
# Current Status and Potential for Algal Biofuels Production

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1st Brazilian Bioenergy Science and Technology Conference, August 2011

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

IEA Bioenergy Task 39

Commercializing 1st- and 2nd- Generation Liquid Biofuels from Biomass

Report T39-T2 6 August 2010

# Current Status and Potential for Algal Biofuels Production

A REPORT TO IEA BIOENERGY TASK 39

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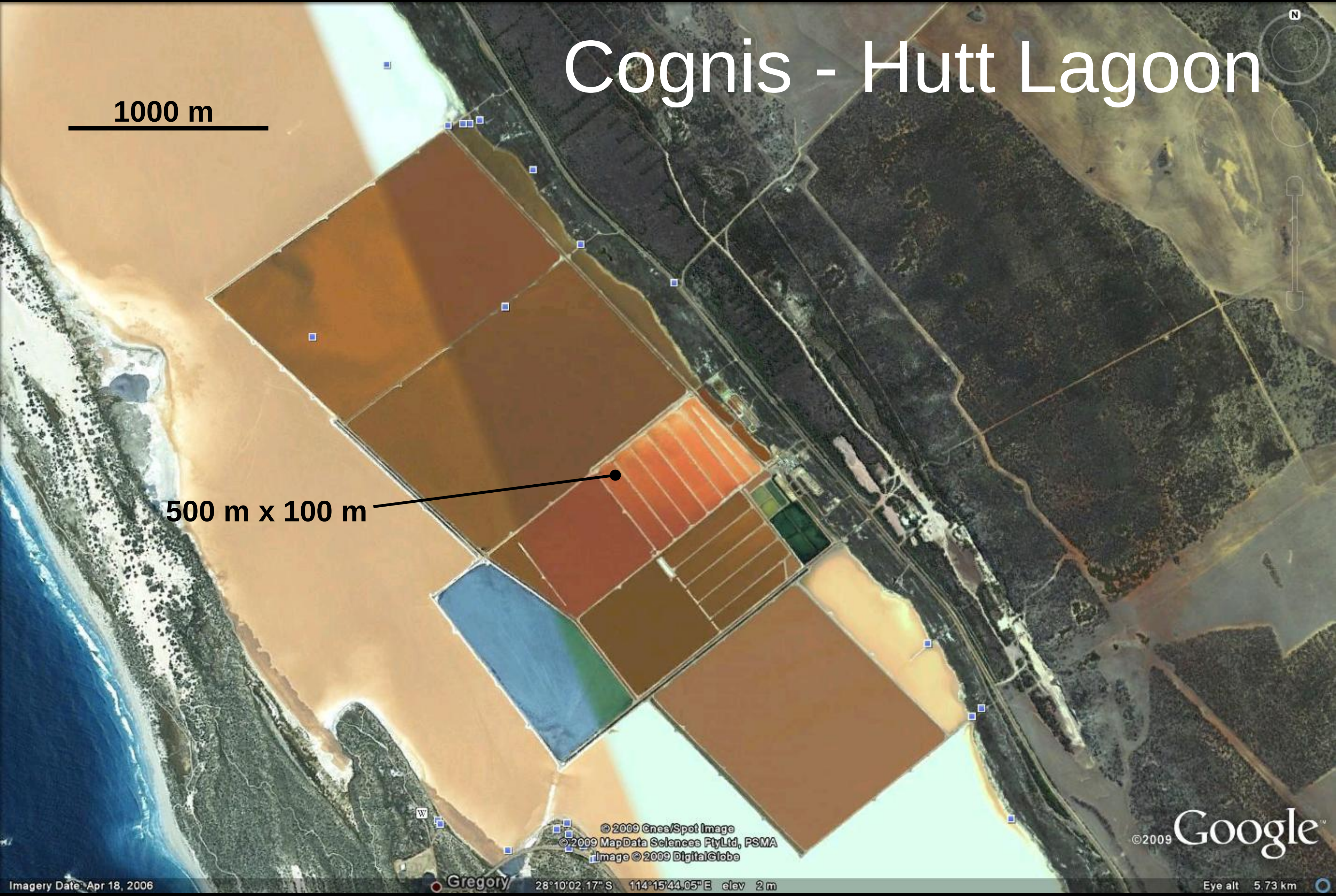
# Current Status and Potential for Algal Biofuels Production

- State of the technology
  - Algae diversity and versatility, photosynthesis and $CO_2$ fixation, physiological limits to growth, lipid production, commercial algal production systems
- Sustainability
- Siting of large scale algal biofuels production facilities
  - Climate, nearness to water, $CO_2$ & markets, soil type, elevation, slope
- Economics of algal biofuel production
  - Impact of technology development on economics
  - Impact of carbon price on economics
- Contribution of Algal Biofuels to future liquid transportation markets
- Appendix – US algal biofuels research, development and demonstration

**http://www.task39.org**

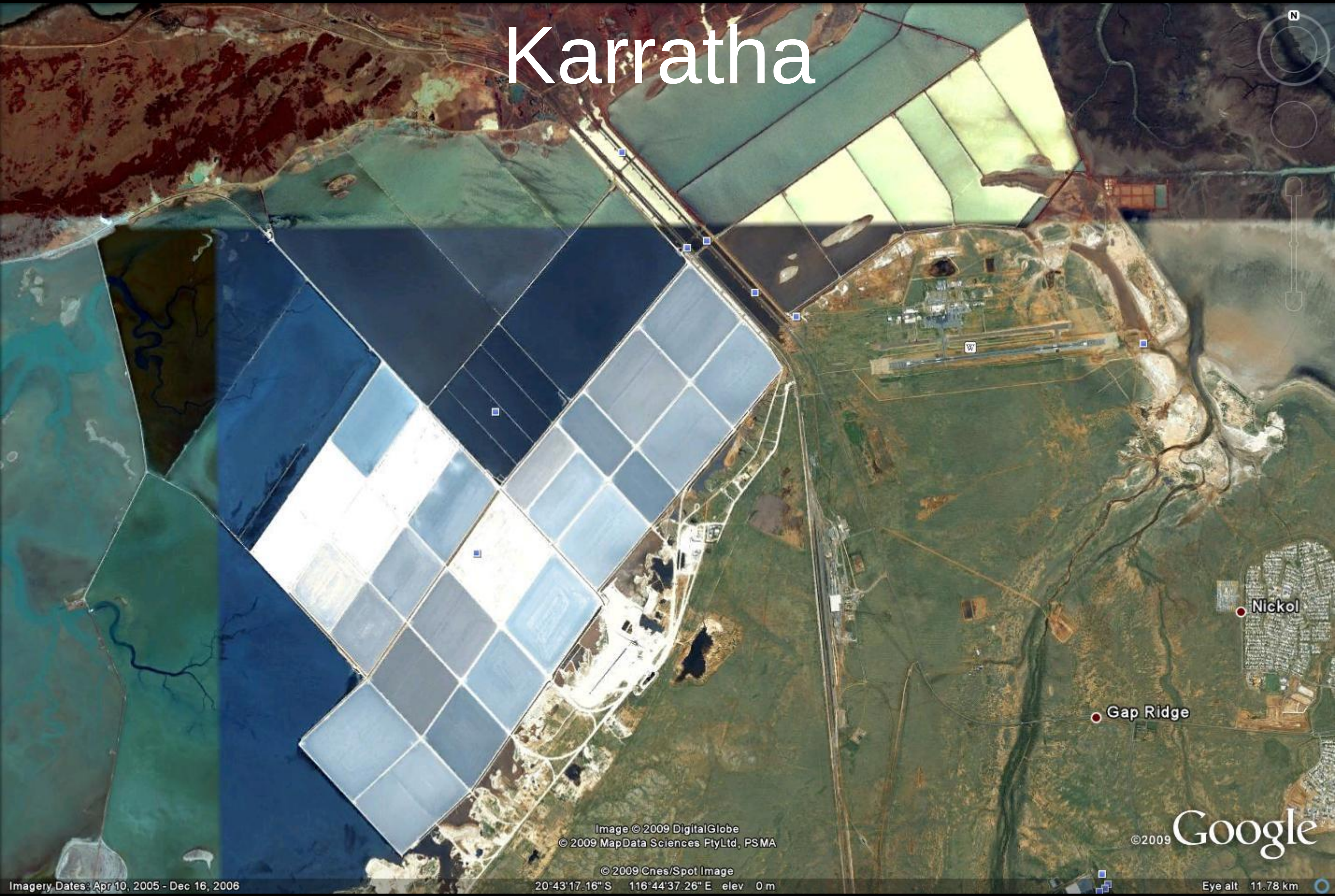
http://www.task39.org/LinkClick.aspx?fileticket=MNJ4s1uBeEs%3d&tabid=4348&language=en-US

