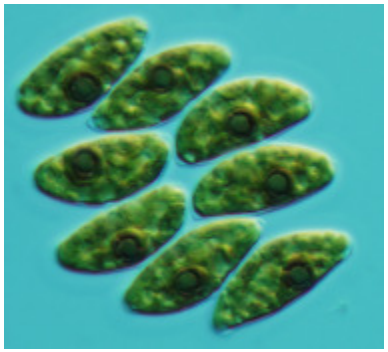
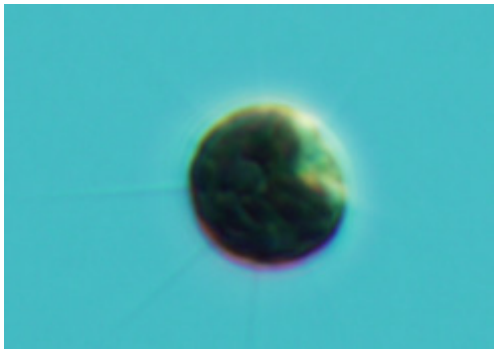
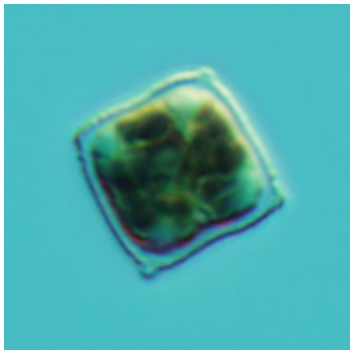
Microalgal Biotechnology: the Future of Aquaculture

AProf. Kirsten Heimann

College of Marine and Environmental Sciences
James Cook University, Townsville, QLD 4811
kirsten.heimann@jcu.edu.au

Global Challenges

Energy security

Water scarcity

Food security

Nitrogen

Peak Phosphorous

Population growth

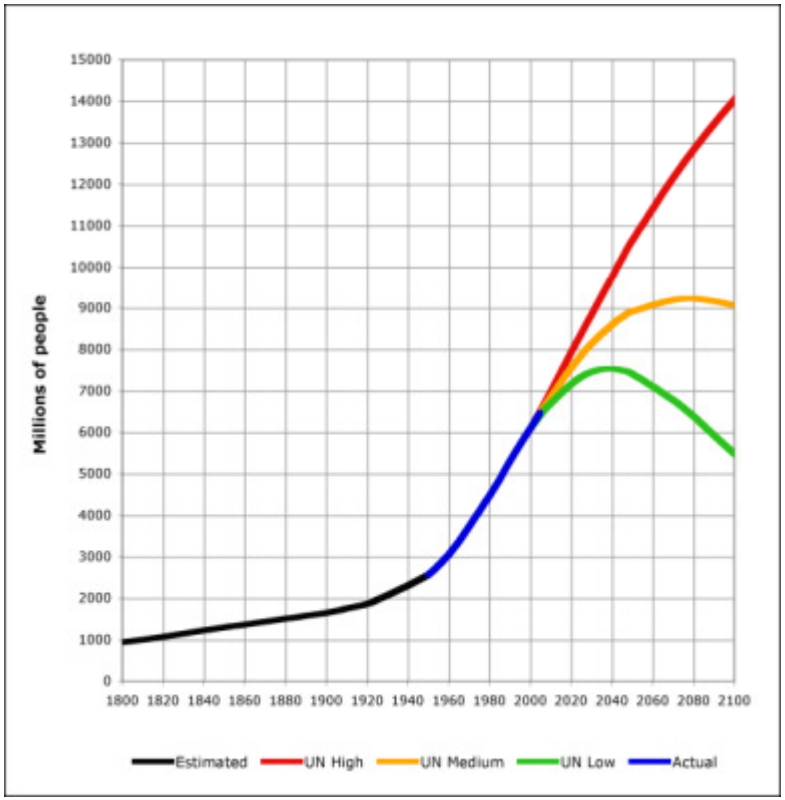
Australian Perspective:

Arable land: 6%

Limited freshwater resources

Large amounts of polluted water resources

2005 Global industrial CO_{2e} emissions
44.2 billion tons (Herzog, WRI 2009)



Cobb 2008 GFDL

Algae Bio-Products

Problem ⟷ Process ⟷ Products



Waste gases



Waste water

Benefitting Industries

Coal-fired Power Stations
Underground coal mines

Metal refineries

Waste water remediation

Algae Cultivation

Outcomes

GHG emission abatement
Water recycling
Nutrient remediation
Bioremediation (metals)

- Animal feeds
- Algal biofuels
- Fertilizer/Biochar
- Biorefining
- Nutraceuticals
  - Carotenoids


Microalgae are the backbone
of the Aquaculture Industry

Microalgae

Unicellular (0.2-1mm), some photosynthetic
50% of global primary productivity

16 phyla (including heterotrophs) –
27,000 – 10 million species

Marine and freshwater

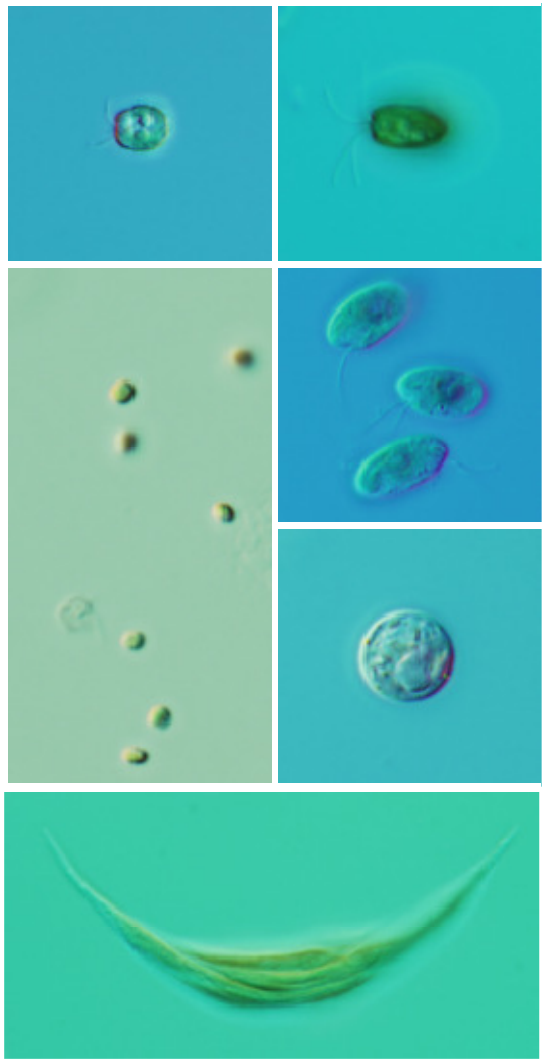
Some flagellated, some coccoid (predation cues)

Differ in their photosynthetic pigments
(pigment enrichment, antioxidants)

Differ in biochemical composition
(nutritional profile)

Differ in size (ingestibility)

Differ in cell wall components (digestibility)



