Challenges and opportunities for biodiesel from algae: approaches by CSIRO, Australia

Susan I. Blackburn, Tom Beer and Kurt Liffman

Energy Transformed National Research Flagship

Biofuels Symposium, Tsukuba, Japan, August 2009
CSIRO Energy Transformed Flagship Team

- Tom Beer – Biofuels Stream Leader; Prefeasibility study
- Susan Blackburn – Strain selection and optimisation
- Kurt Liffman – Thermal and fluids engineering

- David Batten
- Peter K. Campbell
- Chong Wong
- Ben Aldham
- Greg Griffin
- Greg Threlfall
- John Volkman
- Graeme Dunstan
- Dion Frampton
- Lesley Clementson
- Nicolas Labriere
- Ian Jameson
- Lisa Albinsson

Photo Martina Doblin

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Diesel use growing more rapidly than petrol

Australian Petroleum Consumption

- Petrol (ML)
- Diesel (ML)

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Why Algae?

• Worldwide interest in making biofuels from biomass is high:
  • global warming associated with higher levels of GHG emissions
  • onset of peak oil in a global economy
  • national energy security concerns, and
  • perceived opportunities for more sustainable, regional development.

• Algae produced most fossil fuels in the first place.
  • Microalgae are diverse, grow rapidly, yield more biofuel than oil plants, can
    sequester CO₂, contain no sulphur, are highly biodegradable & are less
    competitive with other plants as a source of human food, fibre or other
    products.

• Already they are aqua-cultured to produce various high-value foods,
  nutraceuticals and chemicals
  • Methods adopted have not yet proved to be economically and ecologically
    viable for the production of biodiesel or other biofuels in quantities large
    enough to replace fossil fuels.
Australia’s competitive advantage

Köppen's Climate Classification
by FAO - SDRN - Agrometeorology Group - 1997

15°C or higher

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Australian algae industry

Cognis algae lakes, Whyalla, South Australia (also Western Australia)

Nutraceuticals – largest global producer natural β-carotene; food / feed colourants
Without further research:

Most dedicated algae-to-biodiesel projects will face uneconomically high costs for:

• Algal selection and optimization
• Site acquisition and preparation
• Bioreactor construction materials
• Construction, deployment and reconstruction
• Chemical and energy inputs
• Algal harvesting, dewatering and concentration
• Lipid extraction
• Biodiesel and by-product processing
• Surveillance, process control and maintenance
• Transport

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“Minister for Resources and Energy, Minister for Tourism
SECOND GENERATION BIOFUELS FUNDING ANNOUNCED

The Minister for Resources and Energy, Martin Ferguson AM MP, today announced the successful applicants for funding under the Australian Government’s $15 million Second Generation Biofuels Research and Development Program.

The Second Generation Biofuels Research and Development Program supports the research, development and demonstration of new biofuel technologies which address the sustainable development of the biofuels industry in Australia.”
Three major challenges are identified:

- Develop and apply (in consultation with stakeholders) a sustainability framework to assess the triple-bottom line status of biofuels.

- Discover, develop and use innovative Australian algal strains and enzymes to improve efficiencies of biofuel production.

- Scale up operations to a) continuous and b) commercially viable operations.
Algae to Biodiesel Pathway

- Selection of micro algae species
- Growth of micro algae
- Harvesting of micro algae
- Extraction of oil from micro algae
- Oil for processing into biofuel
- Extraction of protein
- Dewatering and extrusion
- Residual micro algae
- Digestion/Gasification and Combustion
- Green Electricity

High protein content (up to 35%)

- Further treatment to recover other valuable material?
- Waste liquor

- • Aquafeed
- • Animal feed
- • Pet feed

- Incorporate into human foods

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Algae to Biodiesel Pathway

**Pre-Feasibility Study**
- Selection of micro algae species
- Growth of micro algae
- Harvesting of micro algae
- Extraction of oil from micro algae
- Oil for processing into biofuel
- Extraction of protein
- Dewatering and extrusion
- Digestion/Gasification and Combustion
- Waste liquor
- Residual micro algae
- Dewatering and extrusion
- Green Electricity
- GLYCERINE
- BIODIESEL

