of this project the effectiveness of a novel process for extracting lipids from a 25% solids paste of *Nannochloropsis* sp. algae was demonstrated.

- Effectiveness and need for cell disruption

The project demonstrated that breaking apart of the algal cells is required to achieve effective extraction from wet algal paste. The low-cost two-stage cell disruption method developed in this

project has been demonstrated to be highly effective and reliable and is a significant development for the field as it will significantly lower the processing costs associated with microalgal lipid extraction (and other products).

- Effectiveness of wet hexane extraction

It was shown that solvent extraction in an agitated vessel using hexane is effective for extracting lipids from wet algal biomass. This process is effective with much lower quantities of solvent than have previously been required, greatly increasing process efficiency. As a result of the recent successful experiments with hexane, the team identified a potentially promising way of adapting its process to further reduce the use of solvent, therefore reducing time and cost. This is an avenue for exploration in the future.

- Importance of algae paste properties

The University demonstrated that its process can handle a paste of between 20-25% w/w solids concentration, which is much higher than most other processing options, and better than the original target for the process of 15-20%. Being able to operate at such high solids reduces the volumes of material to be processed, greatly improving process efficiency. The project found that the flow properties of the biomass, which may change with different algal species, need to be considered to maximise process efficiency.

- Importance and difficulties in drying

Removal of the remaining water, or drying to about 80-90% w/w solids, is an important aspect of any downstream process. While the use of heat-driven drying technologies, such as spray drying, are effective, they require too much energy to be feasible. Although somewhat costly, solar dryers, such as those used to dry wastewater sludge, are not prohibitively expensive and directly utilise solar energy improving the sustainability of the process. The rate of drying and methods for handling the stickiness of the paste remain challenges in implementing this technology.

- Importance and uncertainty in protein feed price

The economic assessment identified the protein feed price as one of the most important variables in defining the profitability of the process. Despite an investigation into the likely price of an algal feed from the process developed in this project, much uncertainty in the value assigned remains, as a defined market for this product has yet to be established.

Products, patents (applied/granted) and publications produced as part of the project

While there was a commercial focus to this project, a number of scientific developments were made that are at various stages of publication in international journals. In the process of screening strains of algae, methods for quantifying the breakage of cells were developed and compared using a model microorganism. This work has recently been published in *Biochemical Engineering Journal*¹. These methods were also applied to the three leading strains of algae used in this project, and the relative strength of the cells compared accurately. This work has been submitted for publication in *Bioresource Technology*.

In this project methods for characterising lipids were developed that allow more complete understanding of the fatty acid profiles of both the neutral and membrane lipid components of algal sources. A paper has recently been published in *Biotechnology and Bioengineering*² that considers these methods in the context of biodiesel and omega-3 production. This paper provided for the first time a detailed picture of changes in lipid profile resulting from nutrient deprivation of two different species of microalgae of promise for biodiesel production: *Chlorella* sp. and *Nannochloropsis* sp. Another paper is in preparation that will report on another novel analytical method (high-performance liquid chromatography - mass spectroscopy) that has been used to characterise the changes to all of the different lipids in these two species during growth without nitrogen. These methods are powerful new tools that will be used to better understand how the way in which algae are grown affects how the biomass must be processed.

Also in preparation is a manuscript detailing the results from the demonstration of the wet hexane extraction method developed in this project. This paper will be the first to show that neutral lipids can be successfully extracted from wet pastes of *Nannochloropsis* sp. biomass using such low amounts of solvent.

¹ Spiden EM, Scales PJ, Kentish SK, Martin GJO. 2013. Critical analysis of quantitative indicators of cell disruption applied to *Saccharomyces cerevisiae* processed with an industrial high pressure homogenizer *Biochemical Engineering Journal*, 70:120-126.

² Olmstead ILD, Hill DRA, Dias DA, Jayasinghe NS, Callahan DL, Scales PJ, Kentish SE, Martin GJO. 2013. A quantitative analysis of microalgal lipids for optimization of biodiesel and omega-3 production. *Biotechnology and Bioengineering* DOI: 10.1002/bit.24844.

