New Zealand’s Wastewater Algal Biofuel Potential

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Outline

- New Zealand wastewater nitrogen resources
- New Zealand climate maps
- New Zealand land slope maps
- Conventional wastewater treatment ponds
- Wastewater treatment High Rate Algal Ponds
- Potential wastewater algae resource maps
Wastewater Algal Biofuel

- Wastewater treatment plants have many of the resources needed for algal production
  - Water, nutrients, CO₂
- Wastewater treatment ponds grow algae as a by-product of the treatment process
  - Provide oxygen for aerobic treatment
  - Assimilate wastewater nutrients into algal biomass
- Algae removal is required to produce high quality treated effluent
- Capital and operation costs of algal production and harvest are covered by WWTP
Resource assessment of algal production potential in each Territorial Local Authority region of New Zealand based on available wastewater resources:

Municipal Wastewater
- Currently treated in conventional treatment ponds
- Converted to HRAP with CO₂ addition
- All Municipal wastewater treated in HRAP with CO₂ addition

Dairy farm effluent
- Treated in HRAP with CO₂ addition

Piggery effluent
- Treated in HRAP with CO₂ addition

Poultry waste
- Limited and dry waste
NZ Conventional Municipal Wastewater Ponds

- Ponds treat 1/3 of total wastewater flow
  - ~0.5 million m³/d
- Simple, cost-effective WWT
- Low and variable algal production
  - Annual average VSS conc.: 100 g/m³
  - Annual average production: 9.1 t/ha.y
- Potential daily algal biomass yield
  - 50 t/d
  - Assuming 100% harvest efficiency
Algal Production Potential from Conventional Municipal Wastewater Ponds

- 50t/d
- HRT 60 d
- Depth 1.5 m
- 2000 ha
High Rate Algal Ponds (HRAP)

- Shallow paddlewheel mixed, raceway ponds
- Retain the advantages of conventional ponds
  - Simplicity and economy
  - Half capital and operation costs of conventional treatment
- Use less land than conventional ponds
- Daytime algal photosynthesis increases dissolved oxygen concentration to over 20 gm⁻³
- Oxygenation promotes aerobic bacterial decomposition of the remaining dissolved organic matter in the wastewater
- Improved treatment
  - Wastewater nutrients are assimilated into algal biomass
  - Efficient natural disinfection (Solar-UV, DO)
- Both secondary and partial tertiary-level treatment
High Rate Algal Pond Operation

- **Organic loading rate**
  - 100-150 kg BOD$_5$ ha$^{-1}$.d depending on climate

- **Depth**
  - 0.2-0.6 m depending on wastewater clarity

- **Hydraulic retention time**
  - Summer 3-4 d; winter 7-9 d

- **Horizontal mixing velocity**
  - Typically 0.15-0.30 m s$^{-1}$

- **Paddlewheel mixing**
  - Vertical mixing component so algal cells are intermittently exposed to sunlight
HRAP Paddlewheel Mixing
High Rate Algal Ponds

- **HRAP biomass**
  - 70 to 90% algae
  - Algal strains that thrive under the diurnally varying conditions (sunlight, temperature, pH and dissolved O_2)
  - Bacteria, detritus some invertebrates, fungi, viruses

- **Annual biomass productivity 8-12 g m^{-2}.d**

- **Paddlewheels have only one-tenth of the energy requirement of mechanical aeration**

- **Recover nutrients into harvestable algal/bacterial biomass for beneficial use**
  - Fertiliser, feed or biofuel
High Rate Algal Ponds

- Selects for colonial algal species

- Colonial algae settle faster than unicellular
- Algal harvest by simple gravity settling

- Micractinium sp
- Scenedesmus sp
- Pediastrum sp
- Actinastrum sp
Enhancing Nutrient Recovery

CO$_2$ addition

- HRAP algae are carbon-limited
  - Algae have higher C:N ratio than Wastewater
    - 6:1 vrs 3:1
- Use of bicarbonate raises pond water pH >10
- Influences performance
  - Algal production is often depressed by
    - C limitation
    - Ammonia toxicity
  - Aerobic bacteria inhibited at pH above ~8.5
  - Nutrient removal improved
    - Ammonia volatilisation / phosphate precipitation
HRAP CO$_2$ Addition

- Control pond water pH to 7.5-8.5
- Doubles annual average biomass productivity: 16 - 20 g m$^{-2}$d

Promotes nutrient removal by assimilation into algal biomass
HRAP with CO₂ Addition

- All commercial algae farms use CO₂
- Improves wastewater nutrient removal
- Doubles algal production
  - ~60 tonnes/ha.y
- CO₂ Source: Biogas CHP use
  - Biofixation not sequestration
- By converting all existing WSP to HRAP potential daily algal biomass yield
  - 163 tonnes/d
    - Assuming 100% harvest efficiency
- CO$_2$ addition sump
HRAP CO$_2$ Addition
Algal Production Potential from all Conventional WSP Upgraded to HRAP with CO₂ Addition

