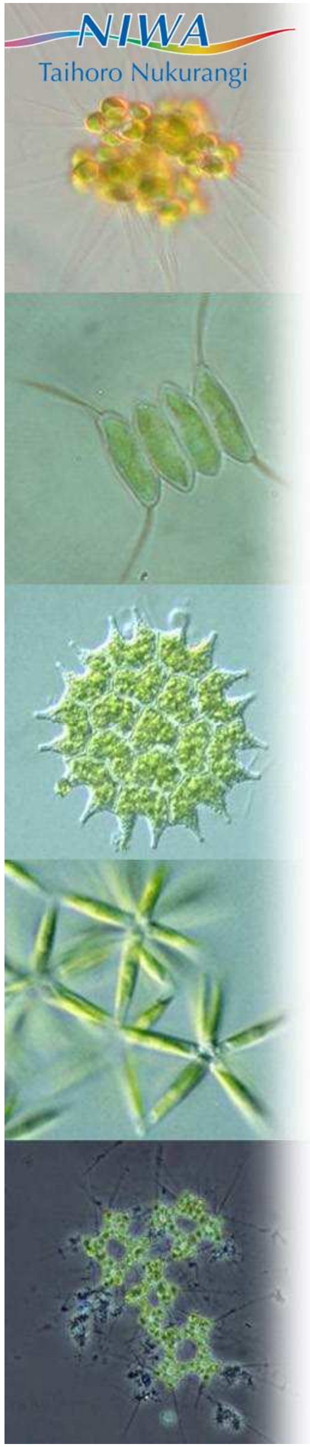
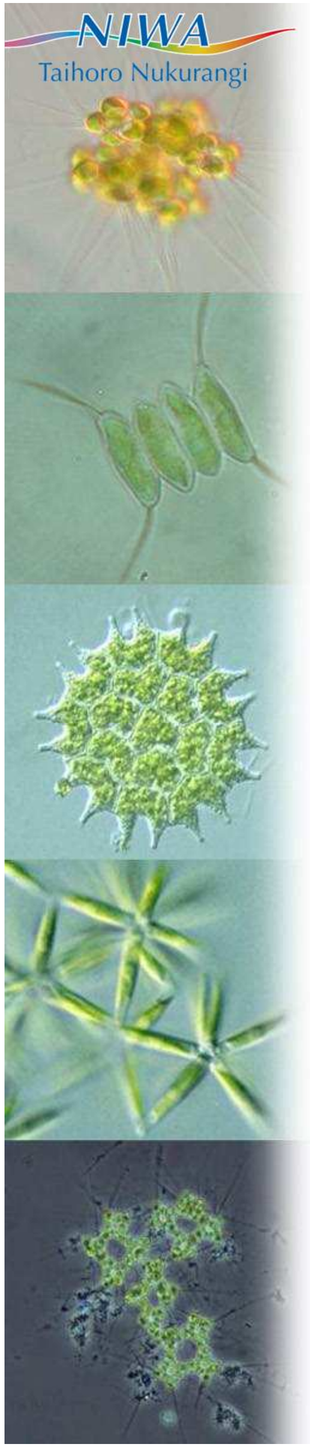


New Zealand's Wastewater Algal Biofuel Potential

**Rupert Craggs, Stephan Heubeck,
Jason Park and James Sturman**

National Institute of Water and Atmospheric Research

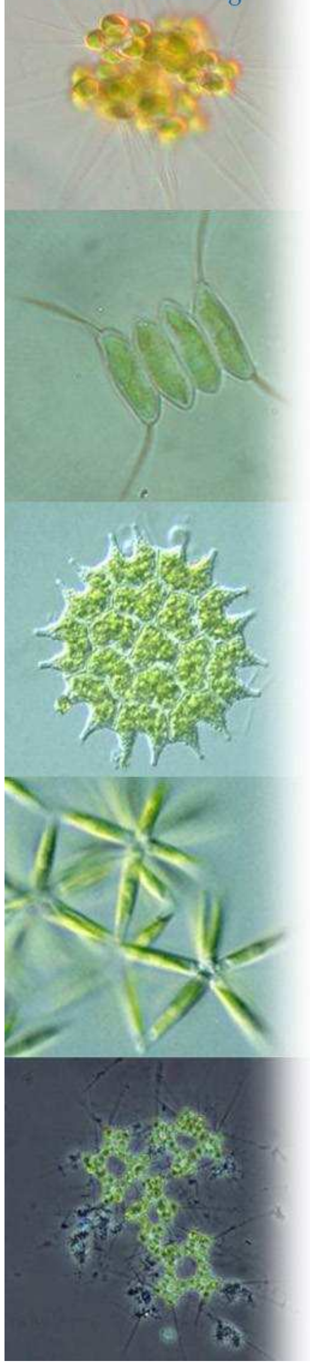
**APEC Workshop on the Resource Potential of Algae for Sustainable Production of Biofuels in the Asia Pacific Region
The Hyatt Regency Hotel, San Francisco
12th September, 2011**



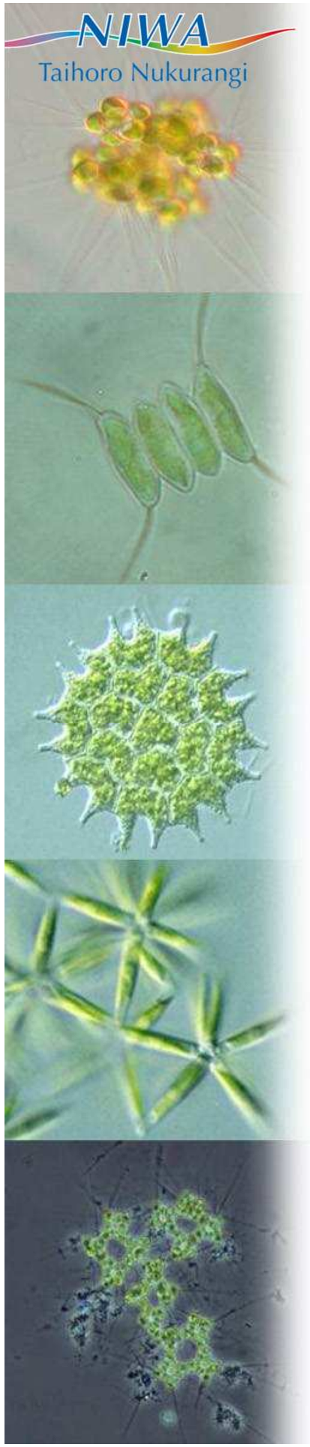
Outline

- 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, CO_2
- **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**



Wastewater Resources

- **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 CO_2 addition
  - All Municipal wastewater treated in HRAP with CO_2 addition

- **Dairy farm effluent**
  - Treated in HRAP with CO_2 addition

- **Piggery effluent**
  - Treated in HRAP with CO_2 addition

- **Poultry waste**
  - Limited and dry waste

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NZ Conventional Municipal Wastewater Ponds

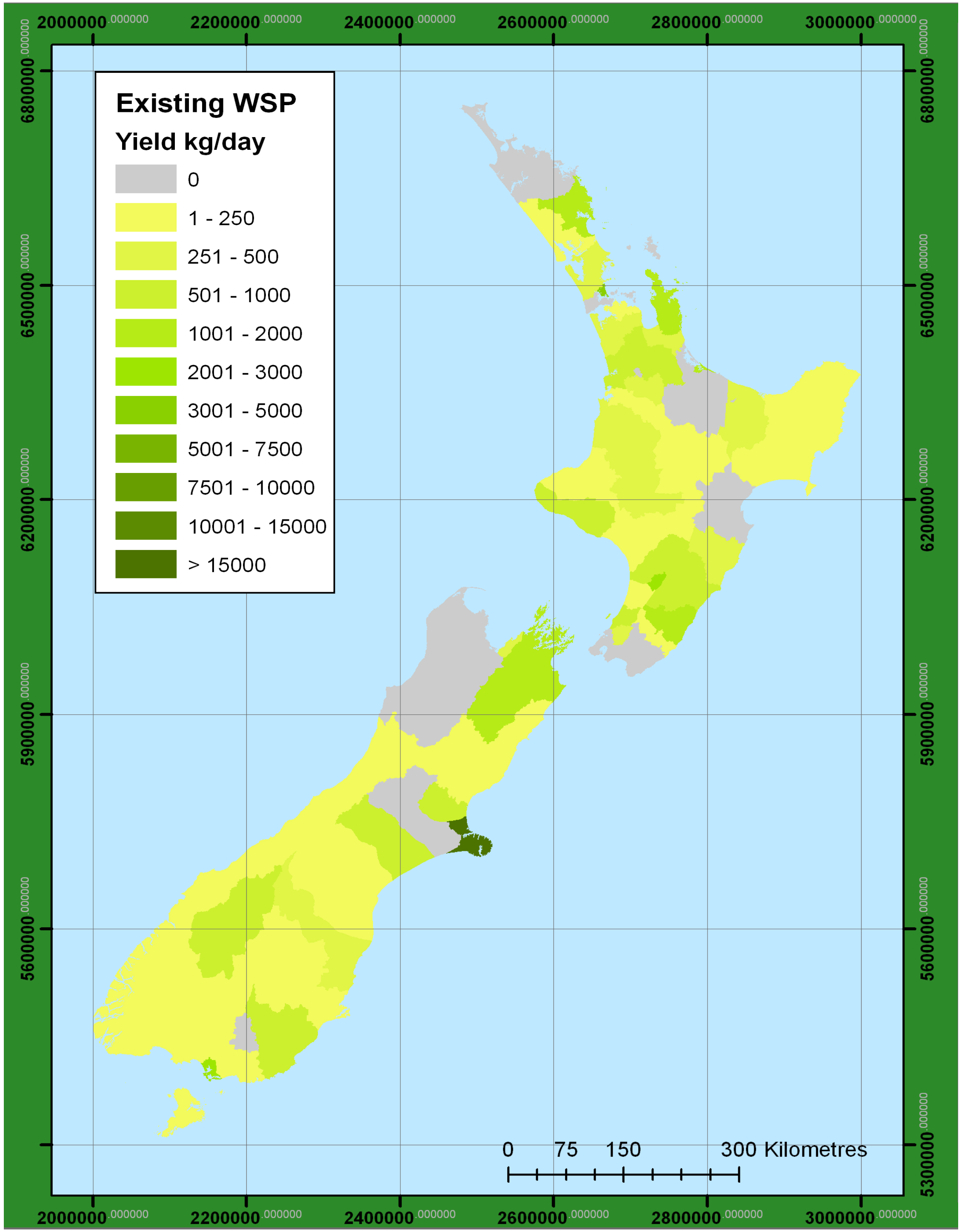


- **Ponds treat 1/3 of total wastewater flow**
  - ~0.5 million m^3/d
- **Simple, cost-effective WWT**
- **Low and variable algal production**
  - Annual average VSS conc.: 100 g/m^3
  - Annual average production: 9.1 t/ha.y
- **Potential daily algal biomass yield**
  - 50 t/d
    - Assuming 100% harvest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