Ancillary benefits

The team for this project included one PhD student whose thesis will soon be completed. In addition, two other PhD projects have been started on the basis of the work performed in the project. These projects have been funded separately from the grant, adding value to the overall project outcomes. Project results have informed teaching of Masters level subjects at The University of Melbourne and been used as the basis of final year undergraduate research projects.

The project has also led to a new University of Melbourne funded project that will utilise the lipid characterisation methods to further explore the effect of growth conditions on the lipid content of these algae. This project involves collaboration with Metabolomics Australia and will employ one of the previous project personnel on a part-time basis.

The project has also led to The University of Melbourne partnering with an algae biotechnology company and another leading Australian University in a current application for funding through the ARENA Emerging Renewables Program. This would allow further development and demonstration of the processes developed in this project.

Finally, the insights into cell disruption developed during this project have led to a new line of research looking into the fundamental mechanisms of cell disruption in high pressure devices. This research is being undertaken in partnership with a major process equipment manufacturing company, and will likely develop into a larger body of work involving PhD students.

Effectiveness

The University has developed an effective method for processing algal biomass into biofuel and protein feed. The method could be scaled up further and still be effective. While this process is effective, novel, and represents a significant advance, it is a baseline process upon which further improvements could be made.

Microalgae have significant advantages over traditional renewable fuel and are one of the attractive options for second generation biofuel production. They are extremely fast-growing, and can be produced throughout the year with potential yields up to one hundred times greater than other renewable crops. Able to grow on non-arable land using saline or grey water sources, they do not compete for resources with food producing crops.

Compared to using fossil fuels, the production of biofuel from microalgae is an essentially carbon-neutral process, with the CO₂ released during fuel combustion originating from the CO₂ absorbed by the algae. Climatically, Australia is one of the best-positioned countries to develop and implement biofuel production from microalgae, with much of the country ideally suited to rapid growth.

In comparison to the amount of work done on algal cultivation over the last half a century, little progress has been made in the development and demonstration of processes for converting algal biomass into biodiesel and co-products, a gap this project has addressed. While the project partner, Bio Fuels Pty Ltd had experience growing and harvesting algal biomass using a pilot scale production facility and commercial experience in the production of biodiesel from lipid feed stocks, at the start of this project there was no clear method available for effective downstream processing of algal biomass that was ready for commercial scale implementation. There was also insufficient

information available to evaluate the economics of such a process. Both of these challenges have now been addressed.

Transferability

The process model developed during this project is a valuable tool for assessing the economics of microalgal projects. The methods developed for quantifying the cell rupture and characterising the lipid content of microalgae will be valuable to other researchers in the field. The insights into downstream processing of microalgae that have or will soon be published in international journals will contribute to the development of this technology.

Conclusion and next steps

The University developed the capabilities and expertise to build further on the development of its method for processing algal biomass into biofuel and protein feed.

Areas for further research and development include:

- Reducing the solvent demand by improving the methods to separate the lipids from the biomass.
- A large-scale project to look at customised solar drying systems integrated with process waste heat and exploring how to modify paste properties to increase the rate of drying.
- Digestion and nutritional studies and market analysis of protein feed.

Each of these activities represents significant research projects that probably require a number of years to perform.

While it is worthwhile investing further in improving this process, it is clear from the marginal economic assessment that the viability of such a process is highly dependent on external market factors. Currently it appears that in the short-term this process would require production of a higher value co-product such as omega-3 fatty acids.

While the process developed in this project did not focus on including omega-3 production, it has been designed such that it could be modified for this purpose. In the long term it appears that three things are required for large scale implementation:

1. More fundamental and applied R&D to help further improve and refine algal growth and downstream processing
2. Demonstration scale processing to gain experience and reduce uncertainty and risk
3. Increase in the market price of protein and biofuel.

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