- 163 t/d
- HRT 6 d
- Depth 0.3 m
- 1000 ha
Potential daily algal biomass yield:

- 487 t/d

Assuming:
- Average TSS concentration of ~325 g/m³
- 100% harvest efficiency

The geographic distribution mirrors New Zealand’s population distribution, with more than half of the potential being associated with the 3 main population centres (Auckland, Wellington and Christchurch)
Algal Production Potential from All Municipal Wastewater Treated in HRAP with CO$_2$ Addition

- 487 t/d
- HRT 6 d
- Depth 0.3 m
- 3000 ha
Dairy Farm Wastewater

- >5 million cows on ~14,000 farms
- But only 10% - 15% of the cows daily manure production is collected during milking
- Daily algae production potential using HRAP with CO₂ addition: 1092 t/d
  - Assuming complete nitrogen assimilation into algae and an annual average algae concentration of 325 g/m³, a 0.3 m pond depth and a 6 day HRT
- Double that which could be produced from all municipal wastewater
- However, production is spread over 1000’s of farms concentrated in the main dairy regions: Waikato, Taranaki, Canterbury, and Southland
- Cost-effective small-scale harvesting and processing technology will be required to realize this potential
Algal Production Potential from Dairy Farm Wastewater Treated in HRAP

- 1092 t/d
- HRT 6 d
- Depth 0.3 m
- 6800 ha
~250 commercial pig farms

Daily algae production potential using HRAP with CO$_2$ addition: 82 t/d
- Assuming complete nitrogen assimilation into algae and an annual average algae concentration of 325 g/m$^3$, a 0.3 m pond depth and a 6 day HRT

Algal biomass potential is mainly in the south Auckland / Waikato and the greater Canterbury regions

The high flows of concentrated wastewater from commercial piggeries compared to those of the largest dairy farms make piggeries attractive for algal biomass production
Algal Production Potential from HRAP Treating all Piggery Wastewater

- 82 t/d
- HRT 6 d
- Depth 0.3 m
- 517 ha
Constraints on Algal Production

- Suitability and availability of low-cost, flat (<15° slope) land
- Suitable climate for algae growth
- Harvest cost and efficiency
- Plenty of land
- Most communities and agriculture waste production in areas of flat land
New Zealand Climate Maps

- Solar Radiation
- Temperature
Annual Average Solar Radiation (W/m²)

- North: >155 W/m²
- South: >140 W/m²

- Limits annual production
- High summer time production achievable
Annual Average Temperature (°C)

- North: >13 °C
- South: >8 °C

Need to have low temperature adapted strains
Algal Removal

- Simple algal settling ponds or shorter hydraulic retention time algal harvest tanks
- Removal efficiency is improved by bioflocculation/aggregation of the algal colonies
  - N limitation
  - With CO₂ addition
  - Recycling settled algae back to the HRAP

Algal Settling Ponds (ASPs)
- Gravity settling of the algal biomass
- Storage for the periodic recovery of the settled algae.

Algal Harvest Tanks
- Engineered to promote efficient gravity settling using lamella plates
- Secondary thickening of settled algae to 1-3% solids.
- Settled algal biomass is removed continuously or daily to avoid deterioration before use
Algal Harvest Tank
Potential technologies to convert algae biomass to bio-energy

- **Transesterification of lipids to biodiesel**
  - 10-20% biomass conversion

- **Fermentation of carbohydrates to ethanol**
  - 10-20% biomass conversion

- **Anaerobic digestion to biogas (methane)**
  - 25 - 35% biomass conversion

- **High temperature conversion to bio-crude oil**
  - 40% biomass conversion
Co-Benefits

- **Recovery of wastewater nutrients for fertilizer**
  - Use of algae and algal biofuel residues
  - Inorganic fertilizer production fossil-fuel use savings

- **GHG abatement from:**
  - Biofuel use of algae offsets equivalent fossil fuel use
  - Reduced WWT CO$_2$ emissions through lower electricity use
    - Sunlight energy powered WWT and disinfection
  - Offset CO$_2$ emissions from inorganic fertilizer production
Integrated WWT and Algal Bioenergy Production

Solids Removal

High Rate Algal Pond

Algal Removal

Effluent Polishing Options e.g.

Maturation Pond

Wastewater Solids

Solids Digestion Pond

CO₂ Addition as Flue gas

Power Production

Fertiliser Recovery

Algal Solids

Cover

Rock Filter

UV Disinfection

Algal Digestion Pond

Cover
Christchurch 5 ha Demonstration
Conclusions

Algae biofuel production in combination with WWT HRAP is realizable today:

- Energy efficient and cost effective tertiary-level WWT essentially funds the capital and operation costs of algal production and harvest

- Numerous co-benefits (clean water, energy recovery, fertilizer recovery, GHG abatement)

- Further improvements:
  - Enhancement of algal production in HRAP
  - Demonstration of efficient cost-effective harvest, particularly, through aggregation / bioflocculation
  - Development of efficient cost-effective algae dewatering technologies
  - Improvement of the efficiency and economics of the algae to bio-energy conversion pathways