# Cognis - Hutt Lagoon



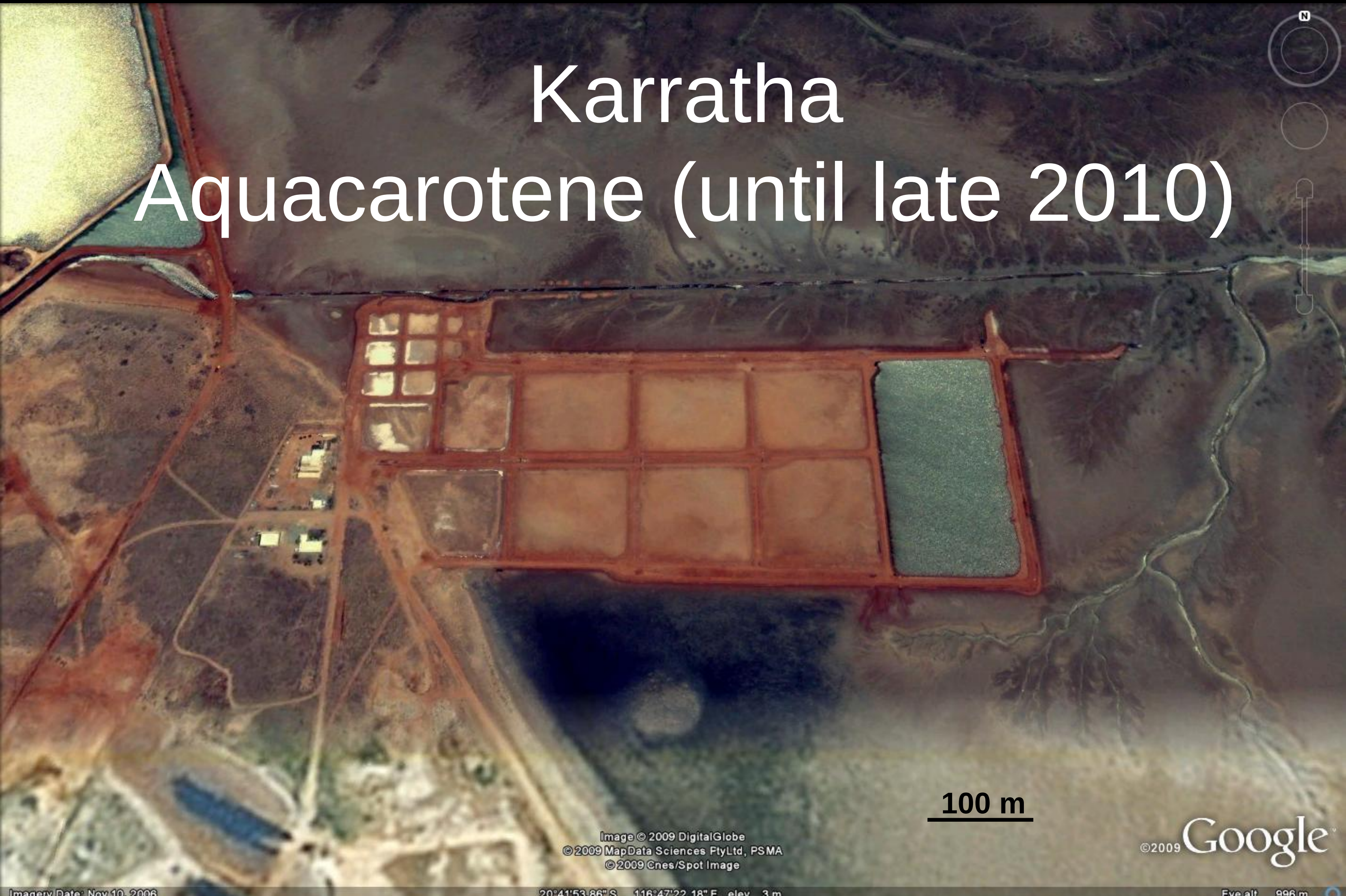
# Cognis - Whyalla

# Karratha

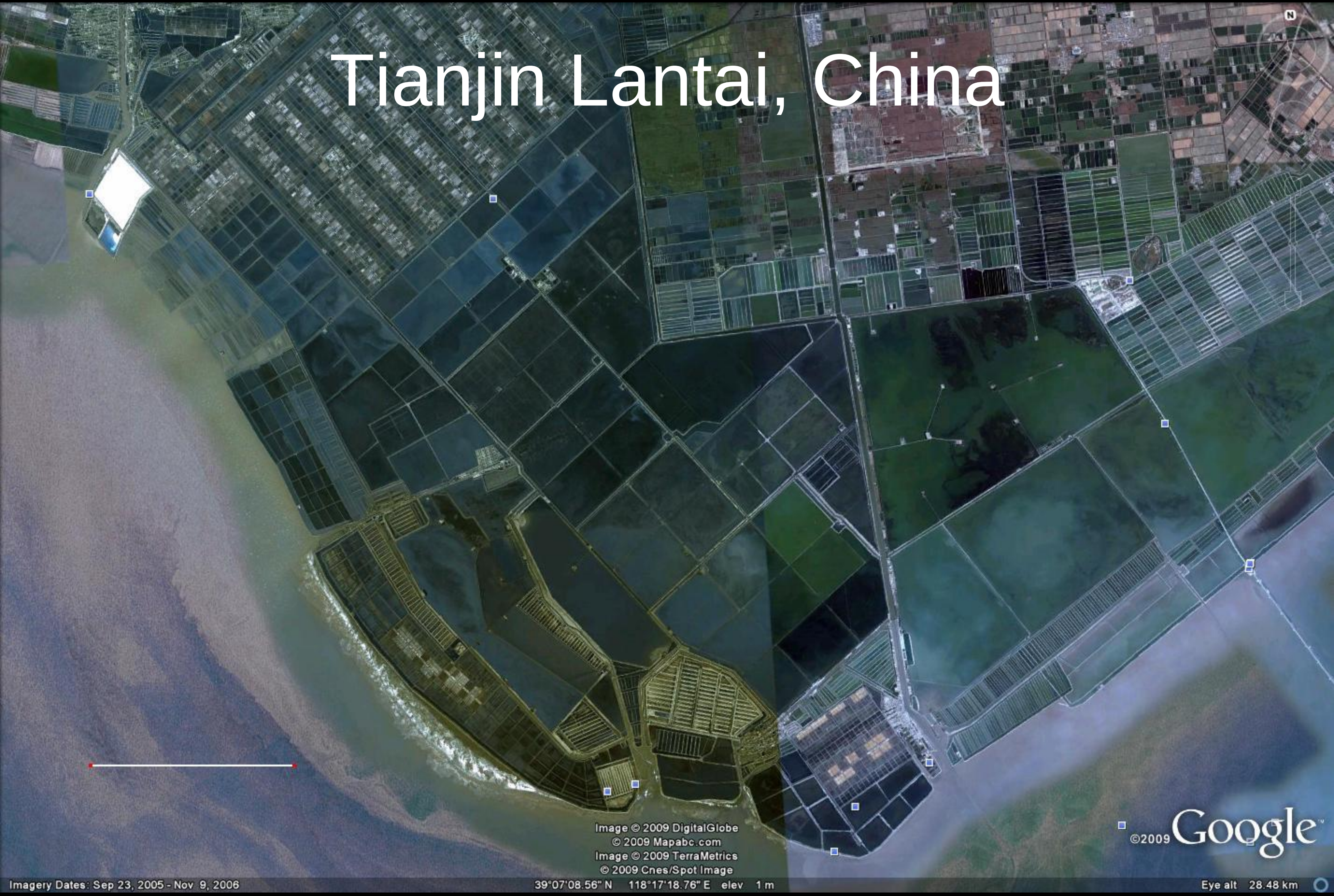


Nickol
Gap Ridge
Image © 2009 DigitalGlobe
© 2009 MapData Sciences PtyLtd, PSMA
© 2009 Cnes/Spot Image
©2009 Google
Imagery Dates: Apr 10, 2005 - Dec 16, 2006
20°43'17.16" S 116°44'37.26" E elev 0 m
Eye alt 11.78 km

# Karratha
# Aquacarotene (until late 2010)



# Tianjin Lantai, China



# *Extensive ponding relies on the bounty of nature with minimal intervention*

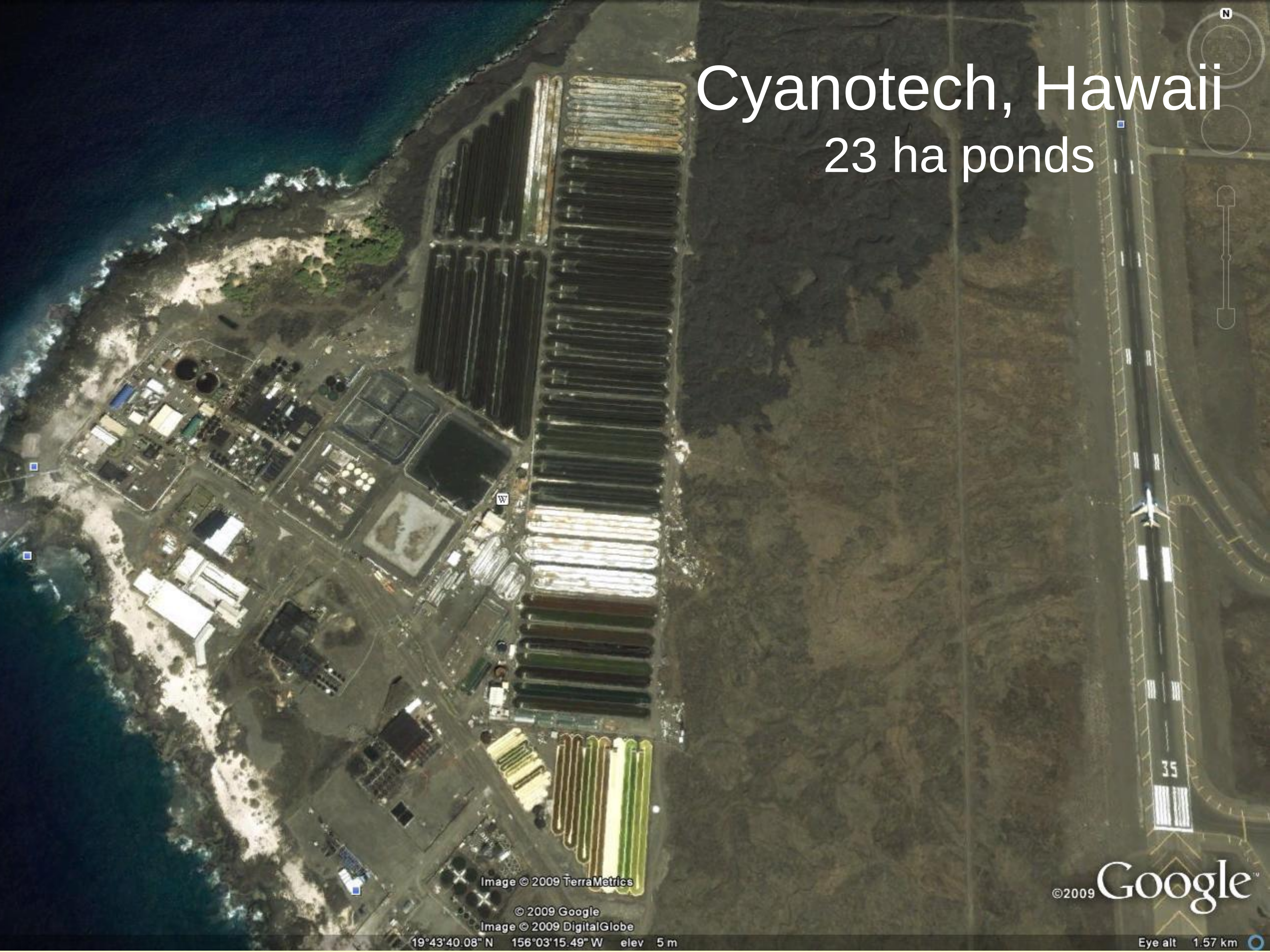
Hutt Lagoon 520 ha

Whyalla 440 ha

Cognis - 80% of world's β-carotene market

Karratha 17 ha, Dampier Salt *ca.* 3,000 ha

# Cyanotech Corp, Hawaii


Cyanotech, Hawaii
23 ha ponds
35
Image © 2009 TerraMetrics
© 2009 Google
Image © 2009 DigitalGlobe
19°43'40.08" N 156°03'15.49" W elev 5 m
Eye alt 1.57 km
©2009 Google