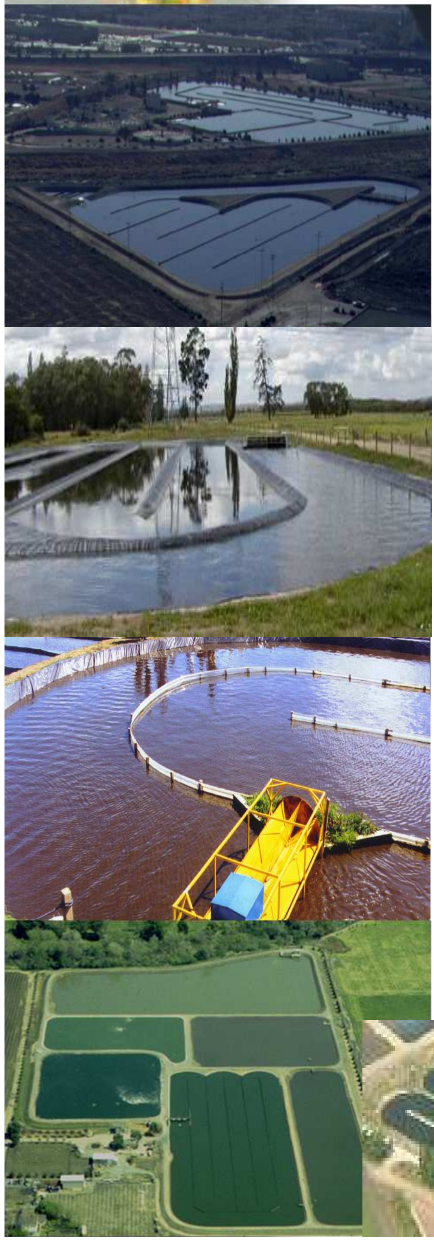



- **Organic loading rate**
  - 100-150 kg BOD_5 $ha^{-1}.d$ depending on climate
- **Depth**
  - 0.2-0.6 m depending on wastewater clarity
- **Hydraulic retention time**
  - Summer 3-4 d; winter 7-9 d
- **Horizontal mixing velocity**
  - Typically 0.15-0.30 m s^{-1}
- **Paddlewheel mixing**
  - Vertical mixing component so algal cells are intermittently exposed to sunlight




HRAP Paddlewheel Mixing

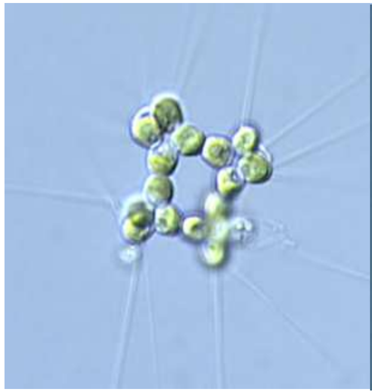
High Rate Algal Ponds



- **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

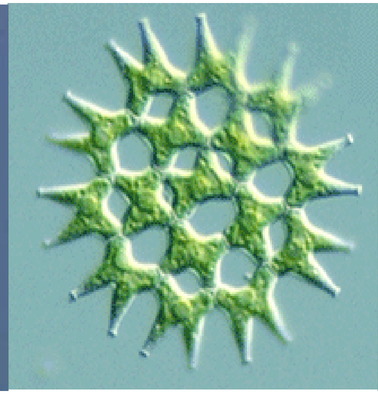
High Rate Algal Ponds

- Selects for colonial algal species

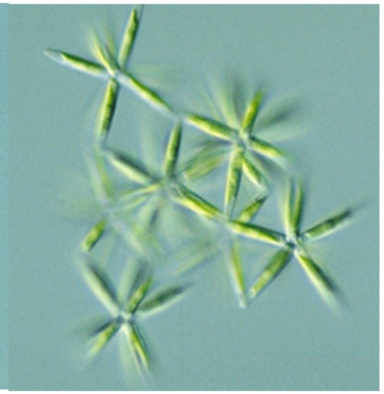


Micractinium sp

Scenedesmus sp



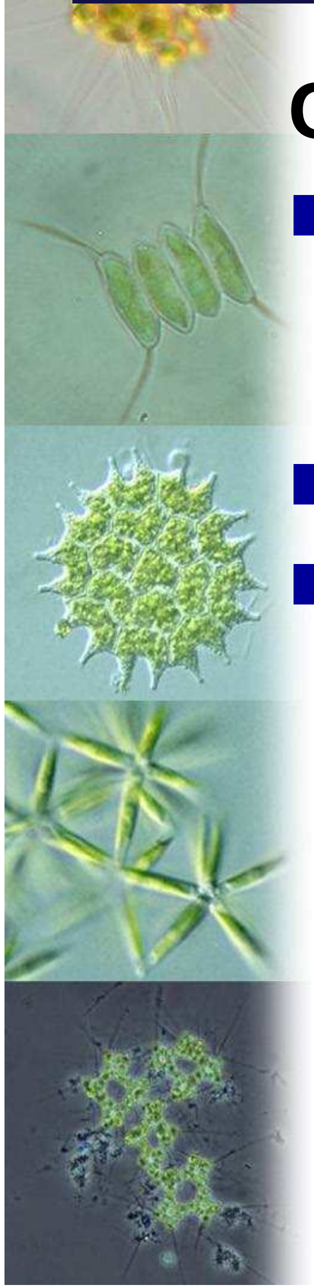
Pediastrum sp



Actinastrum sp

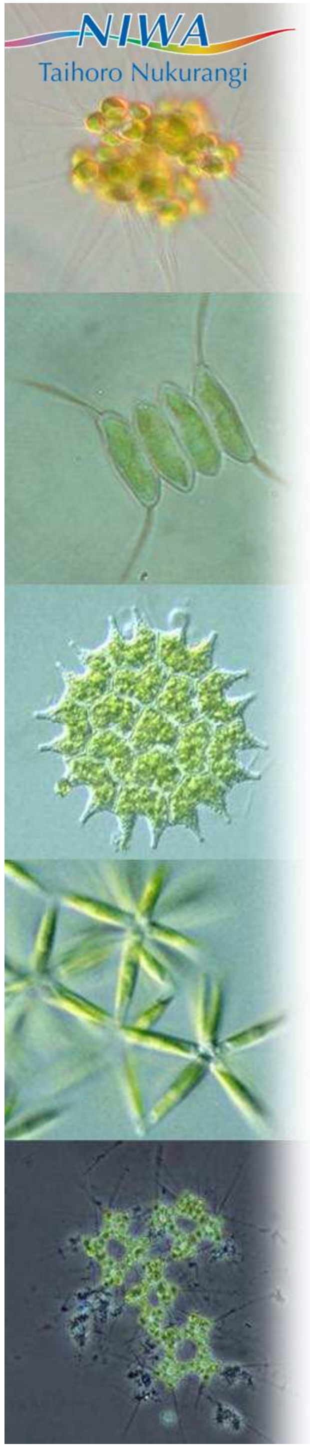
- Colonial algae settle faster than unicellular
- Algal harvest by simple gravity settling

Enhancing Nutrient Recovery



CO_2 addition

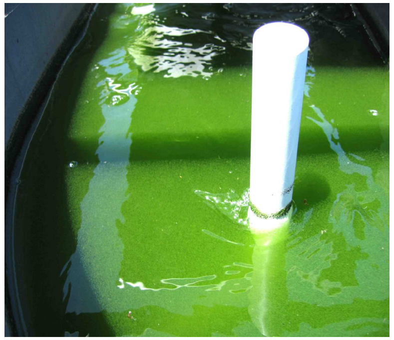
- **HRAP algae are carbon-limited**
  - Algae have higher C:N ratio than Wastewater
    - 6:1 vrs 3:1
- **Use of bicarbonate raises pond water pH >10**
- **Influences performance**
  - Algal production is often depressed by
    - C limitation
    - Ammonia toxicity
  - Aerobic bacteria inhibited at pH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



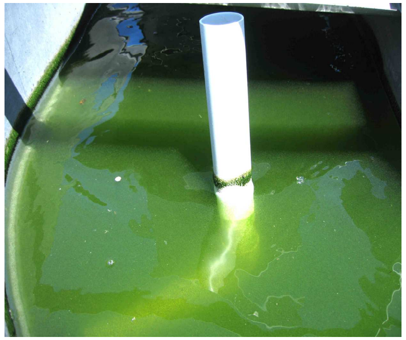
HRAP CO_2 Addition

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

HRAP (CO_2)