**Projects**
- Project on algal speciation
- Project on thermal and fluids engineering

**Further treatment to recover other valuable material?**

**Selection of micro algae species**

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Pre-feasibility study

• Objectives:

• To estimate the realistic potential size of microalgae’s contribution to supplement Australia’s conventional fossil fuels;
• To place bounds on Australian microbial biomass production under different land-use scenarios and process technologies;
• To quantify the greenhouse gas benefits that could emerge as a result of producing biodiesel from algae;
• To examine the possible co-product implications; and
• To provide an indicative evaluation of the triple bottom line benefits associated with the use of algae (and especially microalgae) as a biofuel.

• Project leader:
  • Tom Beer
Life Cycle Analysis
(Full Fuel Cycle or Well-To-Wheel analysis)

The Carbon Cycle

- Carbon dioxide is used to grow algae
- The oil is extracted
- Carbon dioxide is used to grow algae
- Transesterified to biodiesel
- $\text{CO}_2$ that releases carbon dioxide
- Used as an alternative fuel
Life Cycle Analysis
(Full Fuel Cycle or Well-To-Wheel analysis)

The Carbon Cycle

carbon dioxide is used to grow algae

the oil is extracted

carbon dioxide is used to grow algae

transesterified to biodiesel

CO₂

that releases carbon dioxide

used as an alternative fuel

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Life Cycle Analysis
(Full Fuel Cycle or Well-To-Wheel analysis)

The Carbon Cycle

- carbon dioxide is used to grow algae
- the oil is extracted
- carbon dioxide is used to grow algae
- tranesterified to biodiesel
- CO₂ that releases carbon dioxide
- used as an alternative fuel

Do these processes emit more or less carbon dioxide than petrol (or coal) and its manufacture?
Scenarios – Ponds only

Cognis, AquaCarotene, Beta Nutrition


(Google Earth images)
Bioreactors or ponds?

*Spirulina and Haematococcus Cultivation at Cyanotech Corp., Hawaii.*

*Spirulina:* blue-green ponds, *Haematococcus:* orange-red ponds

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Life Cycle Analysis – Design variables

LIQUID FUELS FROM MICRO-ALGAR IN AUSTRALIA

by

D.L. Regan and C. Garstea
CSIRO Division of Chemical Technology
South Melbourne, Victoria

National Library of Australia Cataloguing-in-Publication Entry

Regan, D. L.
Liquid fuels from micro-algae in Australia.
ISBN 0 643 03503 6
667.569

FINAL REPORT

to the
Department of Energy
Pittsburgh Energy Technology Center
under
Grant No. DE-FG22-93PC93204

SYSTEMS AND ECONOMIC ANALYSIS
OF MICROALGAE PONDS
FOR CONVERSION OF CO2 TO BIOMASS

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March 21, 1996

Assume raceway ponds instead of tidal mixing

Assume 30 g/(m2-day) [110 t/(ha-yr)] and 15 g/(m2-day) [55 t/(ha-yr)]
Carbon Dioxide Emissions per Litre

- Biodiesel, algal, 100% CO2 (ammonia plant), AT
- Biodiesel, algal, 15% CO2 (flue gas) - power station, AT
- Biodiesel, algal, 100% CO2 (truck delivered), AT
- Biodiesel, canola, AT
- ULS diesel, AT

CO2-e (all tailpipe) g CO2-e
CO2-e (all upstream) g CO2-e

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Greenhouse Gas Emissions per Litre

- Biodiesel, algal, 100% CO2 (ammonia plant), AT
- Biodiesel, algal, 15% CO2 (flue gas) - power station, AT
- Biodiesel, algal, 100% CO2 (truck delivered), AT
- Biodiesel, canola, AT
- ULS diesel, AT

