School of Chemical Engineering
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An assessment of the techno-economic feasibility of large-scale microalgal lipid production for biofuels

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Microalgal Engineering Research Group

- Dr David Lewis
- Dr Peter Ashman
- Prof Keith King
- 10 Postgraduate students
- Intern students from Anhalt University of Applied sciences
- Honours and summer research students

- Key collaborators:
- Prof Michael Borowitzka [Murdoch University]
- Prof Steven (Feng) Chen [University of Hong Kong]
- Prof Carola Griehl [Anhalt University of Applied sciences, Kothen, Germany]
- Prof John Benemann [UC Berkeley, Californa, USA]
- Dr Cecil Camilleri [Yalumba Wine Company]
- A/Prof Wei Dong [South China University of Technology]
- Dr Alex Elliott [Centre for Ecology and Hydrology, UK]

Background

- Proposed to produce an algal oil feedstock for the production of biodiesel using microalgae growing in saline water.
- Uses elite strains of microalgae isolated from Australian saline water habitats
- Screened for their suitability for large-scale production under Australian conditions,
  - ease of harvesting
  - high lipid productivity while in the active (log phase) stage of growth
- Optimisation of the whole production process
  - algal culture
  - biomass harvesting
  - ease of oil extraction from the biomass
  - effective use of the biomass remaining after extraction
- The process proposed is based on proven open-air raceway pond culture systems

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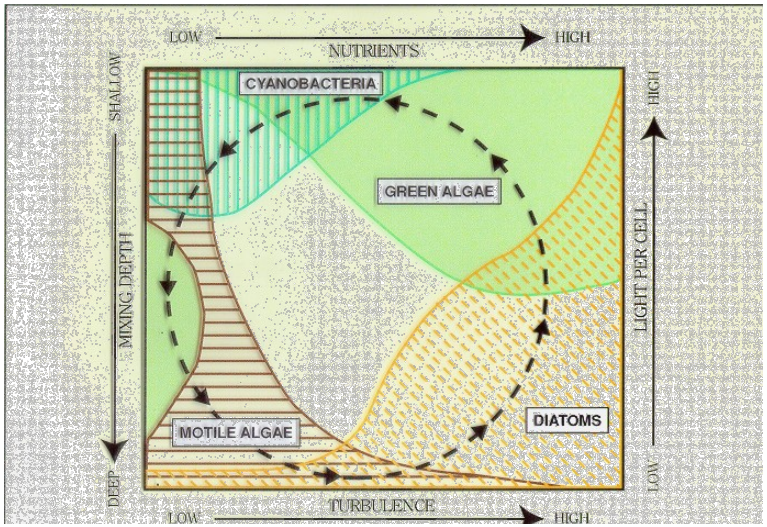
Ecology

- Google
  - ‘microalgae’ 680,000 results
  - 28,200 for ‘photo-bioreactors’
- Web of science
  - ‘microalgae’ 3,858 results
  - ‘photo-inhibition and algae’ 365 results
  - etc



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Microalgae

- Cultures are dilute
- ~500 mg/l dry wt
- Very small (3 – 30 μm)
- For bio-diesel need paste 15% solids
- HRAP 0.5 to 1 % solids
- Typically centrifuge – 20% solids
  - Require pre sedimentation 3% solids
  - Centrifuge – 15% solids