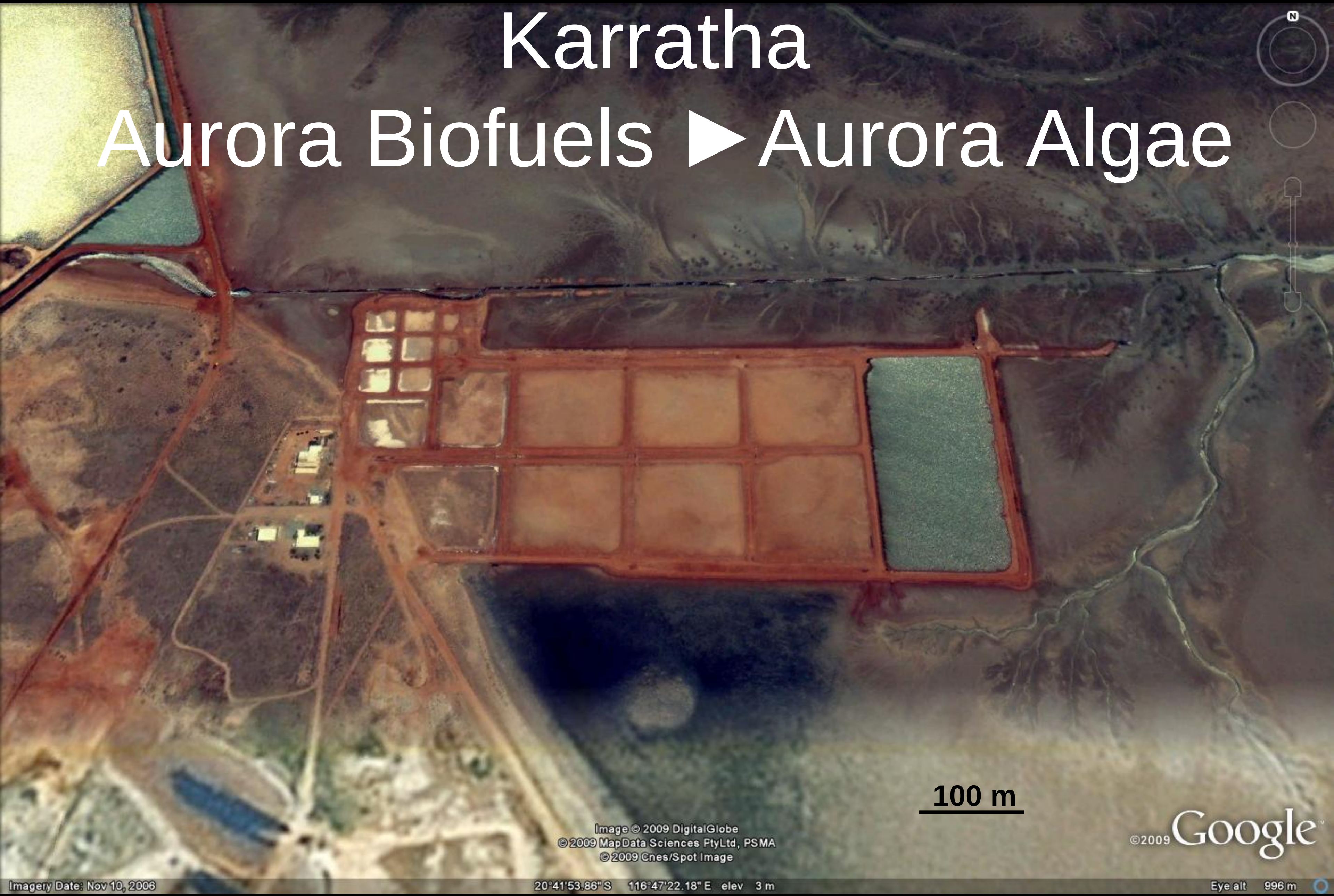
# Eilat, Israel


Earthrise
Nutritionals LLC
32 ha ponds
7 – 8 months/yr operation
100 m

Aurora Biofuels
Florida Institute of Technology
805 46th Place E, Vero Beach, FL 32963

# Karratha

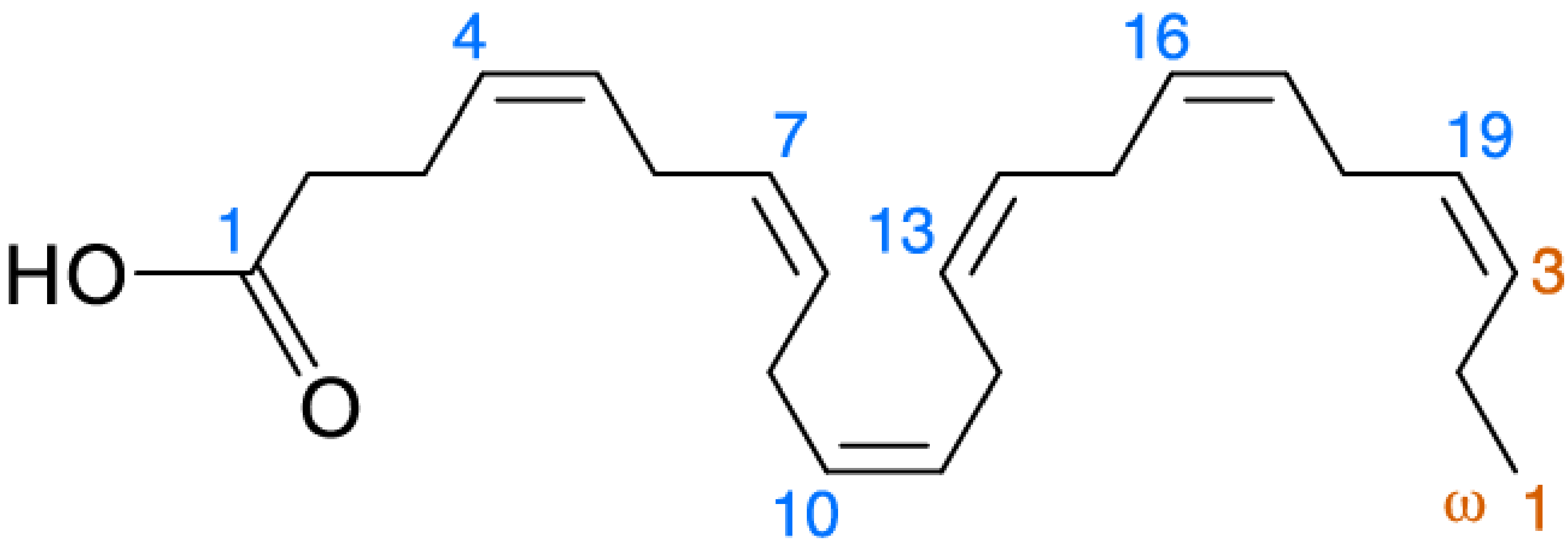
# Aurora Biofuels ►Aurora Algae




***"In US climate conditions it is not economically viable to produce large-scale, cost competitive algae products ......Karratha is an optimal world-wide location"*** **Greg Bafalis, CEO Aurora Algae (April 4, 2011)**

**6 x 0.4 ha ponds producing 15 tons/month algae (18.5 g/m$^2$/day)**
**Secured option agreement on additional 610 ha**

# Docosahexaenoic acid
# 22:6(n-3)




DHA comprises
- 40% of the polyunsaturated fatty acids (PUFAs) in the brain
- 60% of the PUFAs in the retina
- 50% of the weight of a neuron's plasma membrane

# Theoretical maximum yield calculation

- Physical laws, well-known values and no inefficiencies → cannot be disputed as the upper limit to production.
- High solar radiation (receiving >6 kWh/m$^2$/day) → ca.100 g/m$^2$/day (365 t/ha/yr).
- Thermodynamically impossible to exceed this rate in sunlight regardless of whether the algae are grown in ponds or photobioreactors.
- Natural blooms - 50 g/m$^2$/day but not sustainable.
- High values of productivity observed over relatively short periods - 20-30 g/m$^2$/day based on illuminated culture surface area.
- Demonstrated sustained production – 13-18 g/m$^2$/day

eTAP Environmental Technologies Action Plan


*“Soya produces 50 cubic metres per square kilometre per year, colza (rape seed) produces 100 to 140 cubic metres, mustard yields 130 and palm oil 610 cubic metres, while algae produce 10,000 to 20,000 cubic metres of biofuel per square kilometre per year”*

http://ec.europa.eu/environment/etap/inaction/pdfs/sept06_algae_energy.pdf

*“ Selon M. Stroïazzo-Mougin président et fondateur de BFS, une unité de 50 kilomètres carrés serait capable de produire environ 1 million 250.000 barils par jour.”*

*MaxiSciences (March, 2011)*

*http://www.maxisciences.com/biocarburant/des-micro-algues-pour-fabriquer-du-biopetrole_art13564.html#artComments*


BFS

ENERGY.GOV ENERGYBLOG

# Study: Algae Could Replace 17% of U.S. Oil Imports

April 13, 2011 - 6:30pm

*“PNNL Researchers found that by growing algae in strategic locations, the U.S. could produce 21 billion gallons of algal oil”*

Fresh water: *“...a quarter of what the country currently uses for irrigated agriculture — would be needed to produce that much algal biofuel.”*

Authors of report are looking beyond fresh water use

*“Algae can produce more than 80 times more oil than corn per hectare a year. And unlike corn and soybeans, algae aren't a widespread food source that many people depend on for nutrition.”*

More than 80 times more oil than corn ► >13,760 $l.ha^{-1}.yr^{-1}$

M.S. Wigmosta, et al. (2011) National Microalgae Biofuel Production Potential and Resource Demand. *Water Resources Research.*

# Keeping productivity real

- Productivity – 20 $g/m^2/day$ (even this is objectively optimistic - in current operations - 15 to 18 $g/m^2/day$)
- Biomass lipid content – 30%
- 340 days of operation

| Productivity ($l.ha^{-1}.yr^{-1}$) | |
|---|---|
| Corn; Soybean | 172; 450 |
| Jatropha | 2000 |
| Algae @ 15 $g/m^2/day$ | 3650 |
| Algae @ 20 $g/m^2/day$ | 4870 |
| Palm oil | 6000 |

**IEA - 3,800 $l.ha^{-1}.yr^{-1}$ (Roswell) to 50,800 $l.ha^{-1}.yr^{-1}$ (NREL 50 $g.m^{-1}.d^{-1}$ at 40% lipid)**
**Yusuf Christi (2007) Biotechnol. Adv. 25, 294–306 up to 136,900 $l.ha^{-1}.yr^{-1}$**

# Niche opportunities for algal production

- municipal waste water treatment
- other ‘waste waters’
  - e.g. coal seam methane water
- point source $CO_2$ capture
- All economically feasible with GHG emissions reduction policy settings & where it’s possible to do it
- Will not necessarily lead to large volumes of liquid transportation fuel production

# Thinking at large scale 100 ML p.a. facility

- Assumptions: 20 g/m$^2$/day (68 t/ha/yr), 30% lipid, 340 days/yr → 5172 ha (52 km$^2$) of pond surface
- Construction of raceway ponds is more like building a road than digging a ditch
- Fresh water cultivation is probably not sustainable – better uses for the required land and water
- Precipitation and evaporation create major pond management problems
- Nearness to water, $CO_2$ & markets, soil type, elevation, slope, climate (solar radiation & temperature range) → physical limits that are not well understood.