HRAP



- **Promotes nutrient removal by assimilation into algal biomass**

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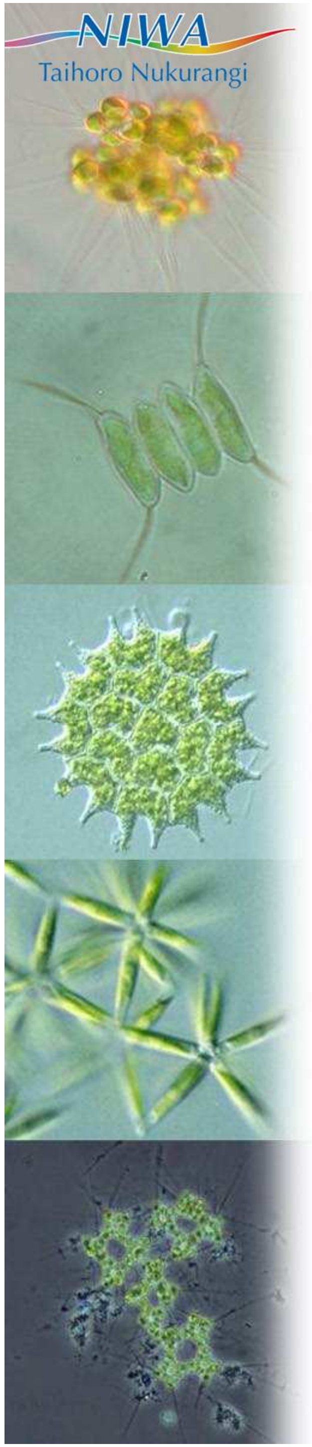
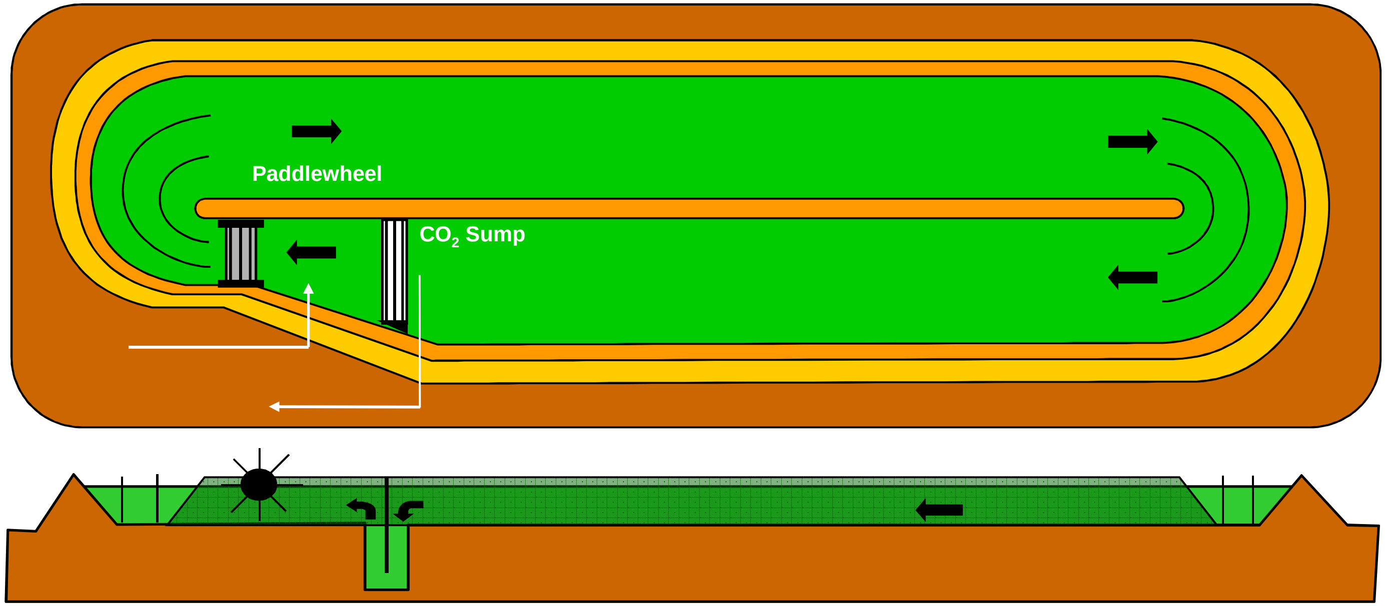
HRAP with CO_2 Addition

- **All commercial algae farms use CO_2**
- **Improves wastewater nutrient removal**
- **Doubles algal production**
  - ~60 tonnes/ha.y
- **CO_2 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



HRAP with CO_2 Addition

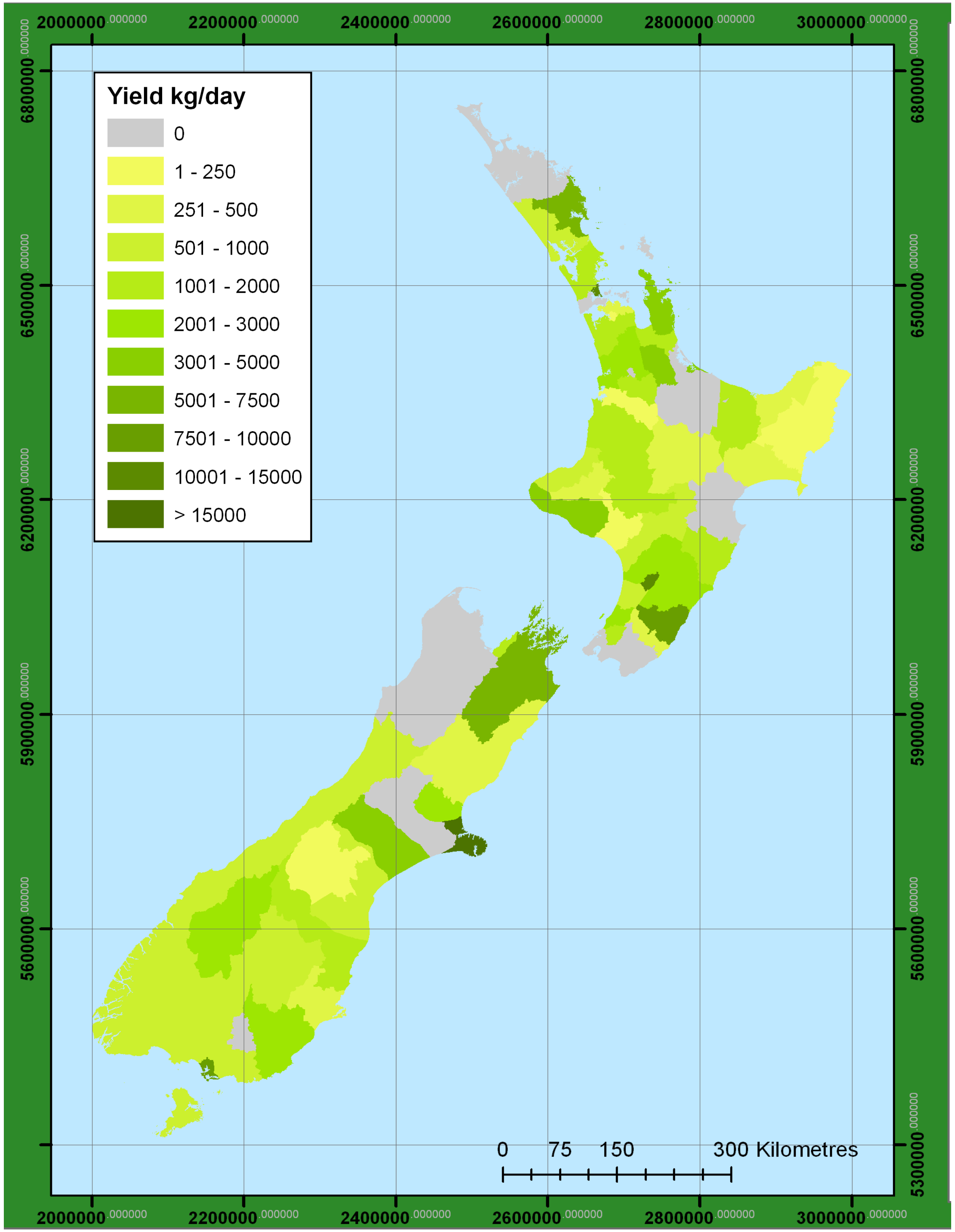
- CO_2 addition sump

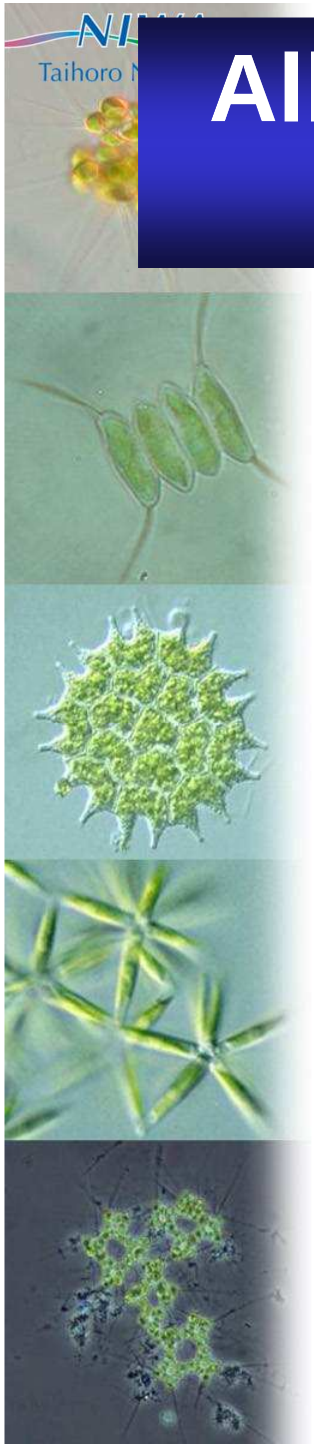


HRAP CO_2 Addition

Algal Production Potential from all Conventional WSP Upgraded to HRAP with CO_2 Addition