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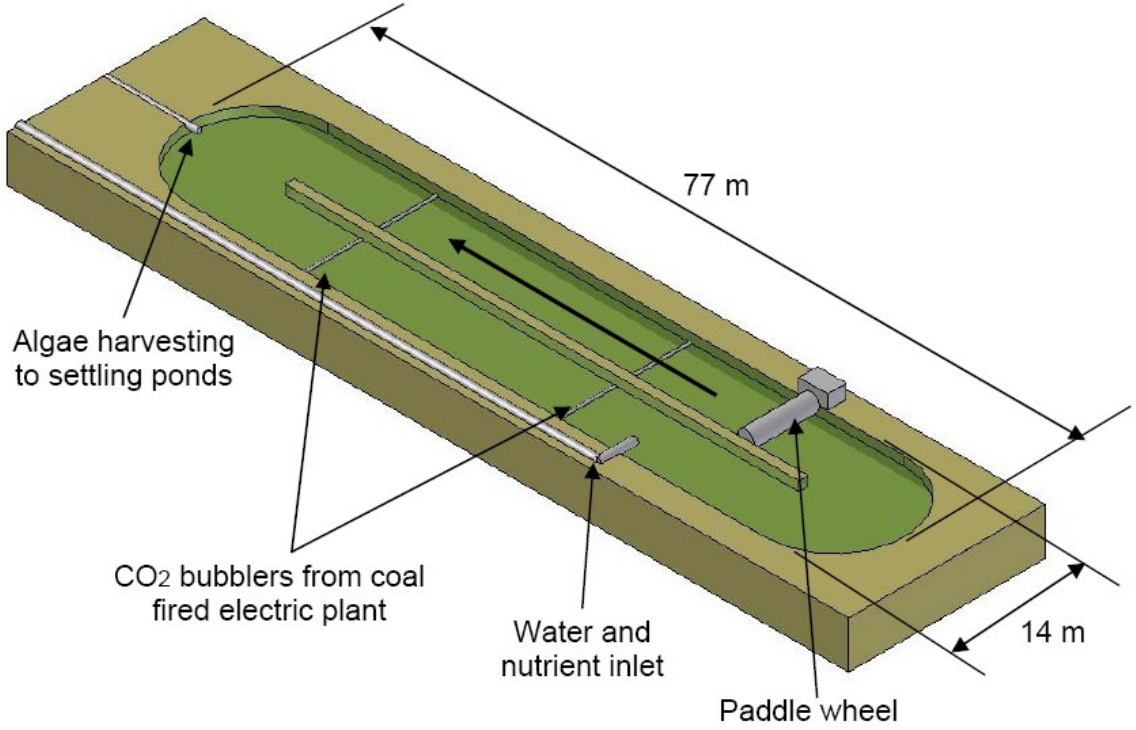
Current systems

Species	Used for	Where grown	Main culture system(s)	Estimated cost of production ($AUS.kg^{-1})
Chlorella spp	Health food, health food extracts	Japan, Indonesia, Germany	Open circular pivot ponds, raceway ponds. Tubular photobioreactors (Germany only)	15+
Spirulina spp	Health food, health food extracts	Japan, Taiwan, Thailand, USA,China, India	Raceway ponds	8-12
Dunaliella salina	β-carotene	Australia, India	Extensive open ponds, raceway ponds (in India)	8+
Haematococcus pluvialis	astaxanthin	USA, Israel	Raceway ponds (USA), closed photobioreactor (Israel)	40+ (photobioreactor)
Crypthecodinium cohnii	DHA	USA	Heterotrophic cultivation on glucose	~2
Chaetoceros spp. *Nannochloropsis* spp. *Navicula* spp. *Tetraselmis* spp. *Pavlova* sp. etc.	Feed for aquaculture species	Throughout the world	Raceway ponds, tanks, large bag reactors	80-2000