# 100 ML plants - Why so big?

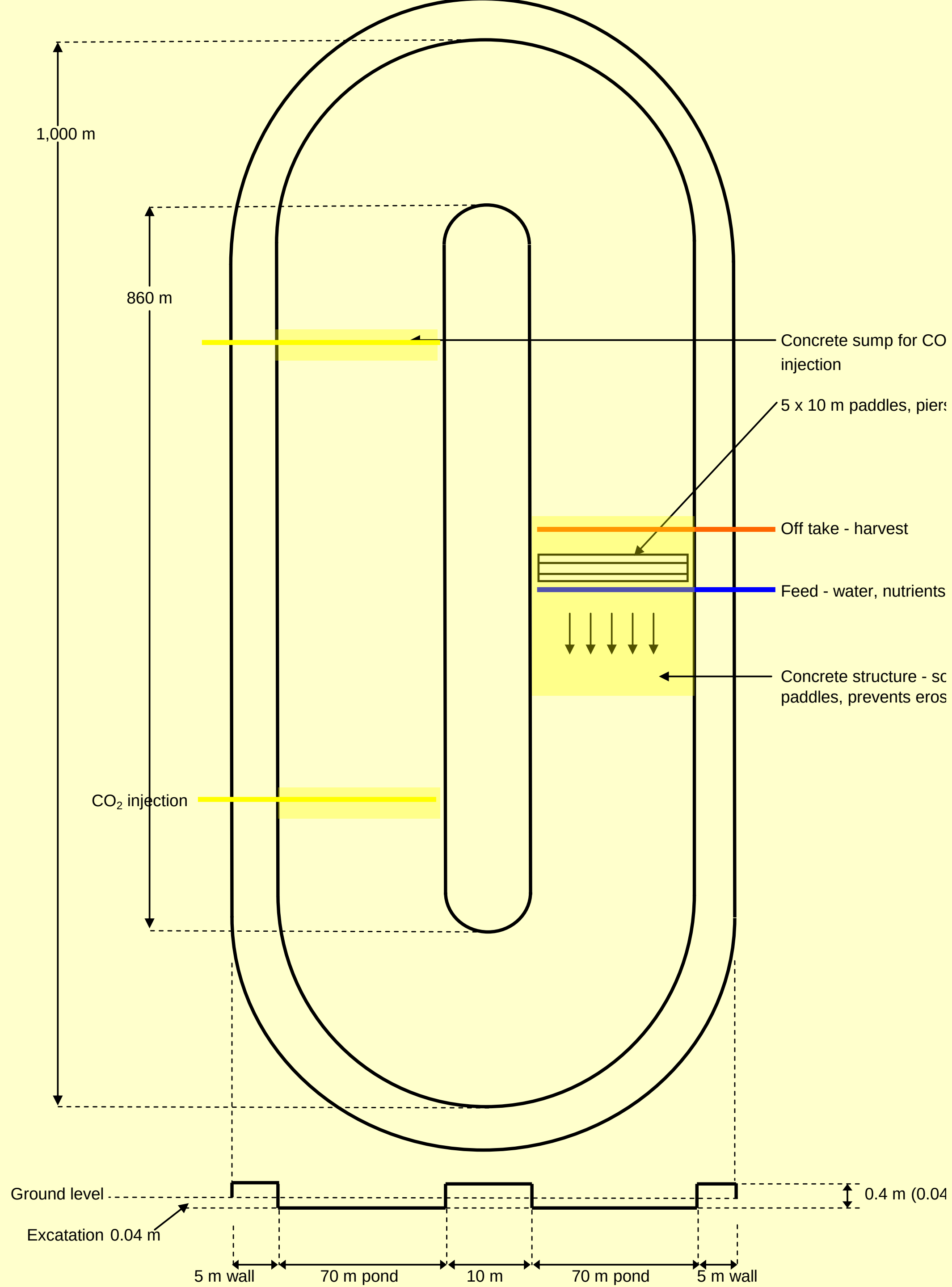
- EIA International Energy Outlook, 2009
- 2030 oil consumption – 6.2 TL/yr
- Transportation 56 % of consumption
- Unconventional liquid fuels – 720 to 1100 GL/yr
- Biofuels – 277 to 416 GL/yr (4.8 to 8.0 %) and use 340 GL/yr as reference

2030 reference case

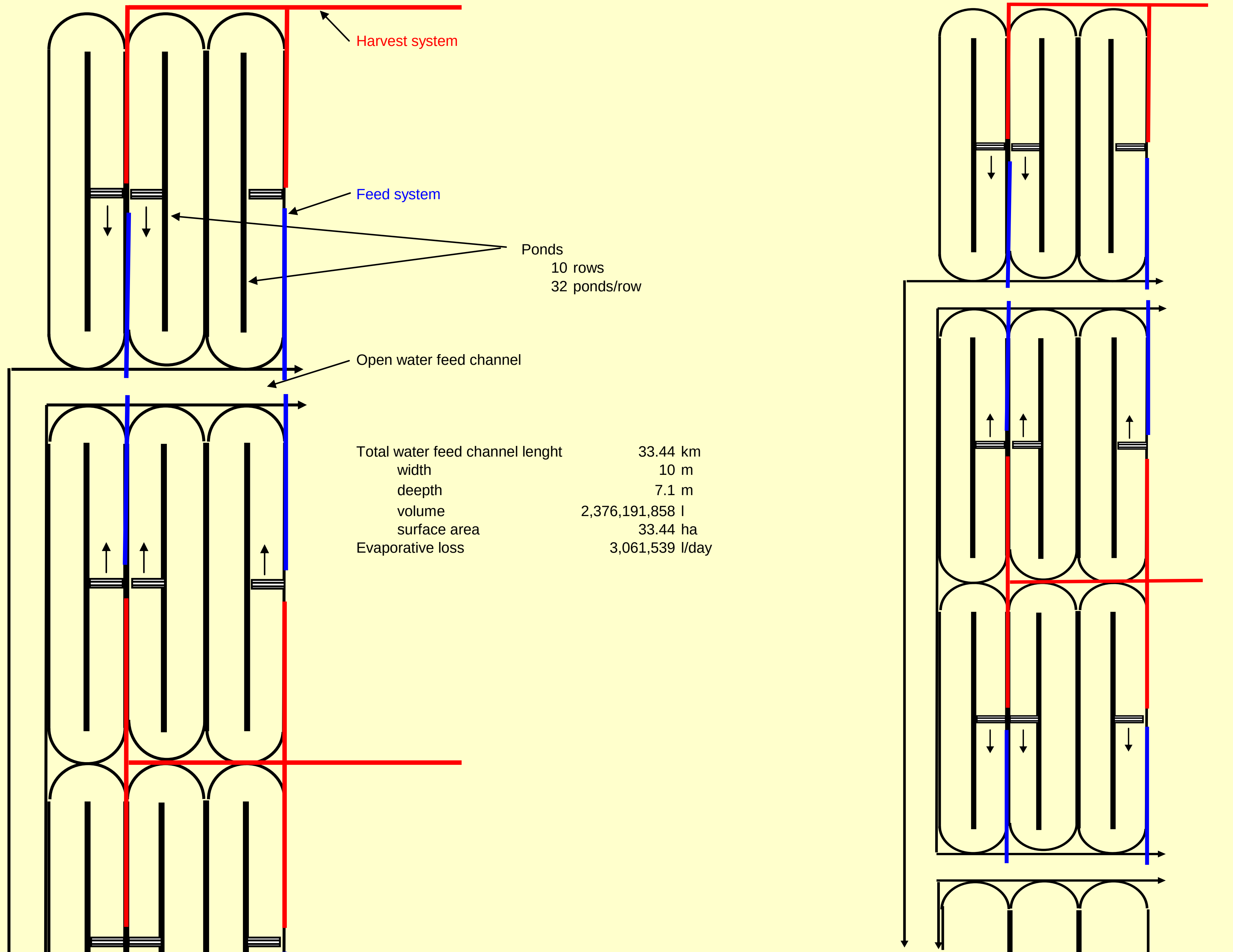
5 % - 170 100 Ml plants

50 % - 1700 100 Ml plants

80 % - 2716 100 Ml plants

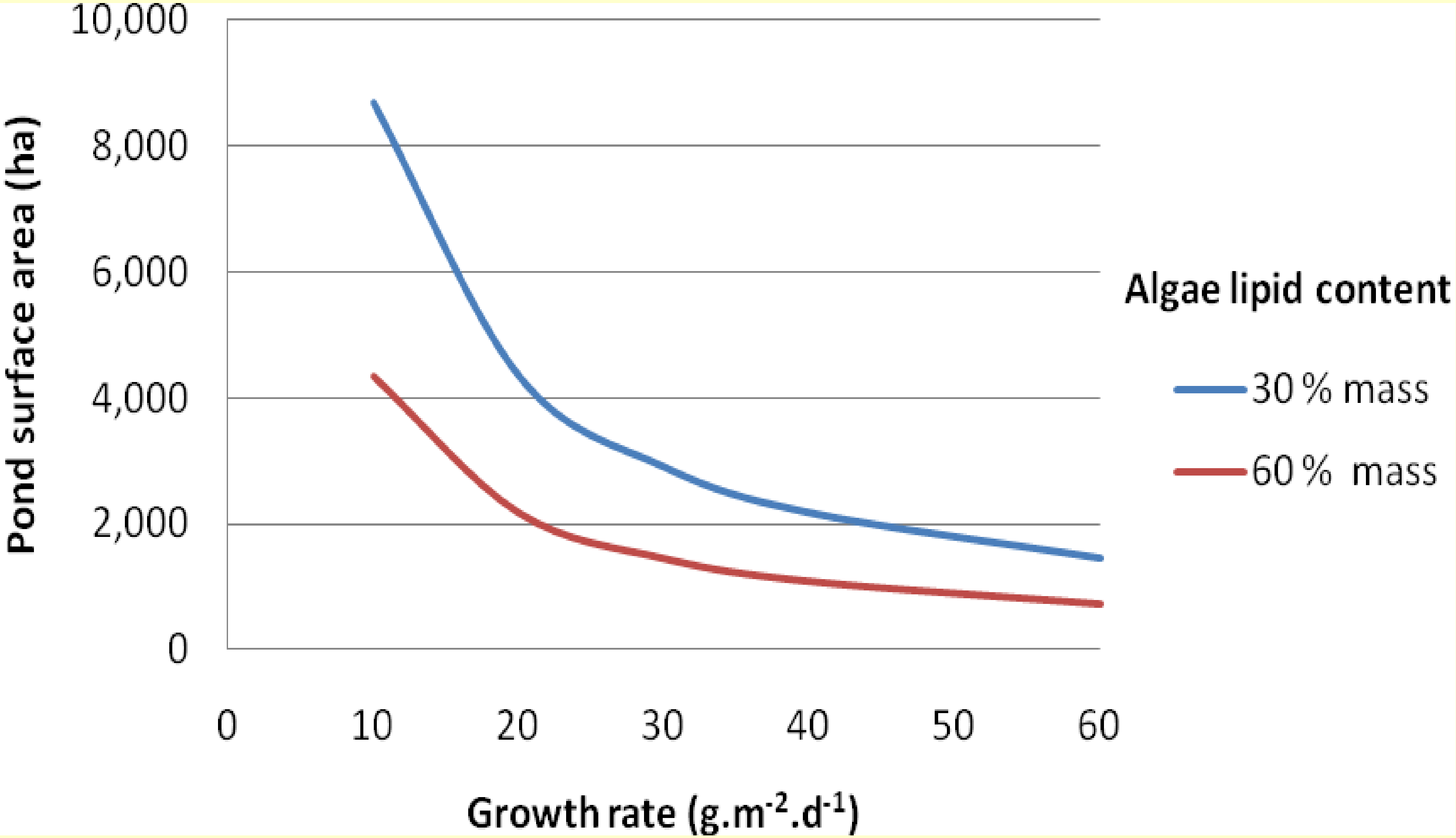



| | | Units |
|---|---|---|
| Excavation deepth | 0.04 | m |
| Excavation volume | 5464 | $m^3$ |
| Mound height | 0.36 | m |
| Mound volume | 7025 | $m^3$ |
| Water deepth | 0.20 | m |
| Pond volume | 27319 | $m^3$ |
| Pond surface area | 13.66 | ha |
| Total pond area | 16.16 | ha |