- 163 t/d
- HRT 6 d
- Depth 0.3 m
- 1000 ha





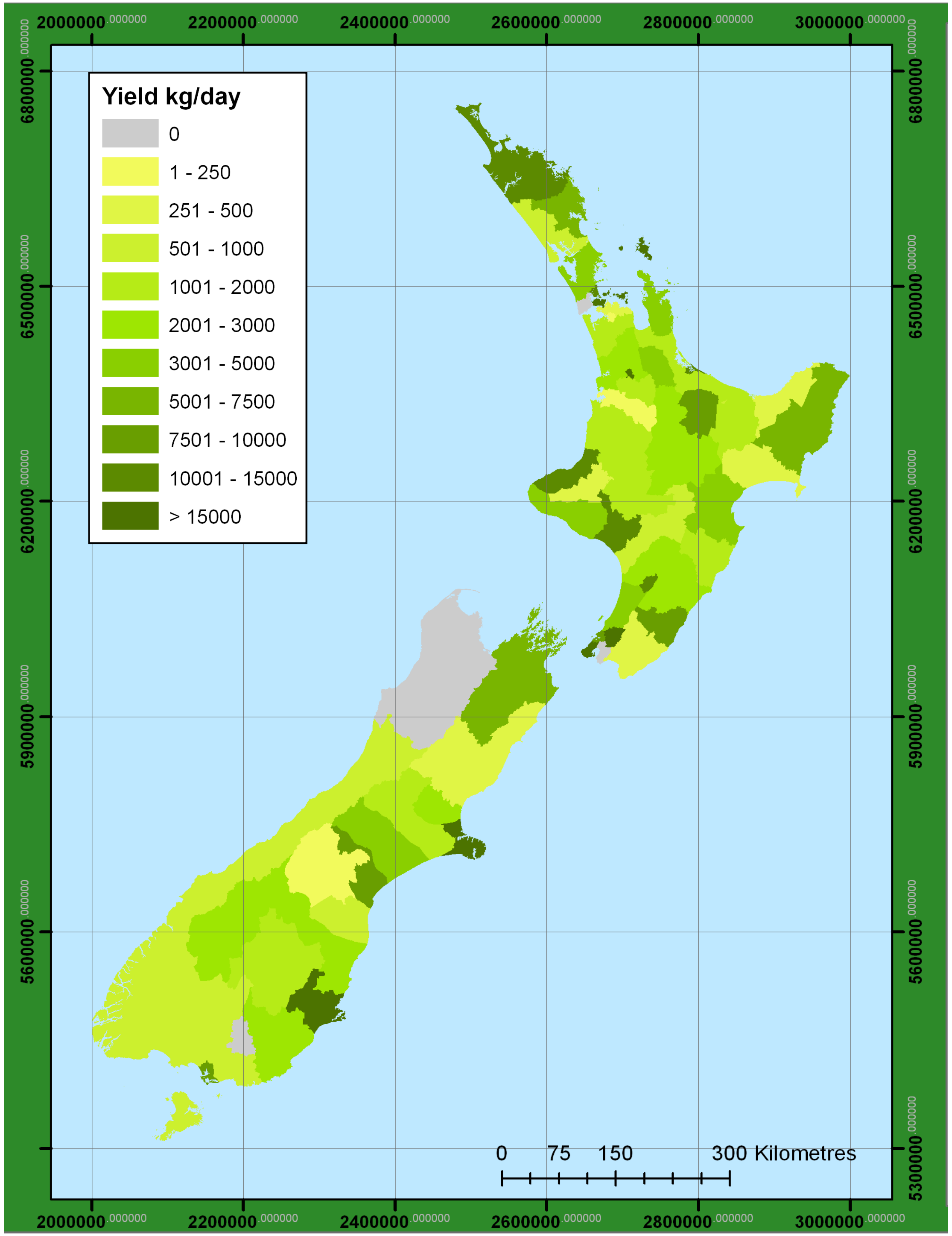
All Municipal WW HRAP with CO_2 Addition

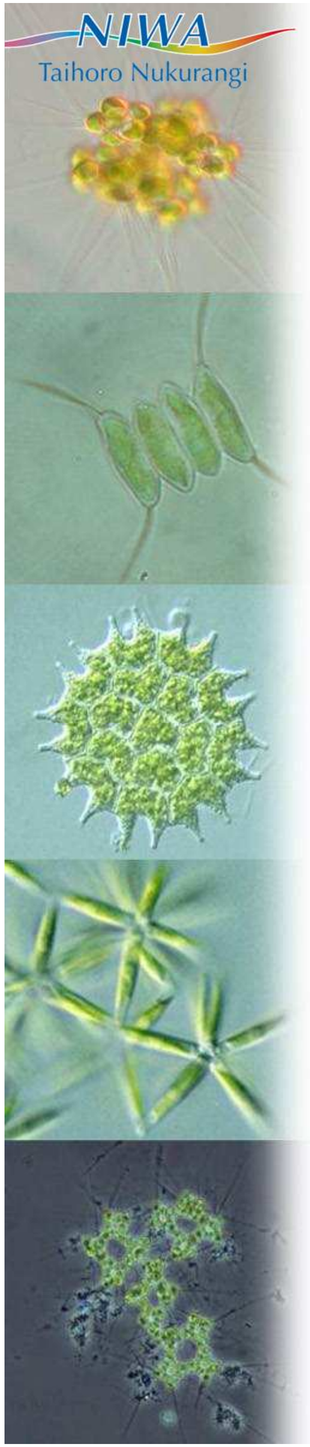
- **Potential daily algal biomass yield:**
  - 487 t/d
  - Assuming:
    - Average TSS concentration of ~325 g/m^3
    - 100% harvest efficiency