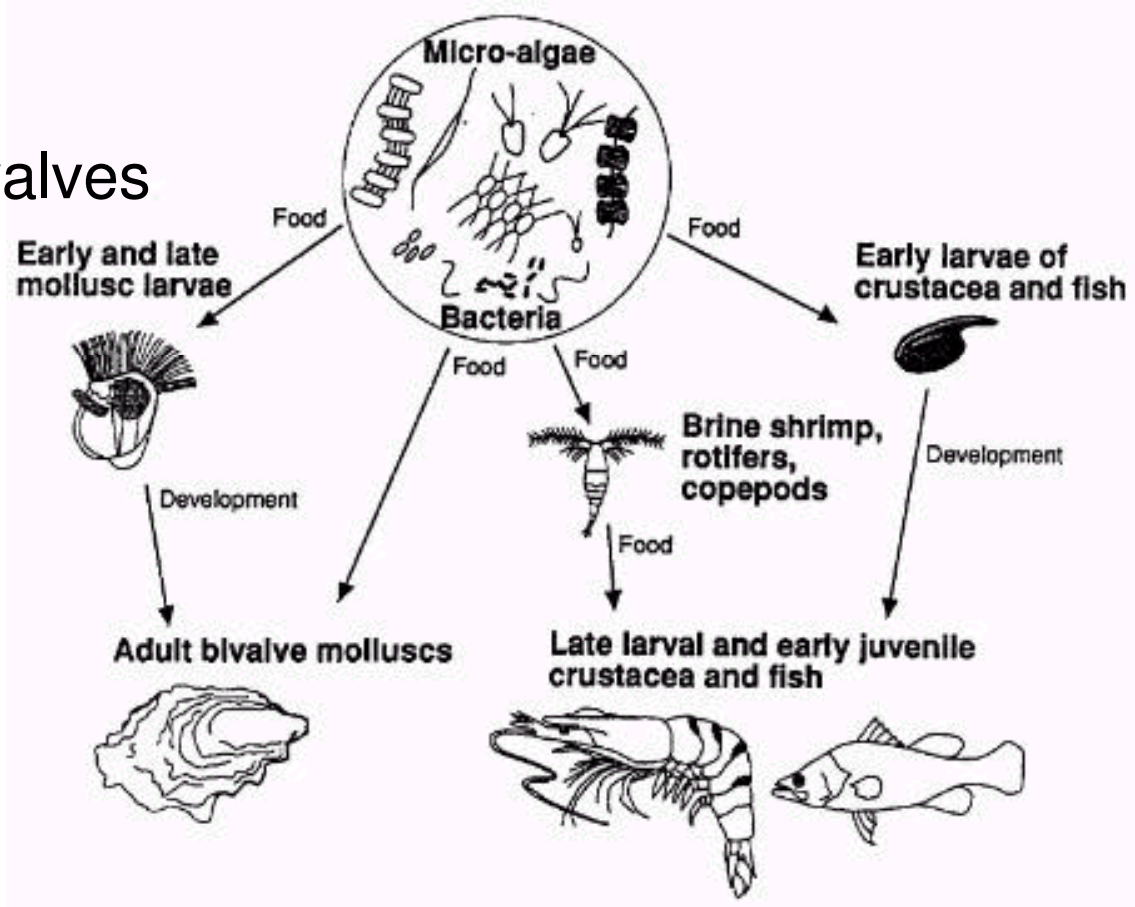
Microalgae as Feed

Traditional uses of microalgae in Aquaculture

Food for:
All growth stages of bivalves
Crustacean
some larval stages

Some fish larvae

Zooplankton
used as food for
larval crustaceans
and fish



Fatty acid enrichment of zooplankton

Algae business in Australia



Commercial Cultivation

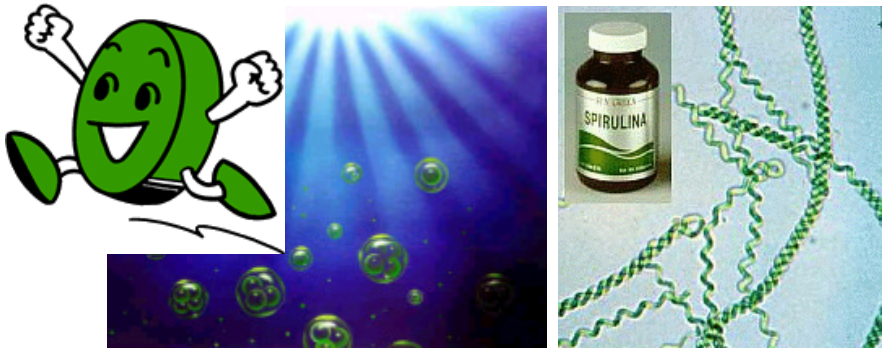
Semi-extensive:

In ponds: 1 ha or
In raceways: 50 x 5 x 1 m

Used for the cultivation of
Dunaliella
Spirulina
Chlorella

Chlorella food supplement

Spirulina (cyanobacterium) (food supplement)

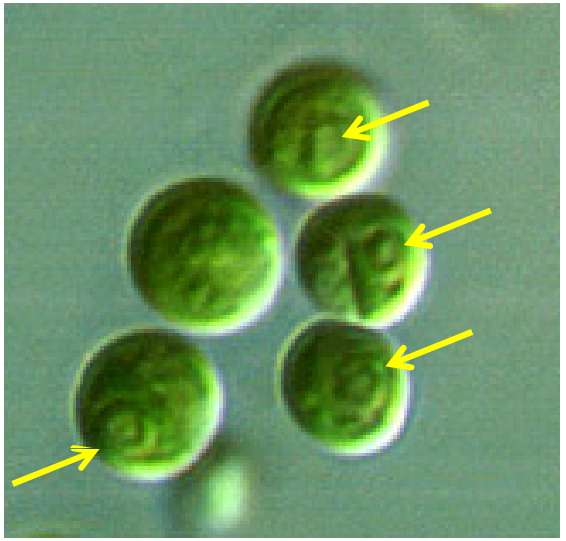




Raceway cultivation of *Dunaliella salina*
Eilat (Israel)

Microalgae as Nutraceuticals

Nutraceuticals and pigments/ antioxidants:



Human health supplements (e.g. *Chlorella, Spirulina*)
Pigments/ antioxidants
Dunaliella commercial β-carotene producer
Haematococcus astaxanthin

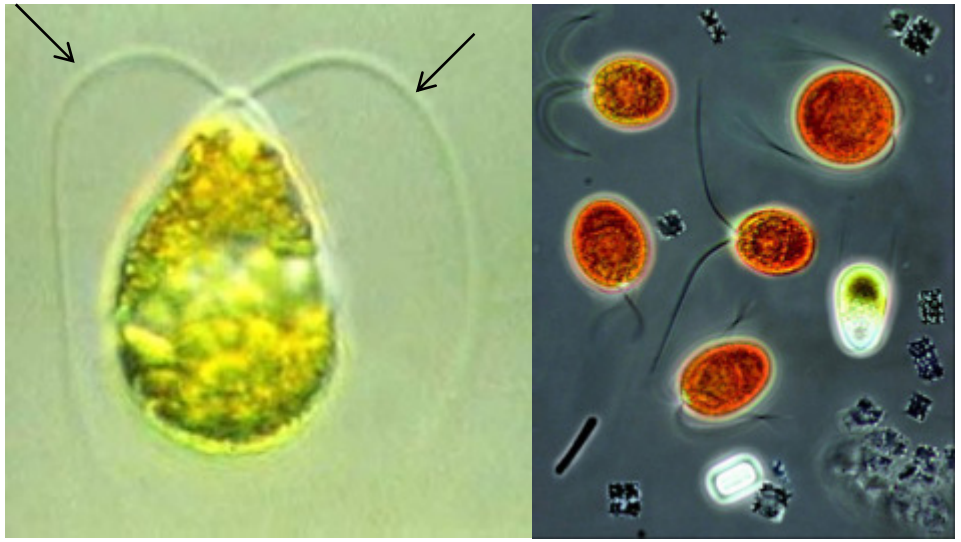
Fish oil
Isochrysis, Crypthecodinium, Schizochytrium (DHA)

Pavlova (EPA, DHA)
Diatoms, *Nannochloropsis* (EPA)









Extensive Raceway/Pond Productions





Dunaliella salina

β-carotene

Only case where natural pigment is less expensive than synthetic forms

β-Carotene – *Dunaliella salina*

Growth conditions:

salinity 30-300 ppt
(good for contamination control, but corrosion of equipment)
temperature 30-40 ℃
β-carotene induction by N-limitation; salinity changes