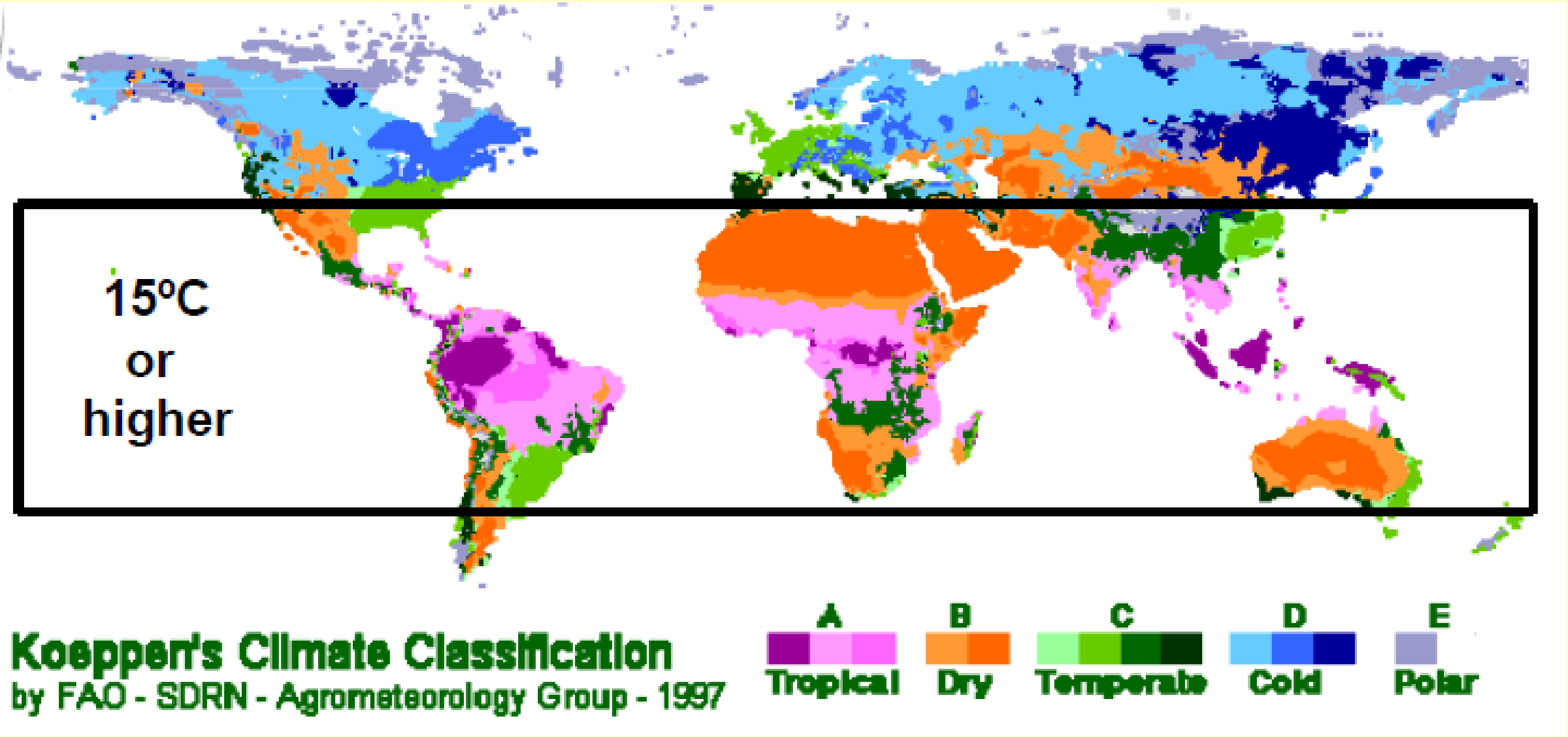

| | | |
|---|---|---|
| Total water feed channel lenght | 33.44 | km |
| width | 10 | m |
| deepth | 7.1 | m |
| volume | 2,376,191,858 | l |
| surface area | 33.44 | ha |
| Evaporative loss | 3,061,539 | l/day |

# Pond surface area for 100 ML production

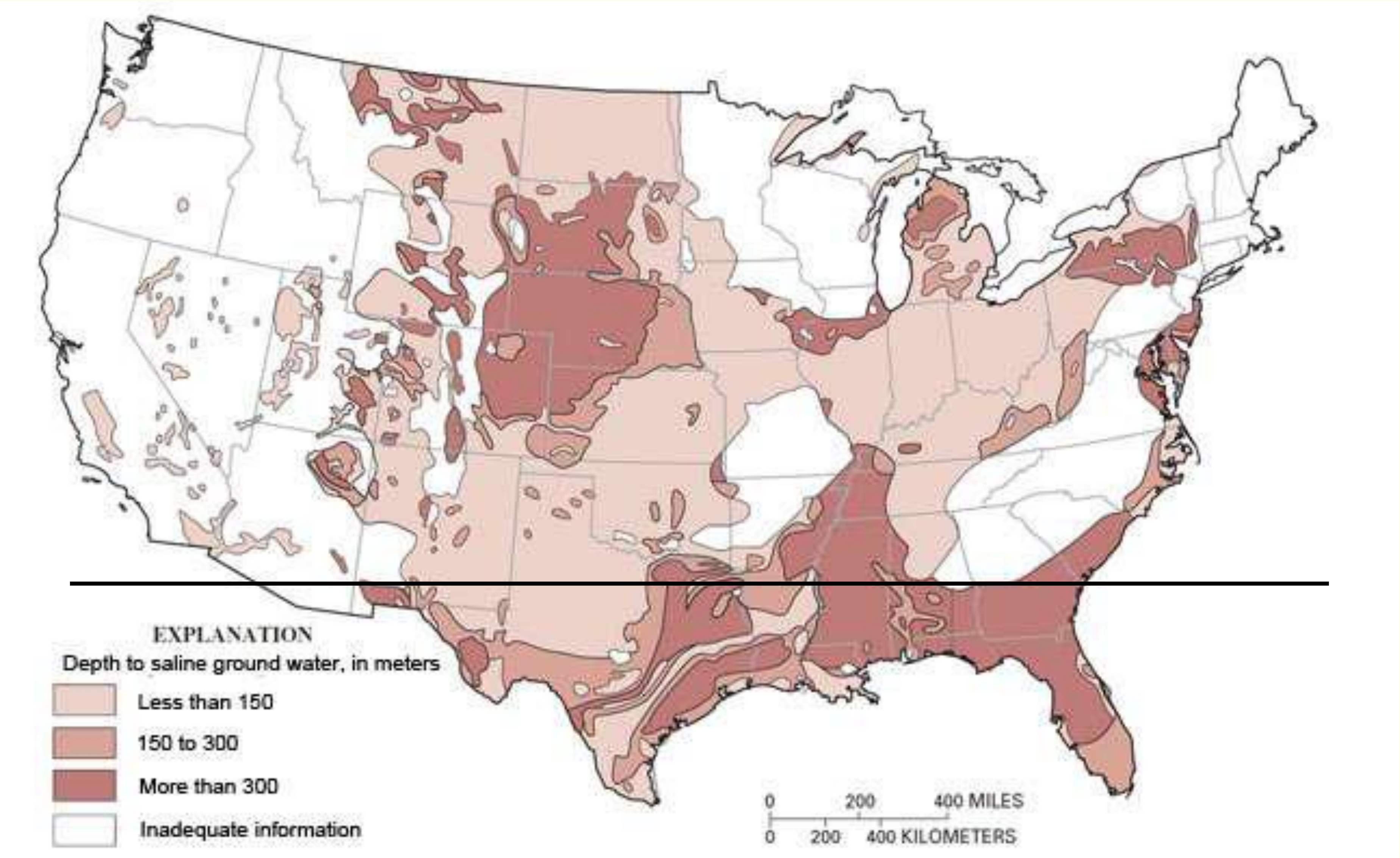


# Suitable climates?

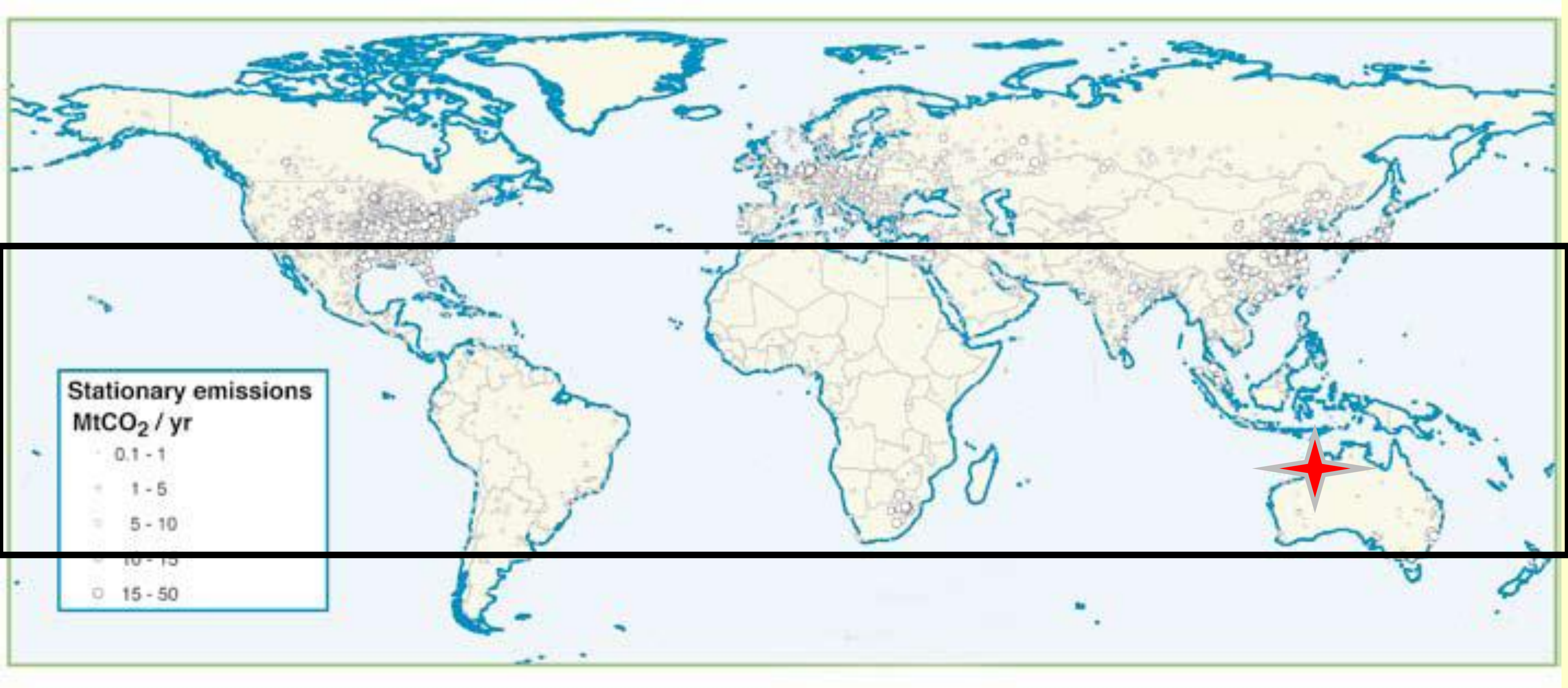
## Average monthly temperature of coldest month