- **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



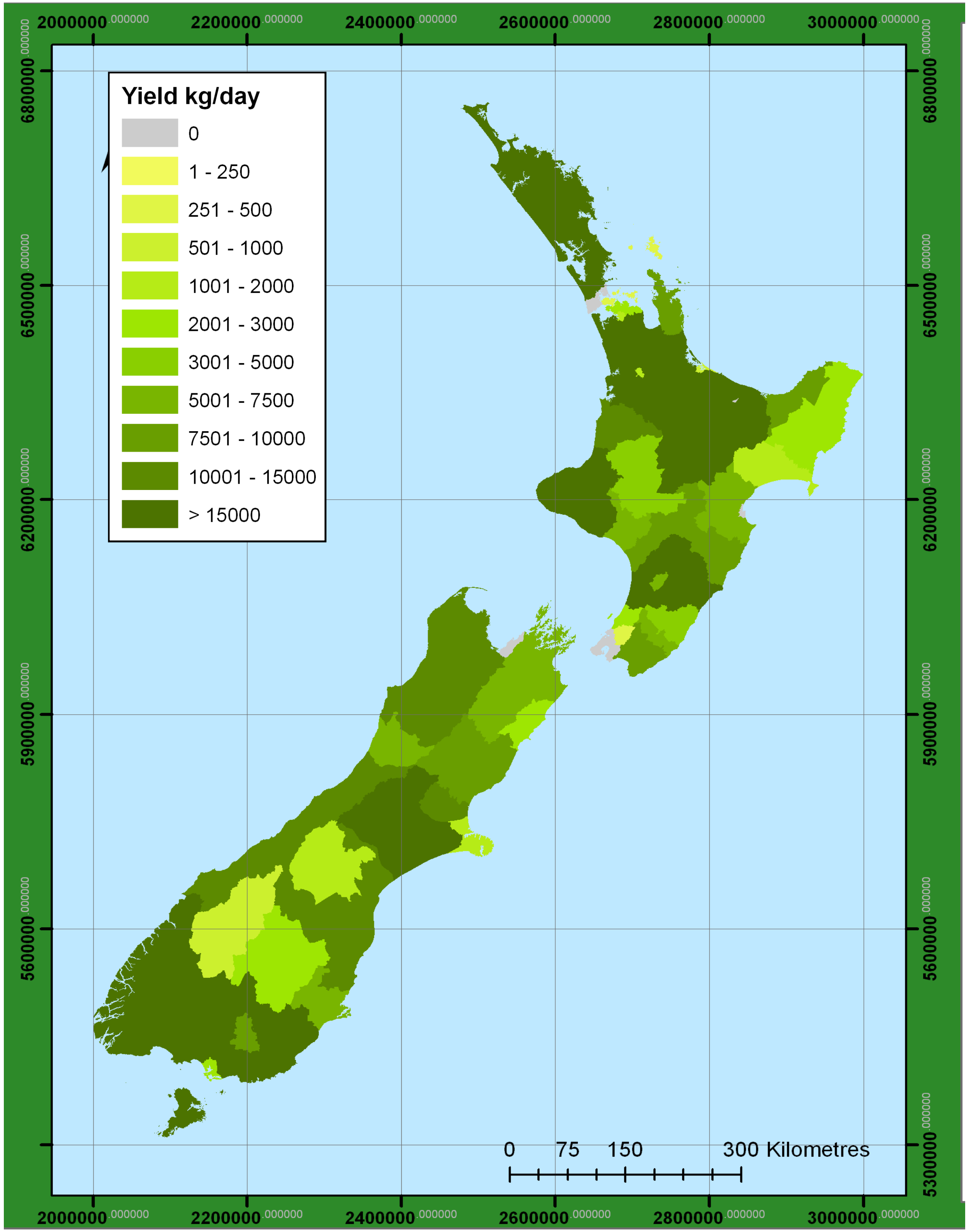


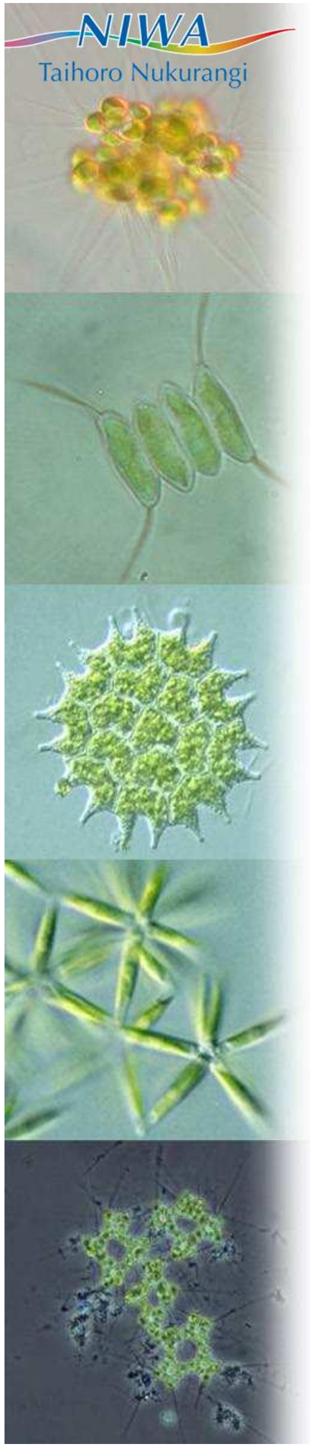
Dairy Farm Wastewater

- **>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 CO_2 addition: 1092 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
- **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