β-carotene: a carotenoid precursor for

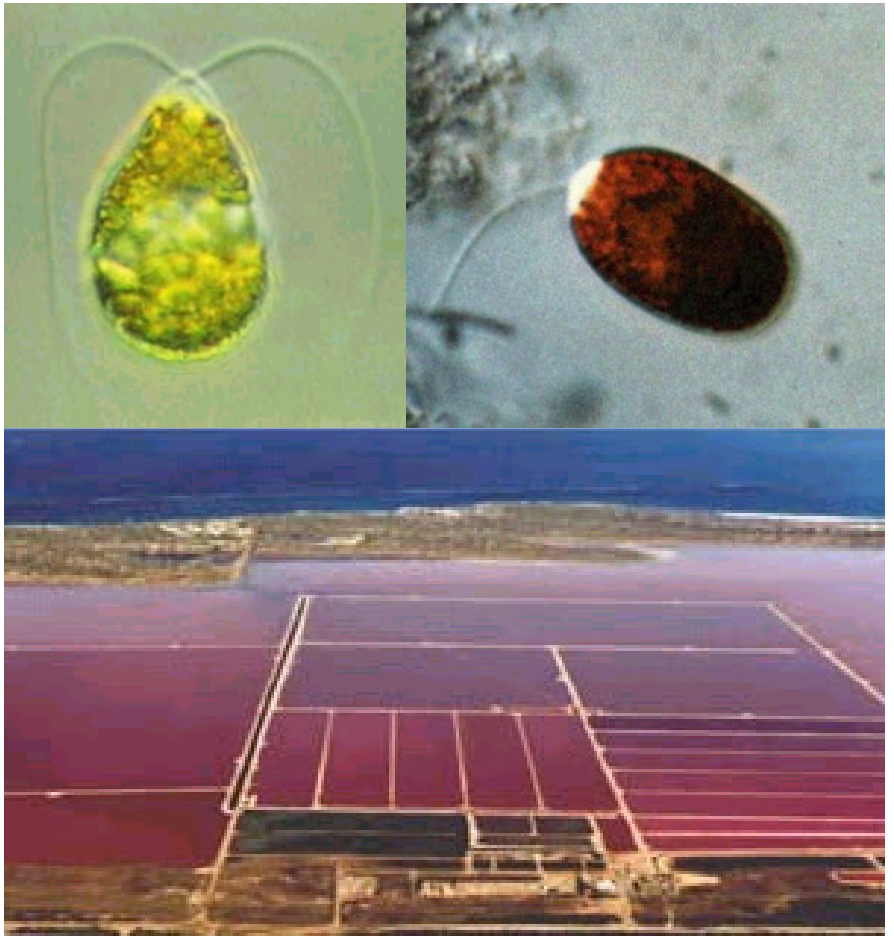
Vitamin A (required for growth and reproduction)