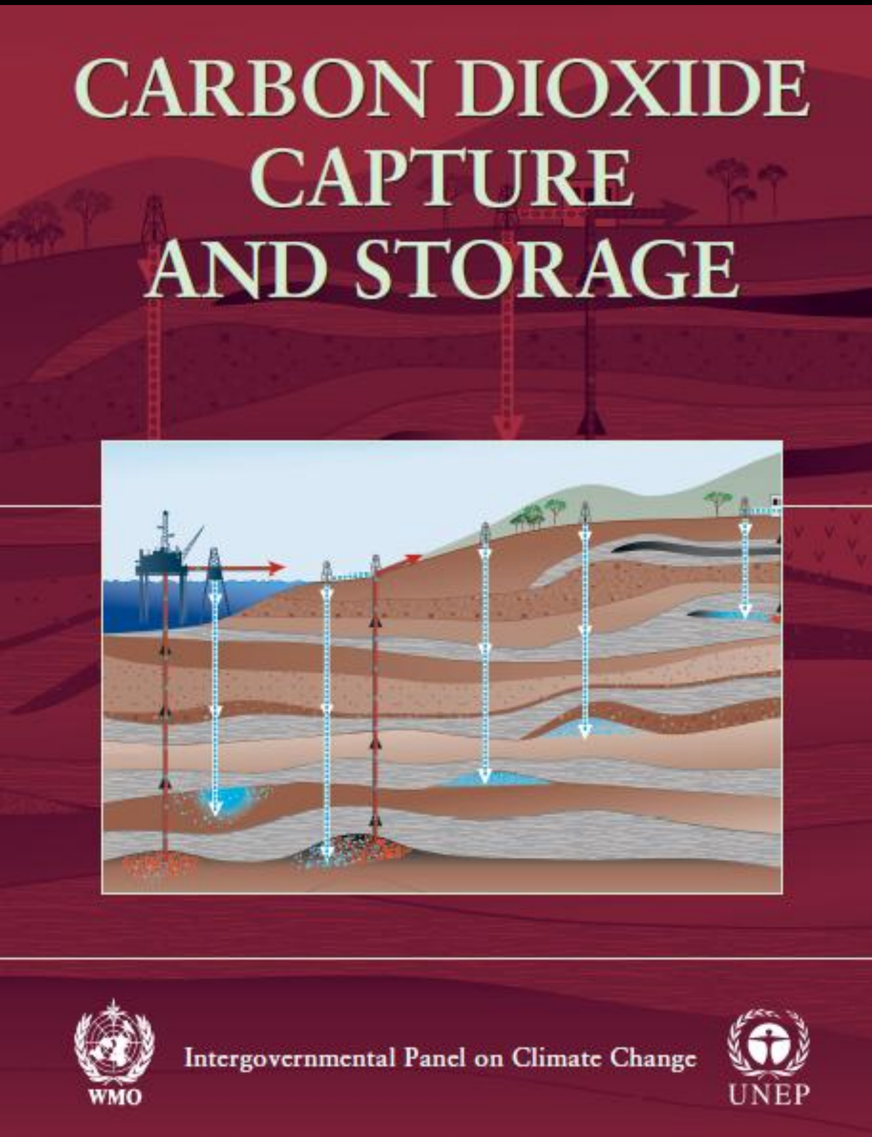
# Where is the water?



# Where is the $CO_2$?




# Where is the available land?




# 4

## Transport of $CO_2$

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# Is $CO_2$ free?

- $CO_2$ consumption at very large scale algal biofuel production facilities (100 ML) matches emissions from small coal fired power stations (100 MW – 37 to 81 t/hr), but at current productivities requires >50 $km^2$ pond surface.
- Cost of emissions credits, Costs of alternatives, Profitability of algal biofuels production, Understanding of and access to liquid fuel markets
  - In cases of mismatches decision is complex (e.g. high emissions penalties - cost of algal production system versus cost of incremental increase in CCS capacity)

- IPCC Special Report on Carbon Dioxide Capture and Storage
  - Power plants with CCS require 10 % to 40 % more operating energy.
  - Physical capture and separation of gases at point source is the major cost of CCS.
  - Proposes pipelines (up to 1000 km) and even liquefaction and shipping for large point source emitters not close to suitable CCS sites.

# Realistic potential of algal biofuels

- Different types of potentials
  - Theoretical
  - Geographic – takes into account available & suitable land
  - Technical – likely productivity & efficiency within geographic potential
  - Economic – cost competitive delivery to markets
  - Ecological – accounts for impact on biodiversity
- Determining real potential requires better land use & suitability spatial mapping data

(types of potentials - Hoogwijk, 2004, Antilla *et al., 2009)*

# Conclusions

- Algae can be grown in large outdoor cultures and harvested.
- The algal biomass will contain a certain percentage of lipids, though not necessarily all in the form of triacylglycerides (TAGs).
- Algal oil can be obtained from harvested biomass by known means, albeit with sub optimal yield, cost and thermodynamic efficiencies.
- Biodiesel (fatty acid methyl ester, FAME), hydrogenation-derived renewable diesel (HDRD) and synthetic jet fuel production from algal oil have been demonstrated at non-commercial scales.

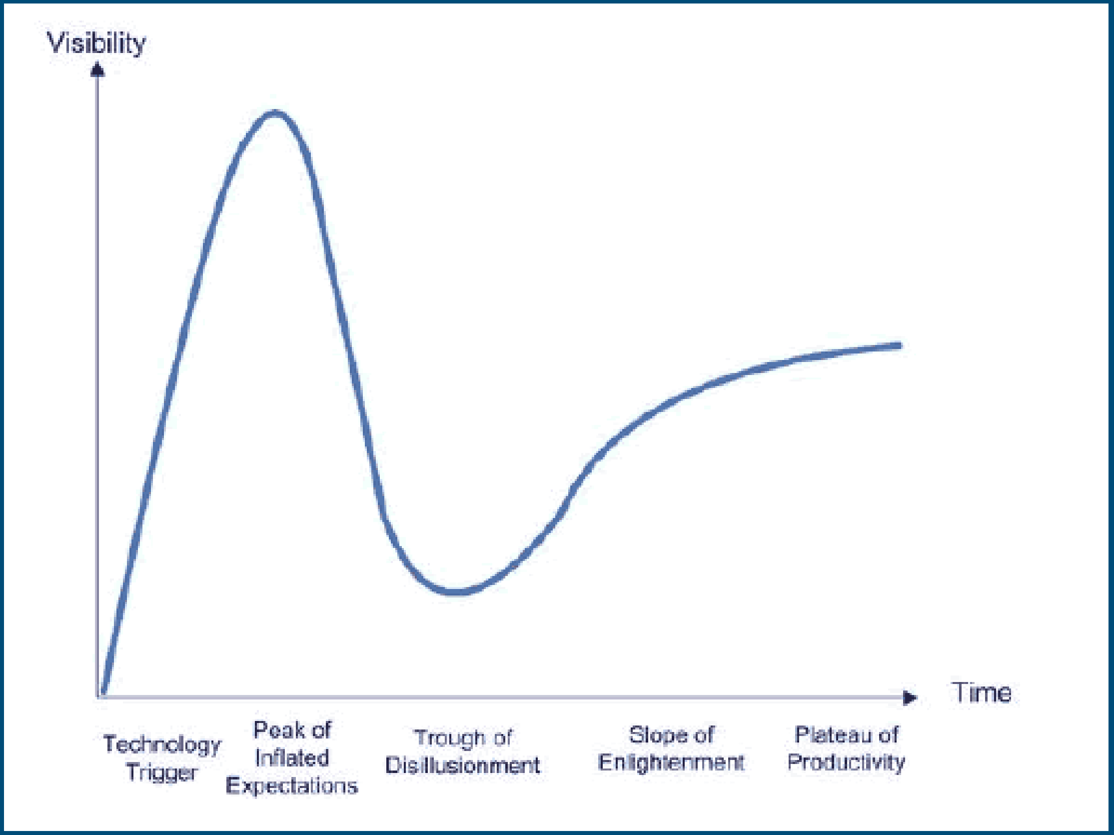
# Conclusions

- There is a need for innovation in all elements of algal biofuels production to address technical inefficiencies, which represent significant challenges to the development of economically viable large-scale algal biofuels enterprises.
- With continued development, algal biofuels have the potential to become economically viable alternatives to fossil fuels.
- Algal biofuels have the potential to replace a significant portion of the total diesel used today and algal biofuel production can be carried out using marginal land and saline water, placing little additional pressure on land needed for food production and freshwater supplies.

# Conclusions

- Land and water in suitable climates for large scale algal biofuels production exist
- Less obvious that the $CO_2$ is available in regions most suited to year round algal growth.
- Optimal siting of large scale algal biofuels production facilities will require that the resources exist in close proximity
  - Economics of production, embodied energy and GHG mitigation of the biofuel will be influenced by the proximity of these resources.
- The availability of land in suitable climates and proximity to water and $CO_2$ resources may place physical limits on the contribution of algal biofuels to future liquid transportation markets.