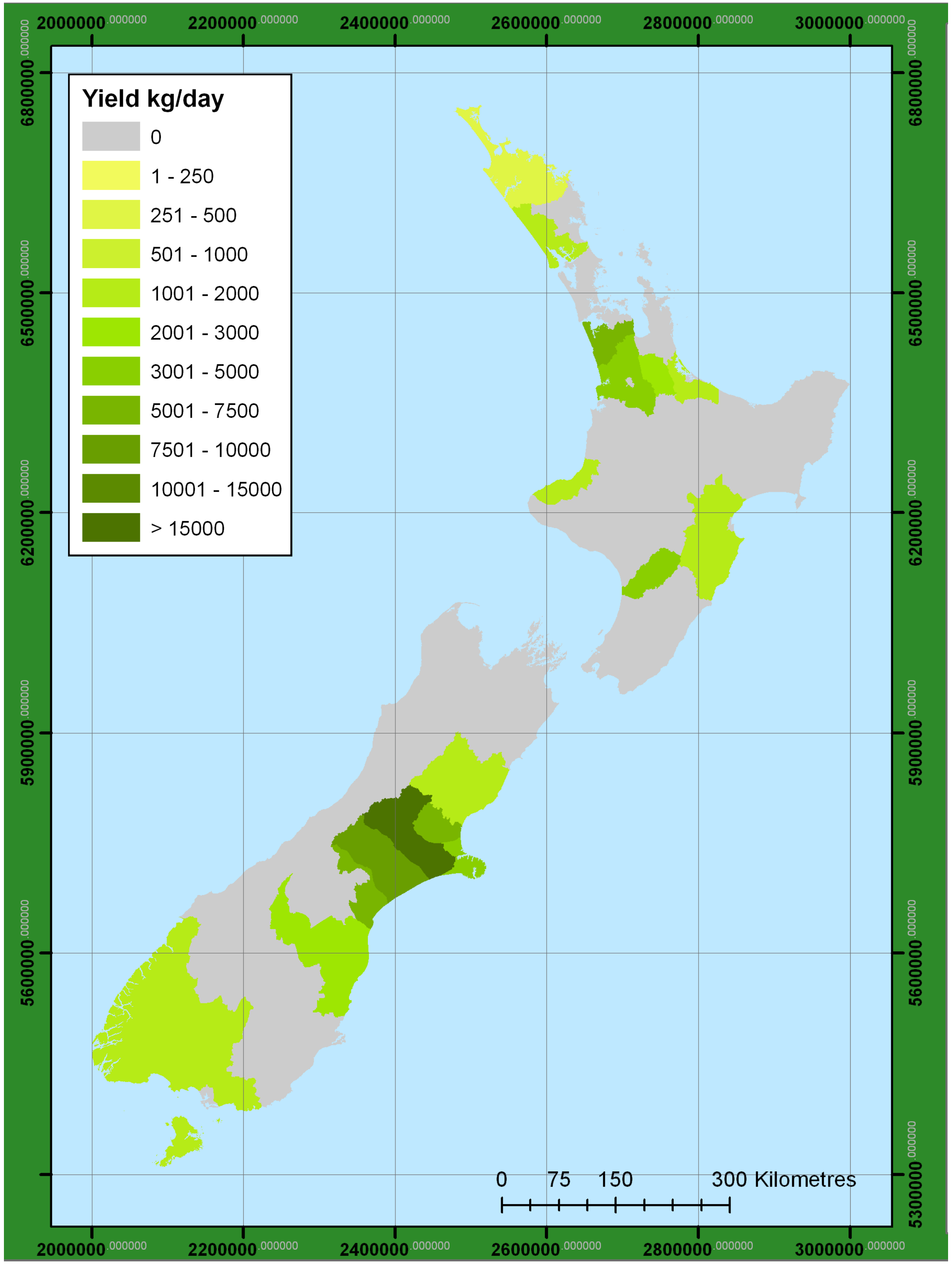


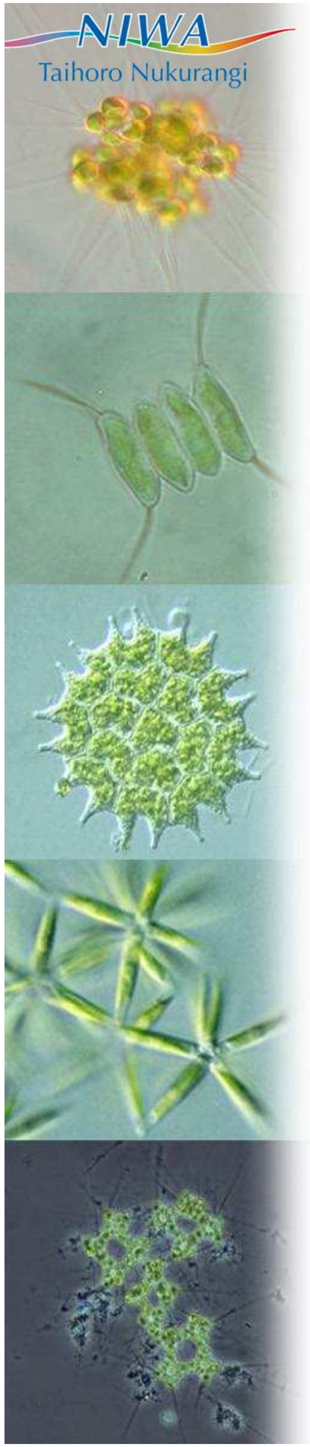
Piggery Wastewater

- **~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

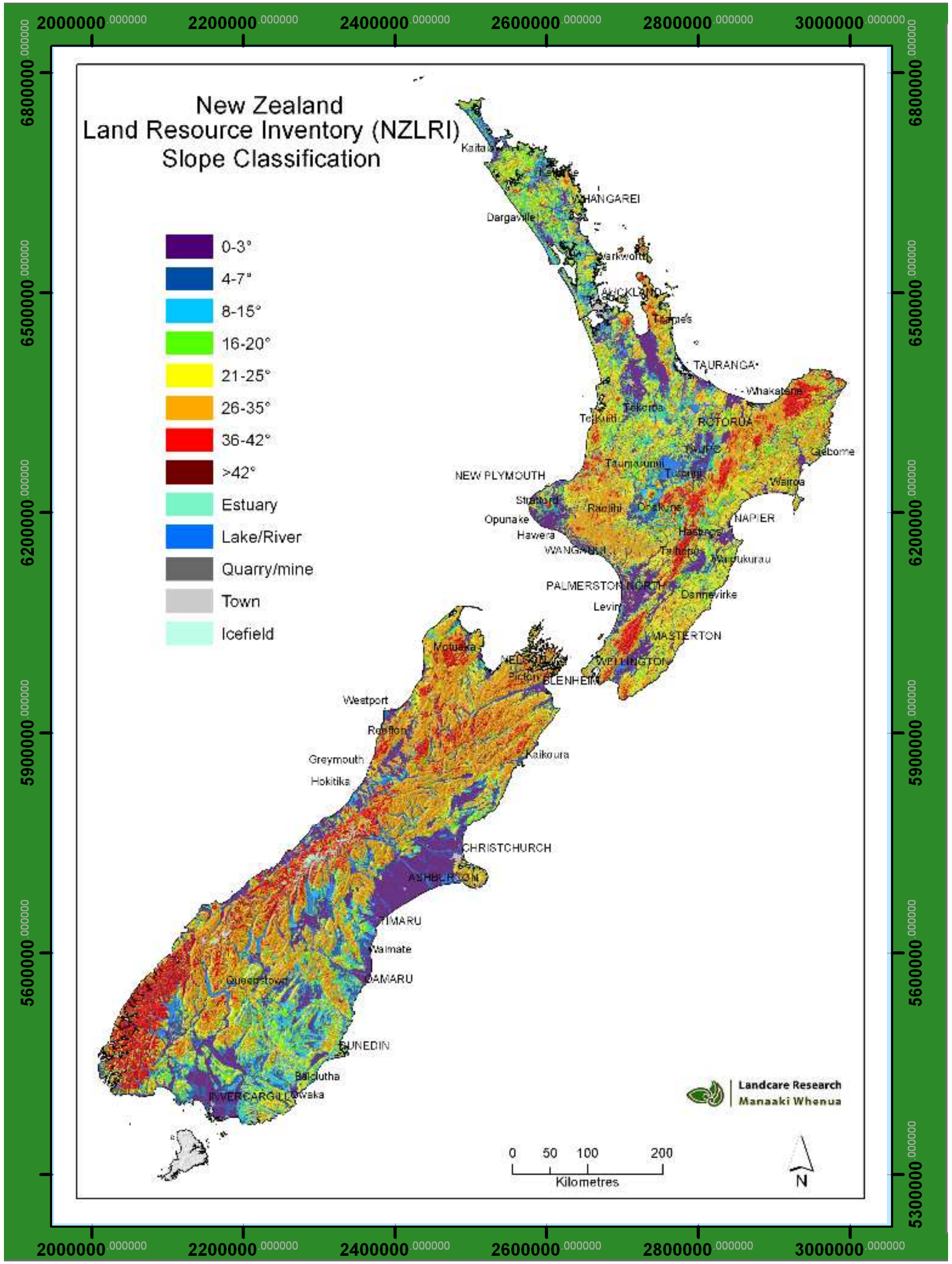




Constraints on Algal Production

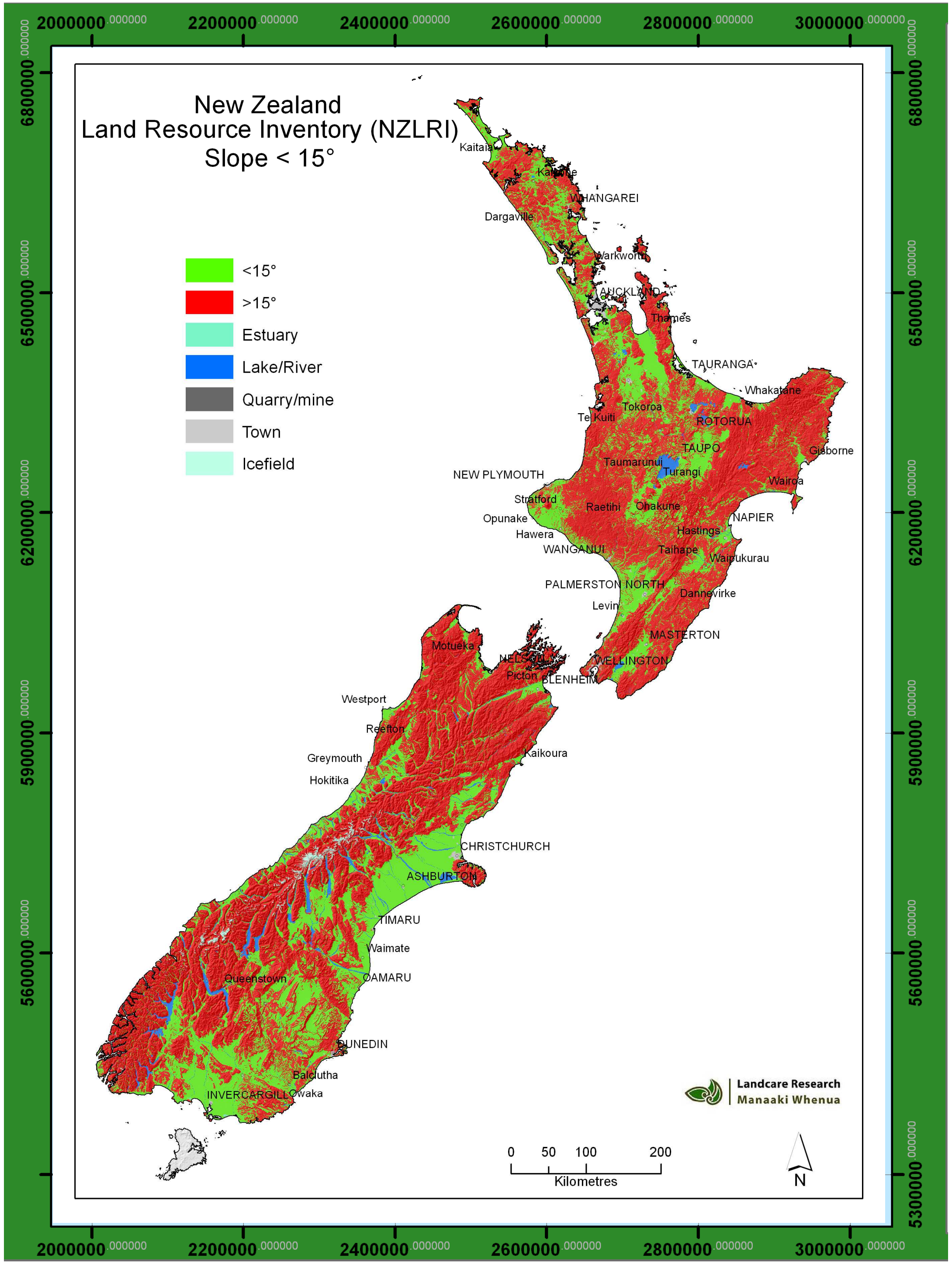
- **Suitability and availability of low-cost, flat (<15^{o}slope) land**
- **Suitable climate for algae growth**
- **Harvest cost and efficiency**

New Zealand Land Slope



New Zealand Land Slope < 15º

- Plenty of land
- Most communities and agriculture waste production in areas of flat land



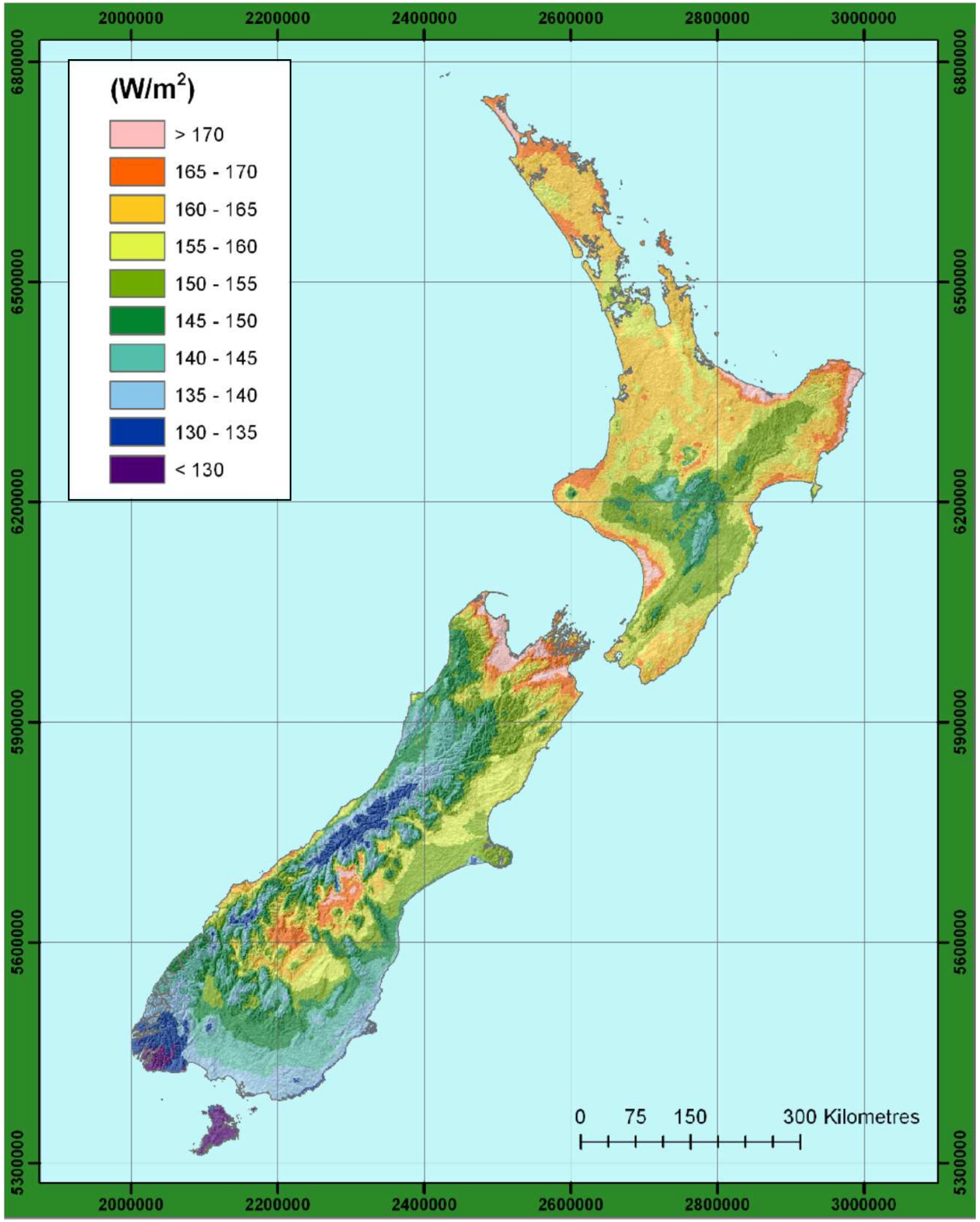
New Zealand Climate Maps

- **Solar Radiation**
- **Temperature**

Annual Average Solar Radiation (W/m^2)