GHG-CO2-e (fossil tailpipe) g CO2-e
GHG-CO2-e (fossil upstream) g CO2-e

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Costs per Litre  30 g/(m²-day) [110 t/(ha-yr)]

- Cost, excise 2008A$
- Cost, capital 2008A$
- Cost, transformation & dist 2008A$
- Cost, feedstock 2008A$

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Costs/L (if only 50% yield) $15 g/(m²-day) [55 t/(ha-yr)]

- Cost, excise 2008A$
- Cost, capital 2008A$
- Cost, transformation & dist 2008A$
- Cost, feedstock 2008A$

Excise regime from 2015 will disadvantage biodiesel more.

$\text{Biodiesel, algal, 100\% CO}_2 (\text{ammonia plant}, \text{AT})$
$\text{Biodiesel, algal, 15\% CO}_2 (\text{flue gas})$
$\text{Biodiesel, algal, 100\% CO}_2 (\text{truck delivered}, \text{AT})$
$\text{Biodiesel, canola, AT}$
$\text{ULS diesel, AT}$

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Greenhouse gas emissions per litre

- Biodiesel, algal, 100% CO2 (ammonia plant), AT
- Biodiesel, algal, 15% CO2 (flue gas) coal power plant, AT
- Biodiesel, algal, 100% CO2 (truck delivered), AT
- Biodiesel, canola, AT
- ULS diesel, AT

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Greenhouse gas emissions per litre

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>CO₂-e (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel, algal, 100% CO₂ (ammonia plant)</td>
<td>103.6c</td>
</tr>
<tr>
<td>Biodiesel, algal, 15% CO₂ (flue gas)</td>
<td>111.0c</td>
</tr>
<tr>
<td>Coal power plant, 100% CO₂ (truck delivered)</td>
<td>155.4c</td>
</tr>
<tr>
<td>Biodiesel, canola, 100% CO₂ (truck delivered)</td>
<td>81.4c</td>
</tr>
<tr>
<td>ULS diesel</td>
<td>140.6c</td>
</tr>
</tbody>
</table>

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Greenhouse gas pollution cost ($/tonne)

- Biodiesel, algal, 100% CO2 (ammonia plant), AT: 3500 g CO2-e
- Biodiesel, algal, 15% CO2 (flue gas) coal power plant, AT: 3500 g CO2-e
- Biodiesel, algal, 100% CO2 (truck delivered), AT: 111.0c
- Biodiesel, canola, AT: 155.4c
- ULS diesel, AT: 140.6c

$468/tonne pollution emission cost

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Greenhouse gas abatement costs ($/tonne)

- Biodiesel, algal, 100% CO2 (ammonia plant), AT: $257/t
- Biodiesel, algal, 15% CO2 (flue gas) coal power plant, AT: $211/t
- Biodiesel, algal, 100% CO2 (truck delivered), AT: $411/t
- Biodiesel, canola, AT: $926/t
- ULS diesel, AT: $140.6c

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Greenhouse gas abatement costs ($/tonne)

Biodiesel, algal, 100% CO2 (ammonia plant), AT
Biodiesel, algal, 15% CO2 (flue gas) coal power plant, AT
Biodiesel, algal, 100% CO2 (truck delivered), AT
Biodiesel, canola, AT
ULS diesel, AT

Algae using power plant flue gases is the optimum algal GHG strategy

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Life Cycle Analysis

Algal strain selection and optimisation

Objective:

To identify and characterise, develop, enhance and trial Australian endemic microalgae with the best growth rates, oil profiles and productivity for production technologies selected and developed by CSIRO and / or industry partners, for biodiesel and co-product applications, including GHG abatement, and suitable for Australian conditions and environments.