# Hype cycle of biofuels?

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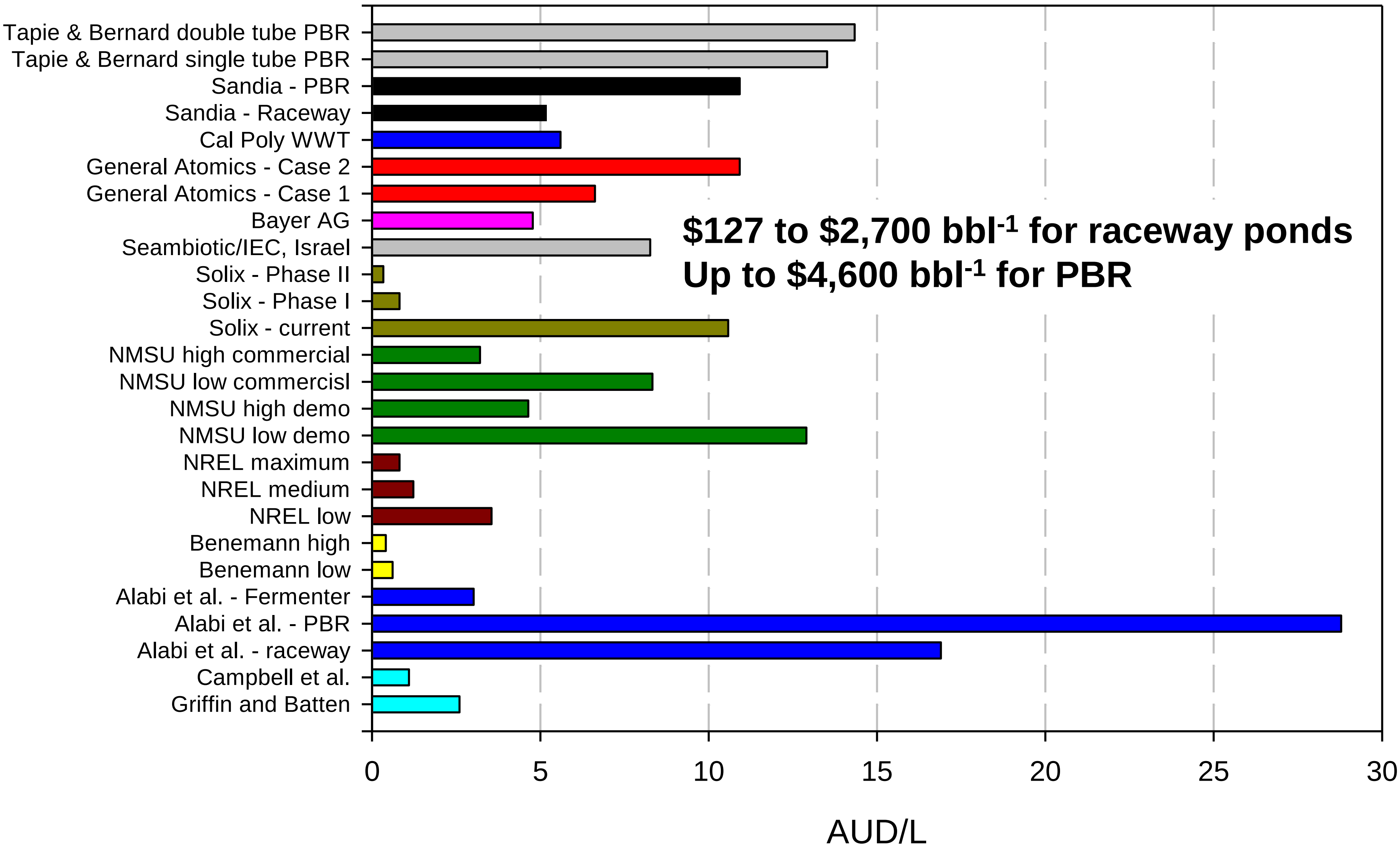
R. Wijffels (Jan, 2008) Biofuels from Microalgae

# Cost estimates for algae to oil production

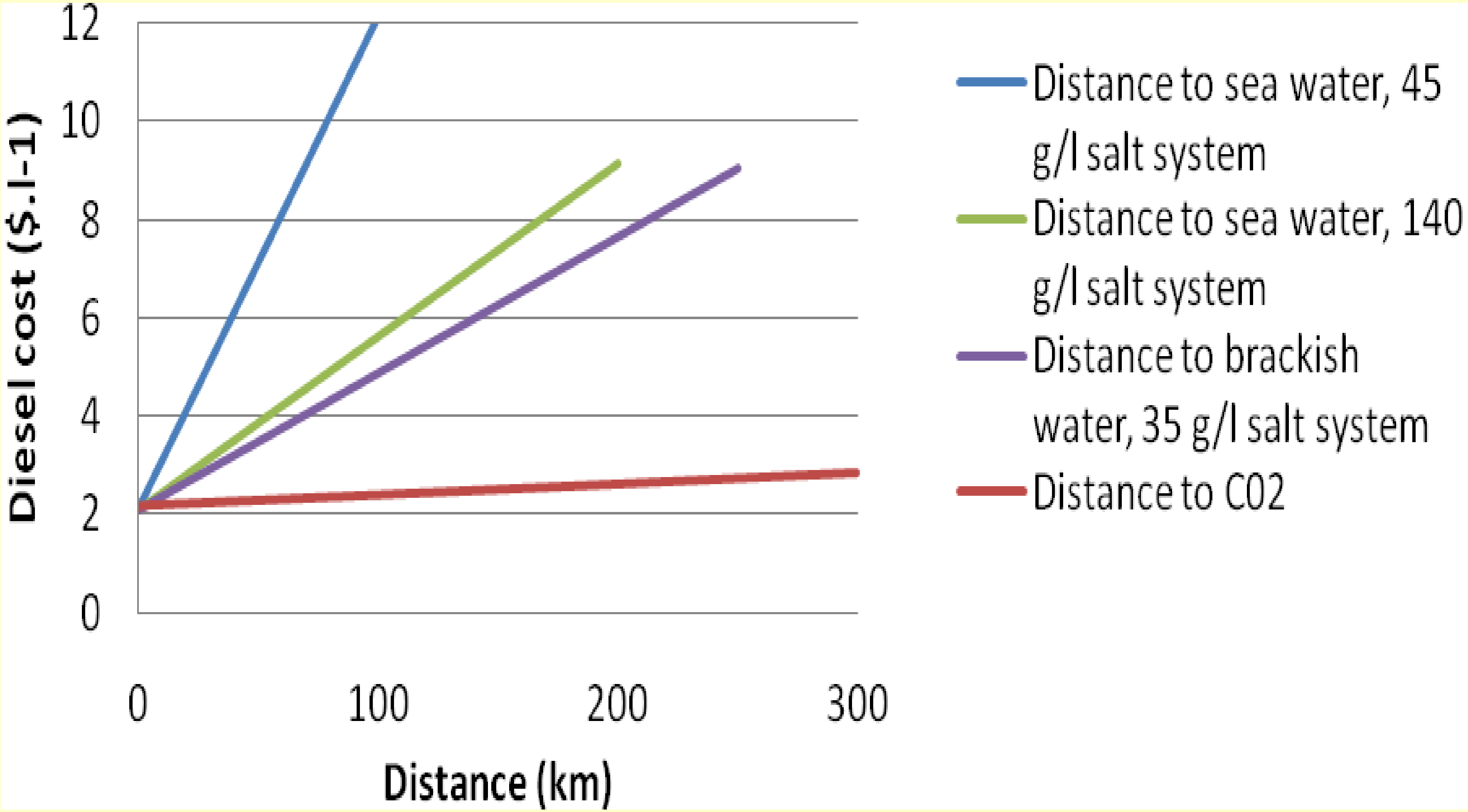



Griffin *et al*. (2010), adapted from the National Algal Biofuels Technology Roadmap, US Department of Energy Biomass Program (2009)

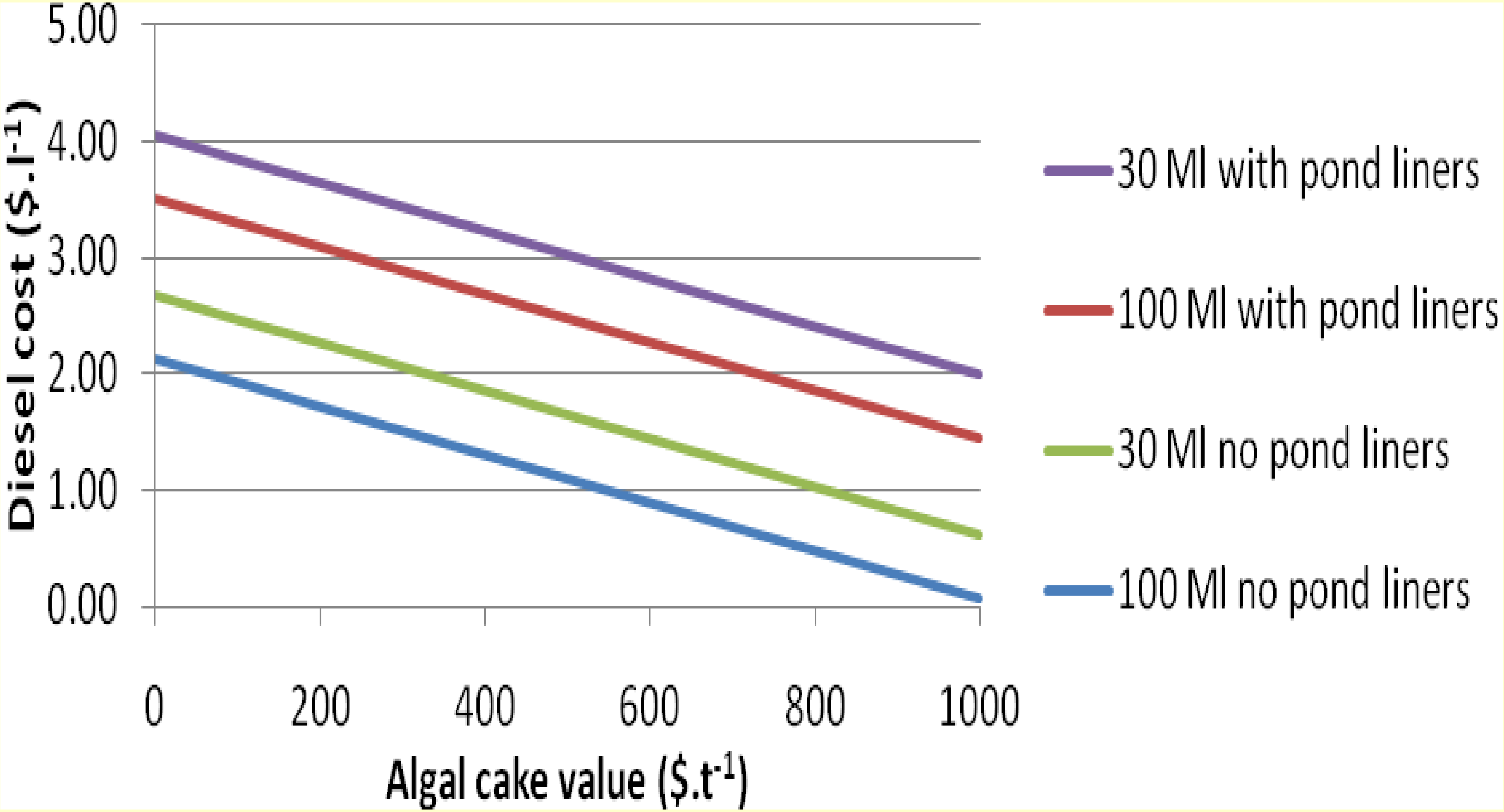
# Economic modelling

- Association for the Advancement of Cost Engineering cost estimate classification system – Class 5 estimates
- Use costs based on factored capacity, parametric models, judgment and analogy
- Expected accuracy in the range of -20 % to -50 % in the low range and +30 % to +100 % in the high range depending upon the availability of reliable reference cost information. It is generally expected that there is 90 % confidence that the cost estimate will be within these accuracy ranges.
- Typically used for evaluating alternatives, screening projects for viability and for long range capital planning.