- **North: >155 W/m^2**
- **South:>140 W/m^2**

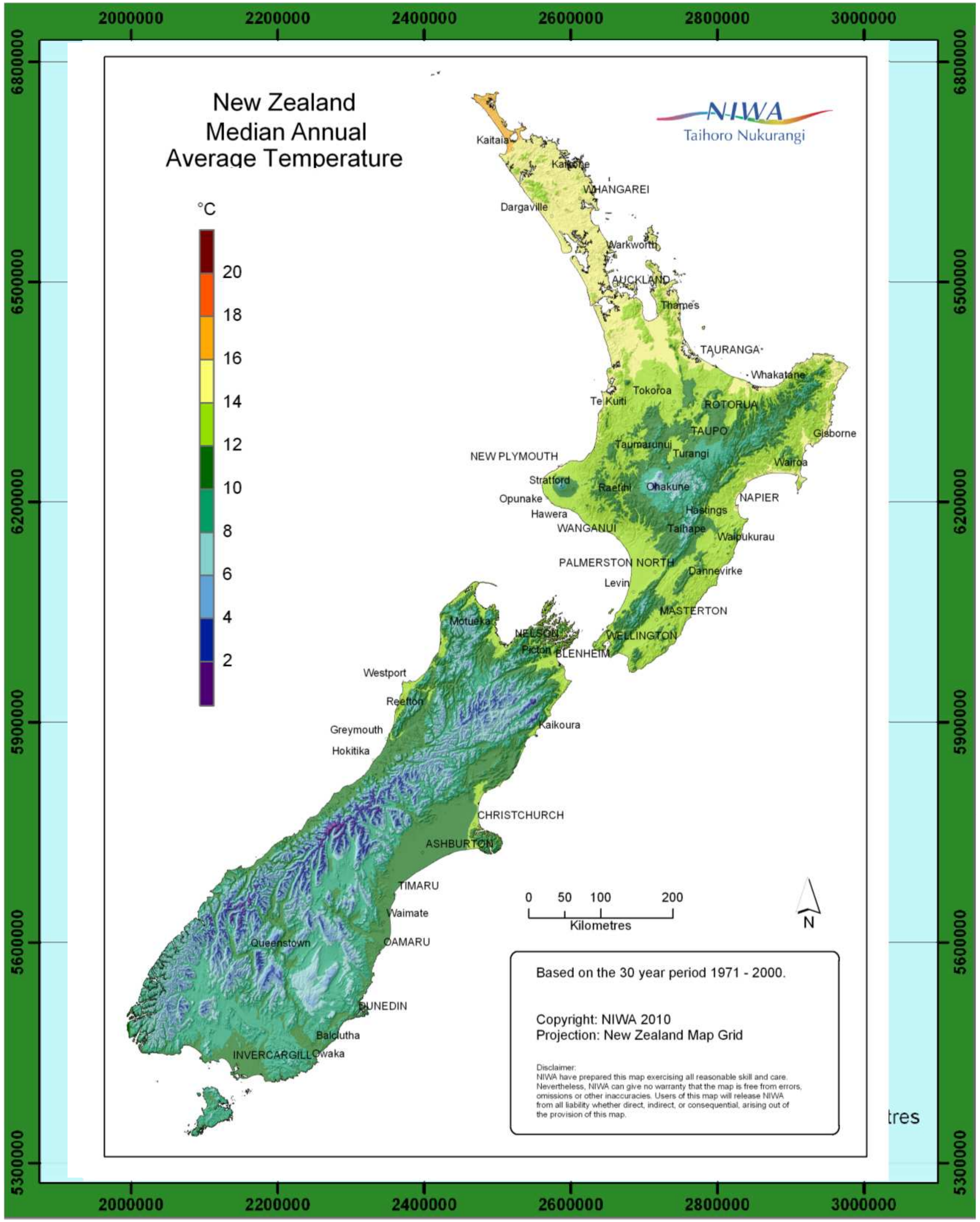
- **Limits annual production**
- **High summer time production achievable**



Annual Average Temperature (^{o}C)

- North: >13 ^{o}C
- South: >8 ^{o}C

- Need to have low temperature adapted strains



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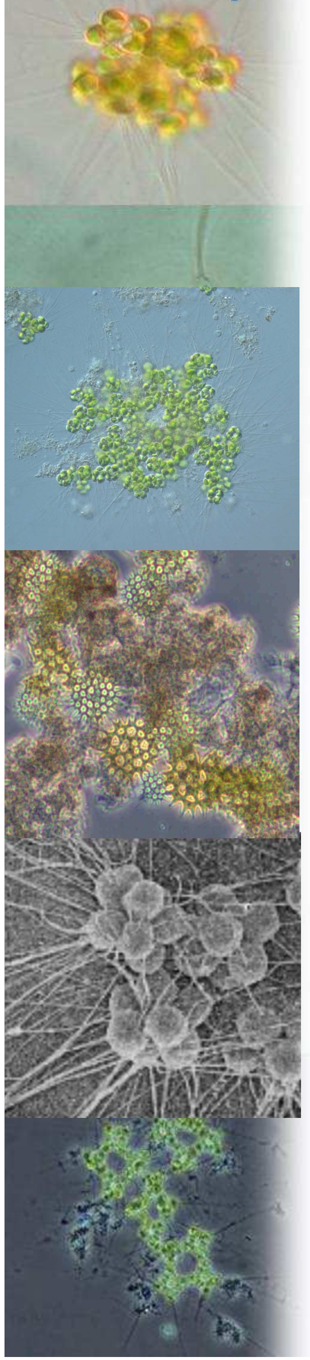
Algal Removal



- **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 CO_2 addition
  - Recycling settled algae back to the HRAP

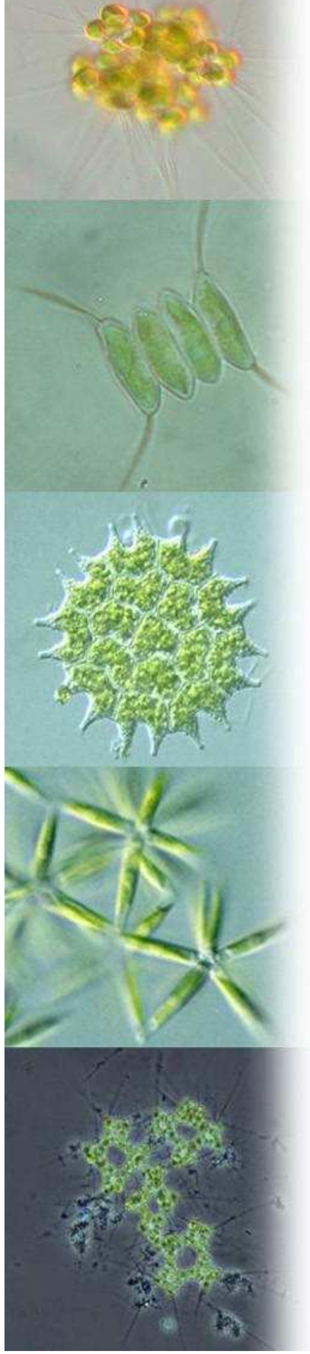
Algal Settling Ponds (ASPs)

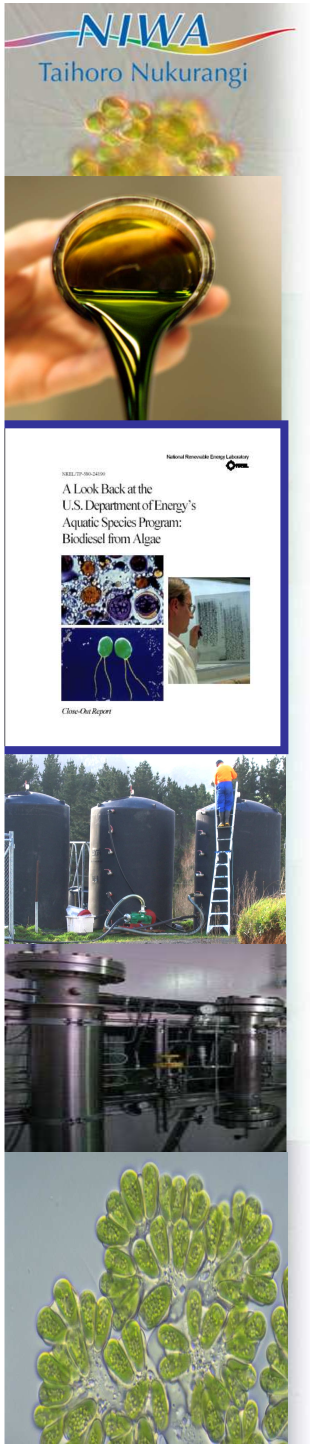
- Gravity settling of the algal biomass
- Storage for the periodic recovery of the settled algae.