Conceptual system



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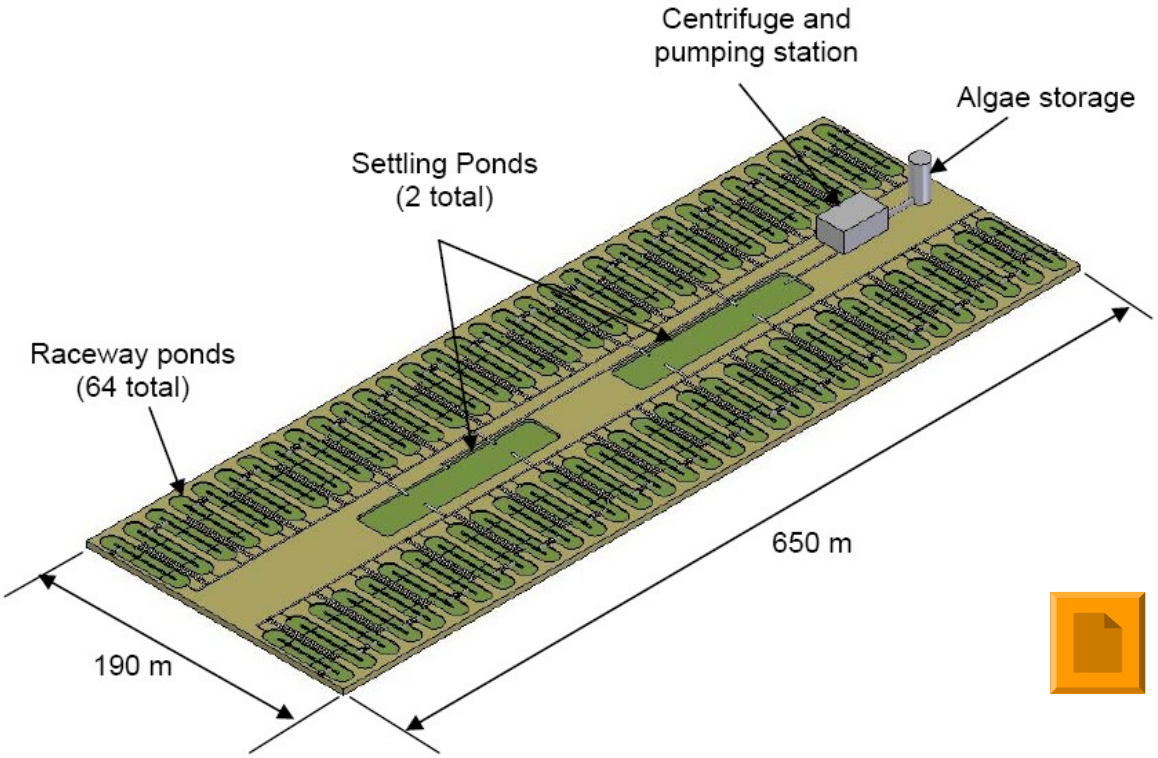
Conceptual system



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Cyanotech production plant at Kona, Hawaii.
Reddish ponds =*Haematococcus*; other ponds = *Spirulina*

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Haematococcus plant operated by Algatech Ltd, Kibbuz Ketura, Israel

Winery wastewater?

- Hydrocarbon rich *Botryococcus braunii*
- Pre/Post-treatment effluent waters
  - Important resource
  - Low nitrate
  - High phosphate
  - High pH
- Trials demonstrated:
  - Ratio N:P not optimal
  - High salinity – *B. braunii* not suitable
- Common agricultural effluent

Harvesting

- Algae can be harvested using
  - Micro-screens
  - Centrifugation
  - Flocculation
  - Froth flotation
  - Auto-flocculation
  - Ultrasound

Harvesting summary

Process	Mechanism	Inputs	Species reliance	Relative cost	Solid concentration	Energy inputs
Centrifugation	Accelerated discrete settling	Power	Minor	10	>10%	High
Chemical flocculation						
Lime	Floc enmeshment	lime/power	Minor	6 to 8	8 to 10%	High
Alum	Destabilise	alum/power	Minor	7 to 8	9 to 10%	High
Poly	Bridging	poly/power	Minor	8 to 8	10 to 10%	High
Cross flow filtration	Membrane (self-cleaning)	Power	Minor	4 to 6	2 to 6%	Medium
Micro-straining	Fabric	Power	High	0.5 to 1.5	2 to 4%	Medium
Magnetic separation	Adsorption	Power	-	-	-	-
Sedimentation	Gravity	Pump/Clarifier	High	0.5 to 1.0	1 to 3%	Low
Bio-flocculation	Spontaneous flocculation	Pump/Clarifier	High	0.5 to 1.1	2 to 3%	Low
Auto-flocculation	Ca/Mg ppt induced floc	Pump/Clarifier	High	0.5 to 1.2	3 to 3%	Low
Auto-concentration	Phototaxis	Pump/Clarifier	High	-	-	-