Project leader:
Susan Blackburn
Algal Production: algae produce high biomass in nature (algal blooms)

Dinoflagellate bloom, eastern Tasmania

Cyanobacterial bloom, Queensland
# Fatty acid composition

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>BDF from Crude palm oil</th>
<th>Crude coconut oil</th>
<th>Lipids from Dunaliella maritima</th>
<th>Dunaliella salina</th>
<th>Chlorella vulgaris</th>
<th>Polytoma oviforme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caproic acid, C8:0</td>
<td>-</td>
<td>7.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Capric acid, C10:0</td>
<td>-</td>
<td>5.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lauric acid, C12:0</td>
<td>0.35</td>
<td>49.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Myristic acid, C14:0</td>
<td>0.92</td>
<td>18.8</td>
<td>0.4</td>
<td>0.5</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Palmitic acid, C16:0</td>
<td>44.1</td>
<td>8.6</td>
<td>11.8</td>
<td>17.8</td>
<td>19.6</td>
<td>39</td>
</tr>
<tr>
<td>Stearic acid, C18:0</td>
<td>4.4</td>
<td>2.7</td>
<td>0.4</td>
<td>1.5</td>
<td>3.3</td>
<td>3</td>
</tr>
<tr>
<td>Arachidic acid, C20:0</td>
<td>0.09</td>
<td>0.18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Sum of Saturated FA</strong></td>
<td><strong>49.8</strong></td>
<td><strong>93.1</strong></td>
<td><strong>12.6</strong></td>
<td><strong>19.7</strong></td>
<td><strong>25.7</strong></td>
<td><strong>42.0</strong></td>
</tr>
<tr>
<td>Palmitoleic acid, C16:1</td>
<td>-</td>
<td>-</td>
<td>4.2</td>
<td>2.5</td>
<td>8.8</td>
<td>2</td>
</tr>
<tr>
<td>Oleic acid, C18:1</td>
<td>39.0</td>
<td>5.5</td>
<td>2.5</td>
<td>3.4</td>
<td>7.3</td>
<td>31</td>
</tr>
<tr>
<td>Linoleic acid, C18:2</td>
<td>11.2</td>
<td>1.3</td>
<td>4.1</td>
<td>6.1</td>
<td>11.8</td>
<td>5</td>
</tr>
<tr>
<td>Linolenic acid, C18:3</td>
<td>0</td>
<td>0.07</td>
<td>45.8</td>
<td>39.4</td>
<td>22.6</td>
<td>8</td>
</tr>
<tr>
<td><strong>Sum of Unsaturated FA</strong></td>
<td><strong>50.2</strong></td>
<td><strong>6.9</strong></td>
<td><strong>87.4</strong></td>
<td><strong>80.3</strong></td>
<td><strong>74.3</strong></td>
<td><strong>58</strong></td>
</tr>
</tbody>
</table>

Sums for algae include other fatty acids.
### Oil content as % dry weight for some microalgae grown under nutrient-sufficient conditions

<table>
<thead>
<tr>
<th>Species</th>
<th>Lipid %</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorella emersonii</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>Chlorella minutissima</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>Chlorella sorokiniana</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Chlorella vulgaris</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Dunaliella salina</td>
<td>14.4</td>
<td>2</td>
</tr>
<tr>
<td>Dunaliella primolecta</td>
<td>23.1</td>
<td>3</td>
</tr>
<tr>
<td>Isochrysis galbana</td>
<td>21.9-38.5</td>
<td>4</td>
</tr>
<tr>
<td>Nannochloropsis sp.</td>
<td>33.3-37.8</td>
<td>5</td>
</tr>
<tr>
<td>Nitzschia closterium</td>
<td>27.7</td>
<td>2</td>
</tr>
<tr>
<td>Phaeodactylum tricornutum</td>
<td>19.8</td>
<td>3</td>
</tr>
<tr>
<td>Tetraselmis suecica</td>
<td>20-30</td>
<td>6</td>
</tr>
</tbody>
</table>


Choice of species is critical
Australian National Algae Culture Collection

• CSIRO National Biological Collections: Algae – a living collection

• 1000 strains of more than 300 microalgae species

• unique Australian biodiversity, sourced from the tropics to Antarctica, marine and freshwater microalgal classes