Markets

food and feed, neutraceutical
cosmetics, colourant, antioxidant

Challenges

Culture densities low: $2x10^5$ cells/mL
Pigment loss due to removal of salt

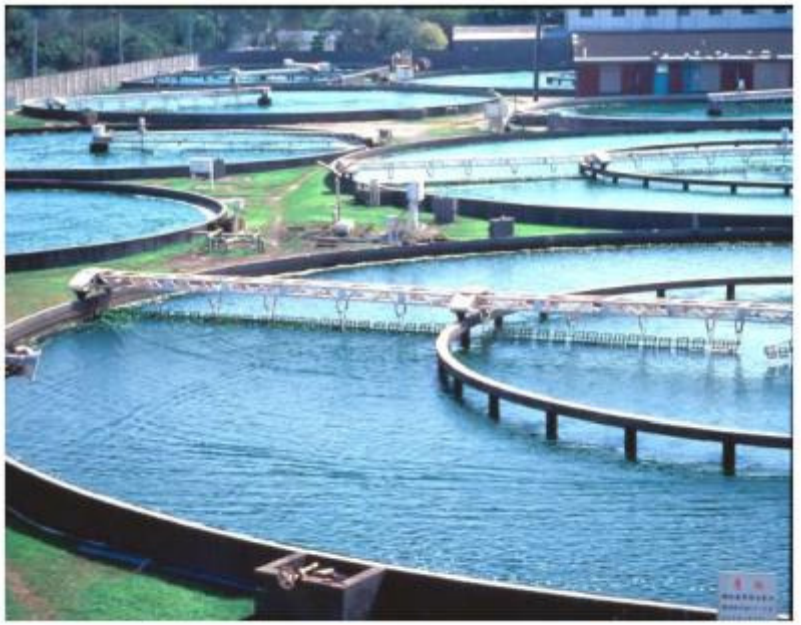


Hutt Lagoon (WA) – open pond
Dunaliella salina β-carotene production

Health Supplement – *Chlorella* spp

Growth conditions:

freshwater
high nutrients
phototrophic & heterotrophic



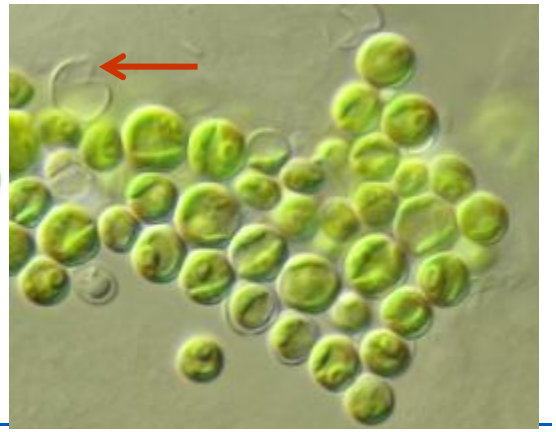
Market:

production 2000t/yr
$44/kg
high in protein and carbohydrate

Potential Market

renewable fuels





Challenges

Tough cell wall = low digestibility
hinders mechanical extraction for oil-based fuels

Health Supplement – *Arthrospira* spp

Growth conditions:

fresh- to marine, marshes, thermal springs
alkaline waters, high pH (10.6)
high conductivity 20-70 g NaCl/L
high temperature (>30 ℃)



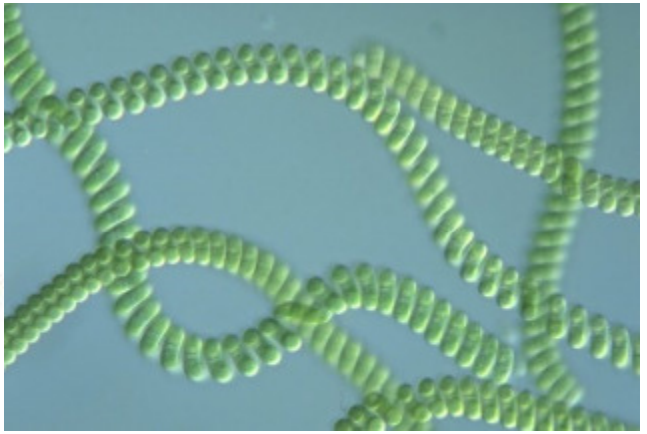
Market:

high in Vitamin B12
high in protein (60-70% of DW)
chlorophylla *a*
phycobiliproteins
(phycocyanin, phycoerythrin)

Challenges

Complex, time-consuming process for desalting

Athrospria synonym *Spirulina*





Astaxanthin Market

Haematococcus pluvialis (Chlorophyta)
Freshwater

Sensitive

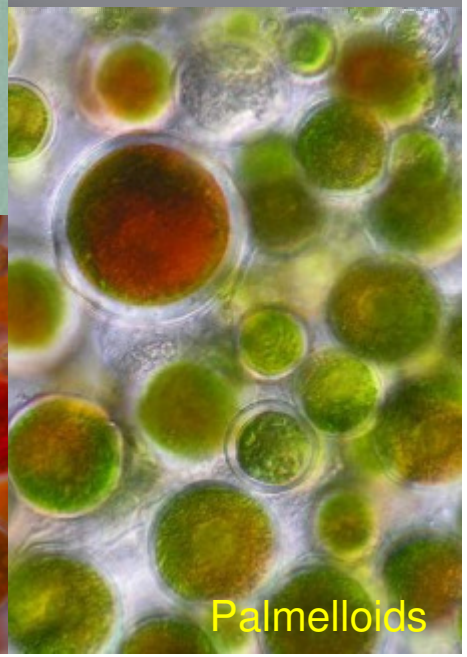
- < 28 ℃
- prone to contamination
- salinity intolerant