* Reproduced from Benemann and Oswald 1996

Auto-flocculation and bio-flocculation

- considered to be the most promising means for the economical harvesting of microalgae
- produce extracellular polymers during ageing
  - can initiate bio-flocculation
- algae sediment more readily upon ageing, possibly as a result of increased ceil density

Extraction

- Chemical solvents: Algal oil can be extracted using chemicals
- Enzymatic extraction
- Expression/Expeller press
- Osmotic shock
- Supercritical fluid
- Ultrasonic-assisted extraction

Economics

- Current (June 2007) prices for oils used in the manufacture of biodiesel (FOB)

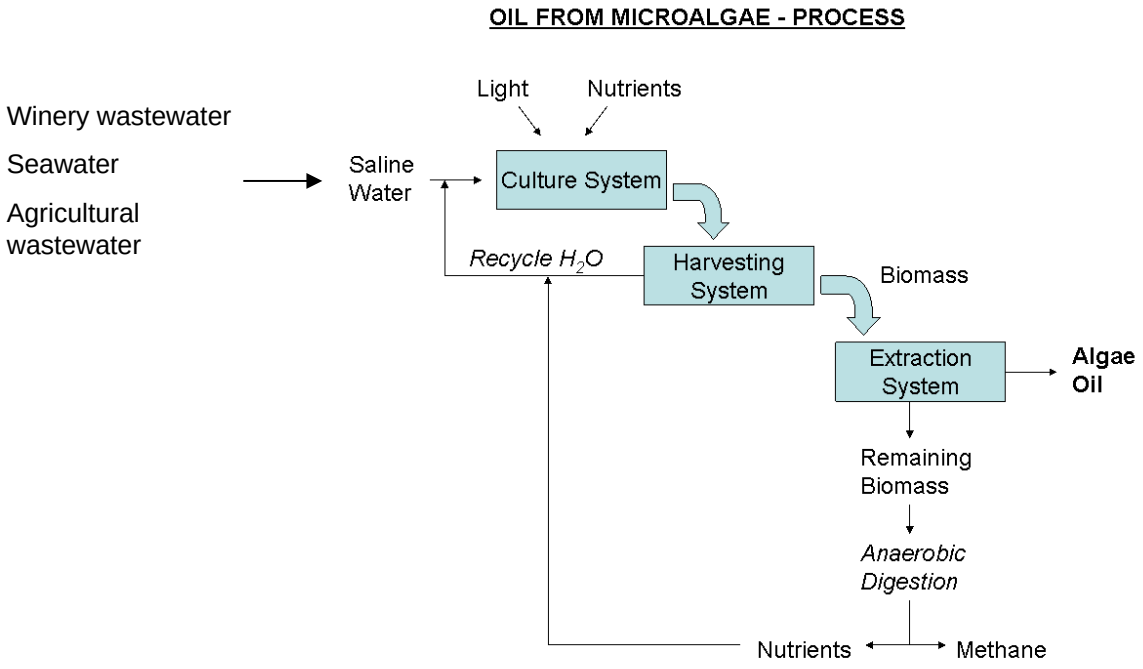
Oil	Price per tonne (US$)
Canola	$632 (mean for 2006) ~$750 (Current)
Rapeseed	~$720
Palm Oil	~$700

- Crude: $US60 – 70 per barrel.
- Current cost of production of microalgae is greater than about $AUS 8 kg^{-1} dry weight. At an oil content of 40% this would mean an algal oil price of about $AUS 20.$kg^{-1}$ or about $AUS 17 l^{-1}.
- For comparison crude oil (at $US68 per barrel) costs about $AUS 0.51 l^{-1} and vegetable oil (at $US700 t^{-1}) costs about $AUS 0.69 l^{-1}; i.e. the algal oil is about 10x more expensive than alternative feedstocks!!

Summary - How can algae oil production costs be substantially reduced?

- In order to reduce the production cost of oil from microalgae one requires high annual average biomass productivities combined with a high oil content of the biomass. Furthermore both capital and operating costs for algal culture, harvesting and oil extraction must be minimised

Summary - AP6 Proposed project



Acknowledgements

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