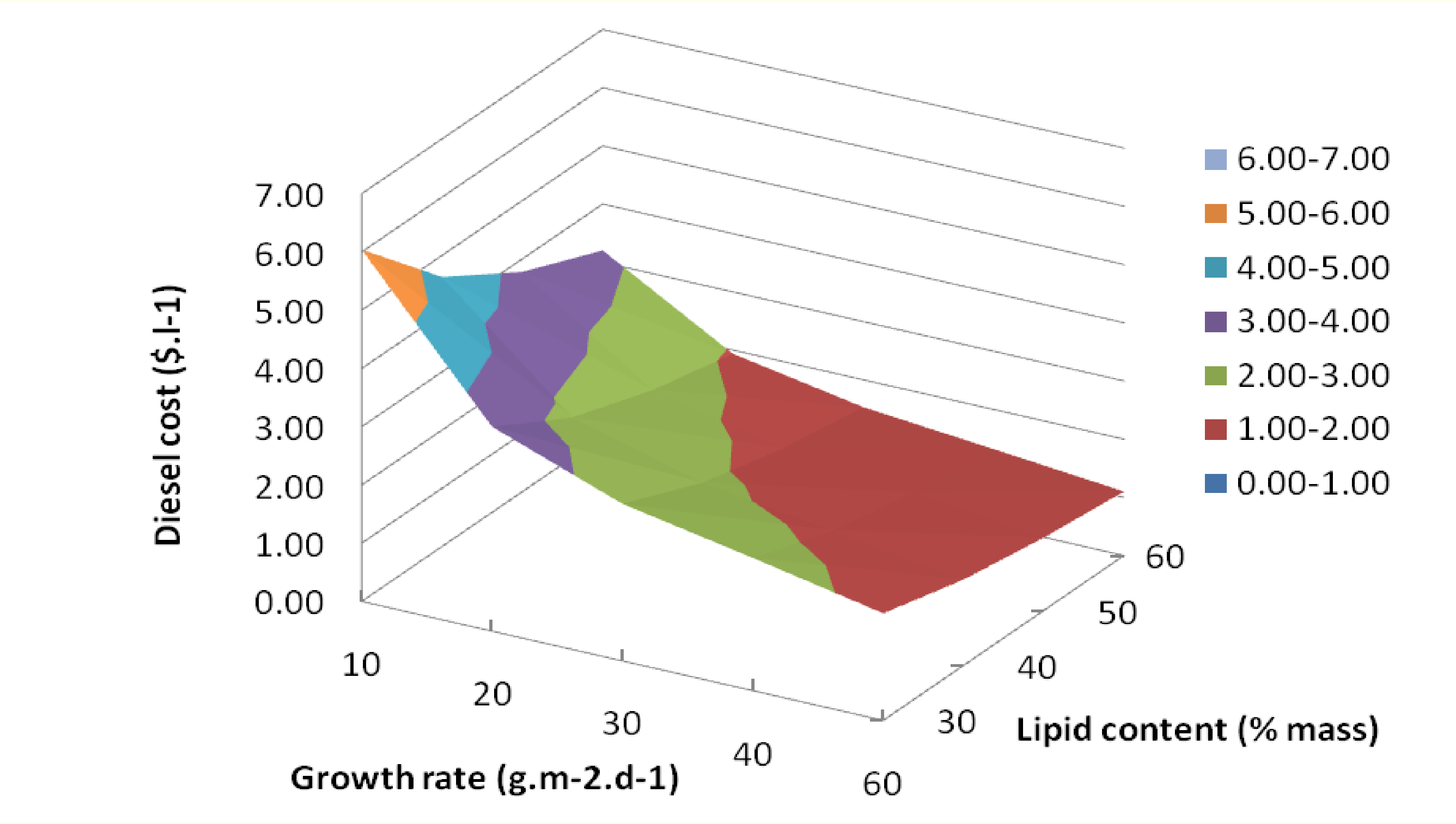
# Provision of water and $CO_2$



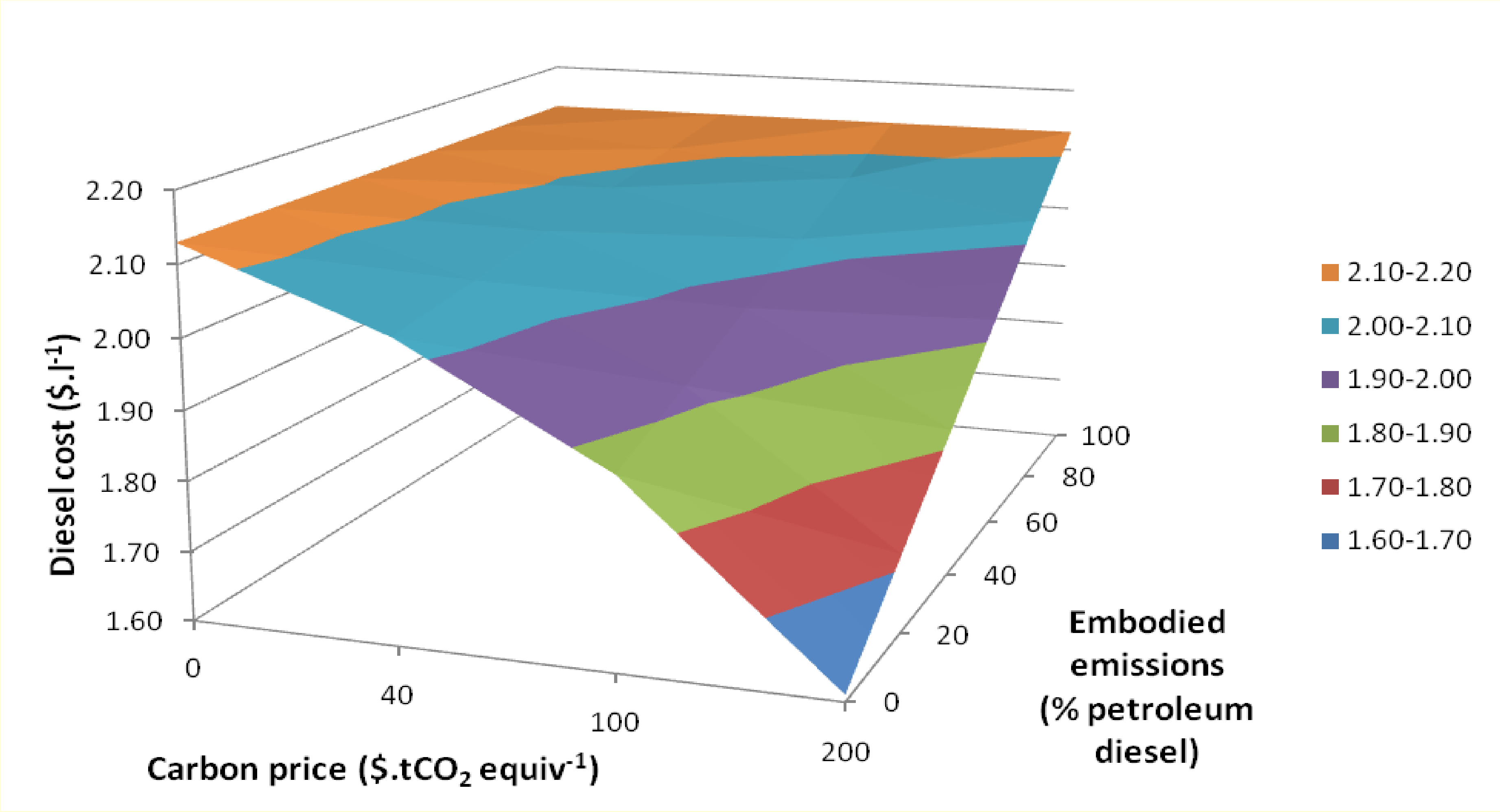
# Impact of coproduct value



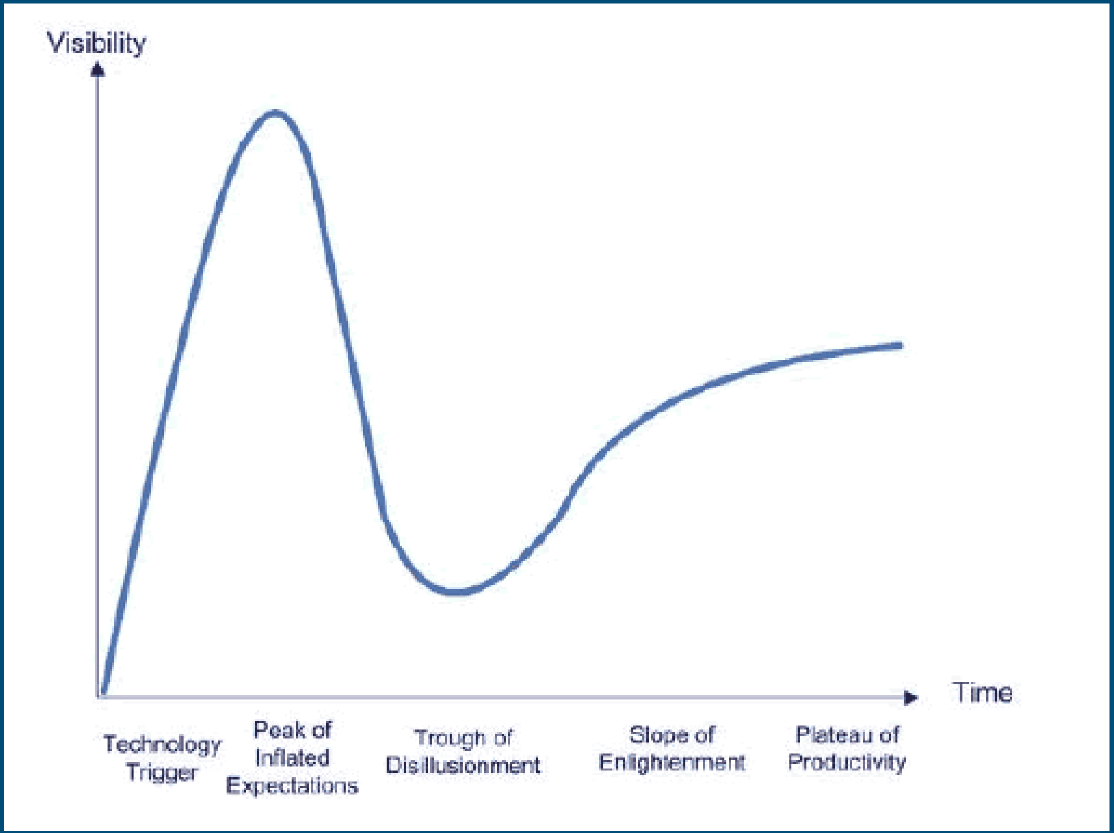
# Effect of growth rate and lipid content of algae on diesel production cost



# Impact of emissions trading



# Hype cycle of biofuels?

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R. Wijffels (Jan, 2008) Biofuels from Microalgae