• isolation of new strains from Australia’s biodiversity

• strain characterisation: taxonomic identification, chemical & molecular characteristics, growth parameters

Algal Culture Facility

• Controlled environment rooms and cabinets

• Secure facility - AQIS
Number of Strains in the Collection, October 2008

- **Bacillariophyceae**: Red (Rest of world), Blue (Australian)
- **Chlorophyceae**: Red (Rest of world), Blue (Australian)
- **Cryptophyceae**: Red (Rest of world), Blue (Australian)
- **Cyanophyceae**: Red (Rest of world), Blue (Australian)
- **Dictyochophyceae**: Red (Rest of world), Blue (Australian)
- **Euglenophyceae**: Red (Rest of world), Blue (Australian)
- **Eustigmatophyceae**: Red (Rest of world), Blue (Australian)
- **Pelagophyceae**: Red (Rest of world), Blue (Australian)
- **Prasinophyceae**: Red (Rest of world), Blue (Australian)
- **Prymnesiophyceae**: Red (Rest of world), Blue (Australian)
- **Rhodophyceae**: Red (Rest of world), Blue (Australian)
- **Rhodophyceae**: Red (Rest of world), Blue (Australian)
- **Rhodophyceae**: Red (Rest of world), Blue (Australian)
- **Rhodophyceae**: Red (Rest of world), Blue (Australian)
- **Zoanthidae**: Red (Rest of world), Blue (Australian)

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Screening of the Australian National Algae Culture Collection (ANACC)

Characterise selected strains for:

‘Biodiesel’ Analysis
• Fatty acid methyl esters (FAME or biodiesel)

As well as ‘Co-product’ Analysis:
• Pigments
• Phytosterols
• Diacylglycerol ethers
• Hydroxy fatty acids
• Long chain ketones and fatty acids
• Other novel lipids

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New Australian strain isolation: Biorational discovery

• Biomass production / oils and other products
  • growth rate; productivity; biomass production
  • lipid profile; oil content
  • co-products e.g. protein, carbohydrates, pigments / antioxidants, omega-3 oils, etc.

• Biogeography / environment
  • Australian – endemic: AQIS issues
  • climatic zones: temperate, sub-tropical, tropical
  • water supply / quality
    • extremophiles e.g. hypersaline
    • wastewater: algae for bioremediation

• Technologies
  • open ponds or photobioreactors or a combination of both
  • flue gas / CO₂ sources (high CO₂ assimilation)
New Strains isolated 2009

Hypersaline 13 cf Dunaliella

Hypersaline 40 cyanobacteria

KTPL3-19 Closterium sp.

BBUL04 Botryococcus

Lauderia annulata

DF_Hypersaline Nitzschia closterium
Botryococcus braunii: source of long-chain hydrocarbons

Up to 86% of the dry weight of the green alga Botryococcus braunii can be long-chain hydrocarbons. The composition depends on the particular “race” of Botryococcus. The classic hydrocarbons are called botryococcenes. These are C_{30}-C_{37} isoprenoid triterpenes having the formula C_{n}H_{2n-10}.

Botryococcus can bloom in Australian waters; however it grows slowly.

University of Western Sydney / CSIRO collaboration: Energy and Nanotechnology: nano-scale catalysts for production of biofuels.
Screening of ANACC microalgae
Fatty acid yield versus biomass production

Diagonal line indicates 10% of dry weight is fatty acid

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Screening of ANACC microalgae
Fatty acid yield and Cetane Number (90 strains)

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Biodiscovery: hypersaline green microalgae

Typically *Dunaliella* spp. do not produce the long-chain C\textsubscript{20} and C\textsubscript{22} Omega 3 PUFA