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

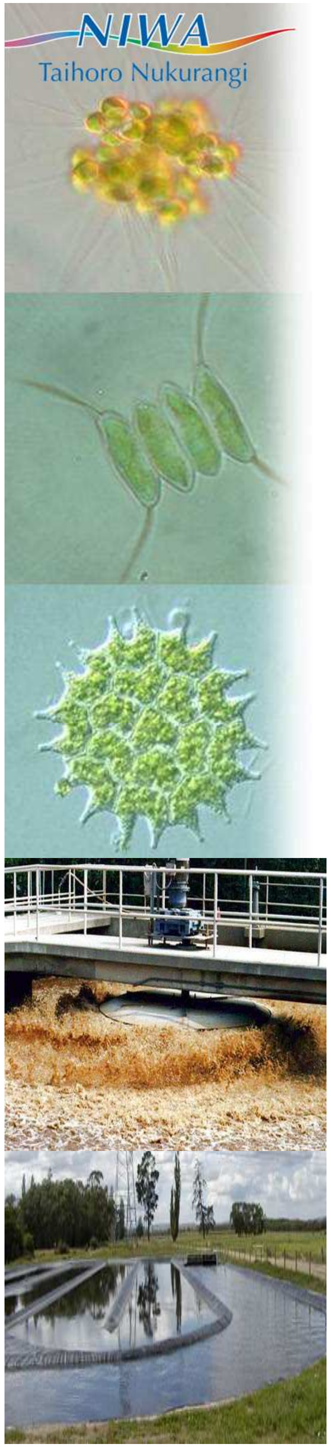




Algal Bioenergy Conversion

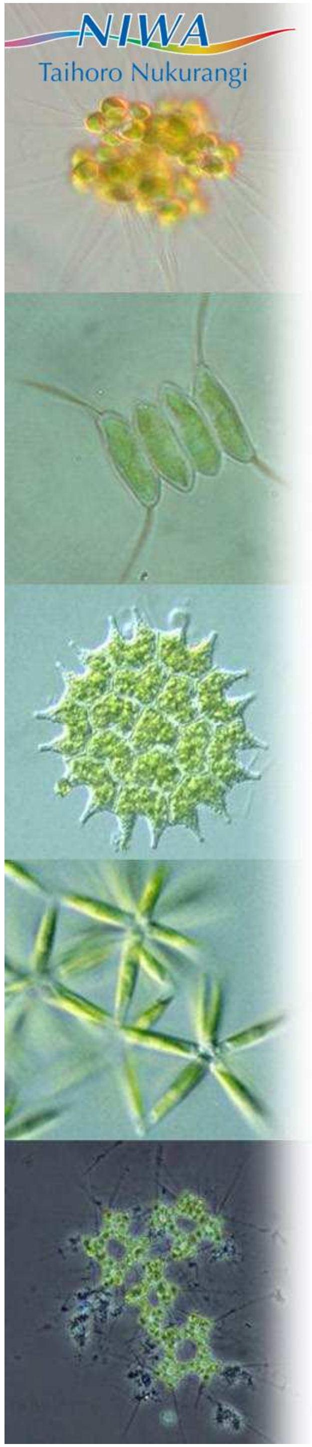
Potential technologies to convert algae biomass to bio-energy

- **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

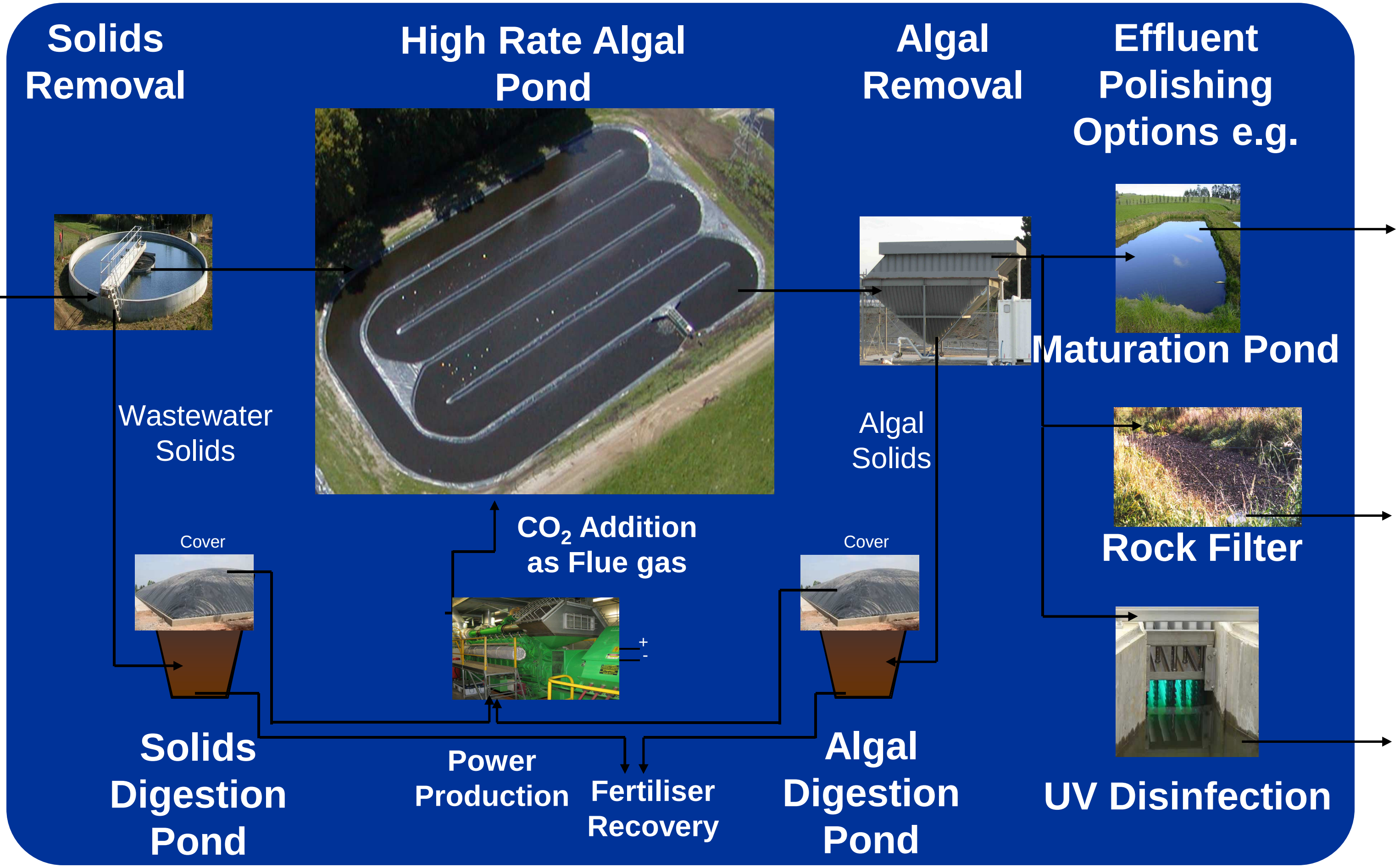


Co-Benefits

- **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



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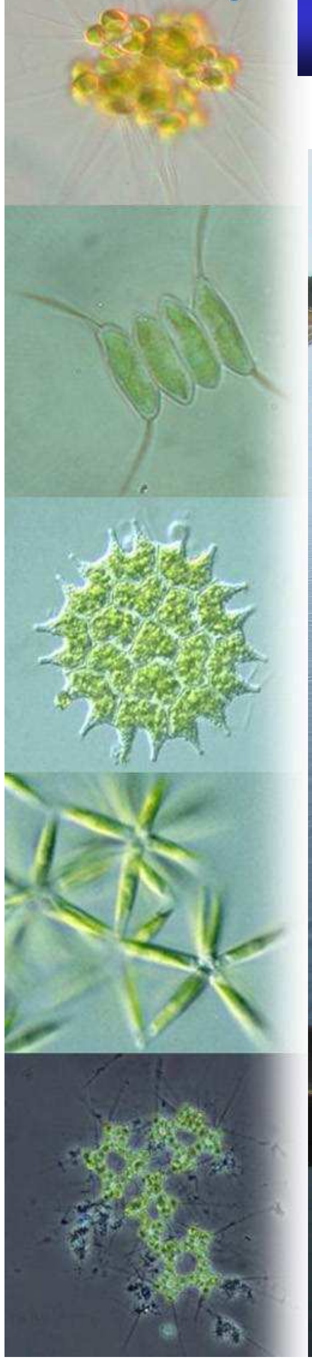
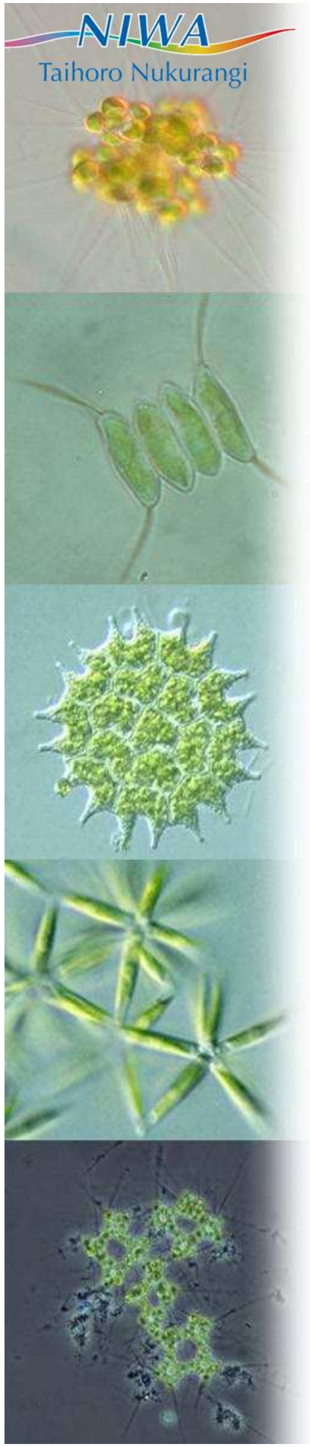


Christchurch 5 ha Demonstration



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