<table>
<thead>
<tr>
<th>fatty acid</th>
<th><em>Dunaliella tertiolecta</em></th>
<th><em>Dunaliella-like</em> which produces long-chain PUFA</th>
<th><em>Tetraselmis-like</em></th>
<th><em>Tetraselmis suecica</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS-175*</td>
<td>BD3-01</td>
<td>BD3-03</td>
<td>BD3-05</td>
</tr>
<tr>
<td>16:4 w3</td>
<td>21.0</td>
<td>12.1</td>
<td>14.0</td>
<td>13.4</td>
</tr>
<tr>
<td>20:5 w3</td>
<td>-</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>22:6 w3</td>
<td>-</td>
<td>0.2</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Volkman *et al.* 1989

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Potential co-products: Pigments
High pigment producing strains

<table>
<thead>
<tr>
<th>Sample code</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. salina</td>
</tr>
<tr>
<td>Cyanophyte (F)</td>
</tr>
<tr>
<td>Dunaliella</td>
</tr>
<tr>
<td>Cymatosira</td>
</tr>
<tr>
<td>Eustigmatophyte ?</td>
</tr>
<tr>
<td>Symbiodinium</td>
</tr>
<tr>
<td>Botryococcus</td>
</tr>
<tr>
<td>Haematococcus (N)</td>
</tr>
<tr>
<td>Haematococcus (C)</td>
</tr>
</tbody>
</table>

Highest lipid producers

% of total pigments

Perid  Fuco  Zea  Lut  Chl b  B,B-carotene  Tot. astax isomers

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Thermal and fluids engineering project (CSIRO Materials Sciences and Engineering)

• Task Objectives:
  • To provide the following areas of expertise and equipment:
    • Optimising Flow Conditions
    • Flow Optimisation within Pipelines
    • Algae Separation
    • Heat Transfer
    • Impellor Design
    • Sparging Systems
  • To evaluate the cost-efficiency of Open Ponds versus Covered Ponds or Raceways versus Enclosed Photobioreactors

• Project Leader:
  • Kurt Liffman
Project Background

- Relatively straightforward to make fuel from micro-algae.
- Technologically viable process since the 1970s
- Lance Hillen (DSTO, Aust) produced jet A and petrol from *Botryococcus*

- Challenge: to produce algal fuel economically.
- Fundamental problem: Algal slurry is a dilute medium
- Ten tonnes of algal slurry/water processed to produce one litre of oil

- Potential solution: minimize capital costs and “free” energy input, i.e.,
  - Cheap land
  - Stirred, open ponds; not photo-bioreactors
  - Atmospheric CO$_2$, for true biosequestration
  - Cheap, quick harvesting system

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Improving Open Pond Productivity

We wish to understand the factors governing the productivity in race-way ponds and then apply these principles to basic open ponds.
Computational Fluid Dynamics (CFD)

We have built a computational code to model the growth of algae in raceway and open ponds. Factors of interest are: intensity of sunlight, CO$_2$ absorption/diffusion, turbulence, pressure drop, velocity, algae growth.
Raceway Ponds tend to be expensive and energy intensive, as the water is always in motion.
Computational Fluid Dynamics – Mixing of algal ponds

Our initial (qualitative) results suggest that the degree of mixing is a fundamental driver of algae productivity. We are attempting to quantify this mathematically within our CFD code. Industrial scale mixing simulations of open ponds.

Computation of a plume of fertiliser – real pond scenario. Wind powered mixing.
Besides capital cost, harvesting algae is the major cost impediment (10-20%) in making algae a commercially competitive feed stock for biodiesel.

There are a number of algae harvesting technologies, e.g. sedimentation, floatation, filters and centrifuges. The separation system has to be designed for an individual alga / growth technology.

We have developed a potential in-line harvesting system called the CST, which uses centrifugal force, but without the expensive centrifuge (provisional patent).
In-line Algae Separation System (CSIRO SeparaTor or CST)

500L capacity

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
CST – experimental results

Percentage of oil in water

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
The future: Combined technologies / bioremediation / multiple bioproducts

- Biodiesel
- Fermentation to alcohols
- Protein meal
- Speciality chemicals

S.I. Blackburn, Biofuels Symposium, Tsukuba, Japan, August 2009
Thank you