Complex life history

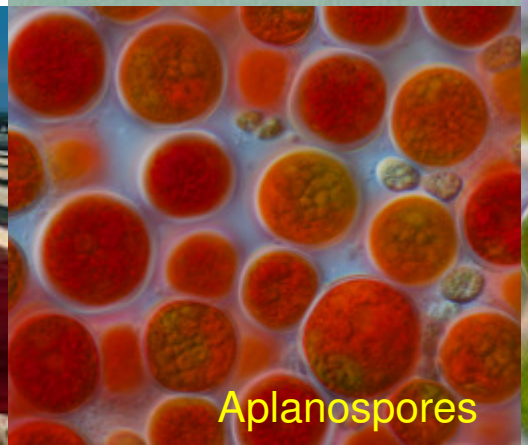
$100 – 500 kg^{-1} DW microalgae
Crop: 5 g L^{-1}











Haematococcus challenges

Fastest market growth

Market not saturated

Challenges

Sensitive

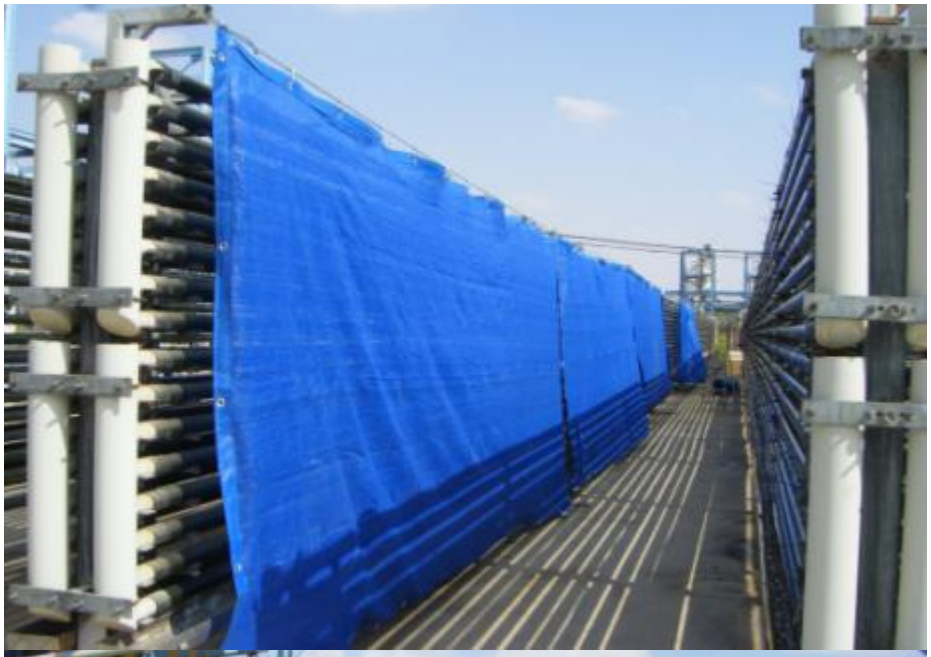
- wall-less vegetative stages
- light sensitive (vegetative stages)
- < 28 ℃
- prone to contamination
- salinity intolerant

Up-scaling: 2-stage process

- nutrient management

Astaxanthin extraction and drying

- reactive to O_2
- difficult from cysts





Microalgae Market Overview

ω3-Market (global)

2004:
690 M USD
annual growth 12%

ω3-Asian Market

2012:
596 M USD

EPA Market (global)

2014:
300 M USD

DHA Market (global)

1.5 B USD

ω3-Global demand

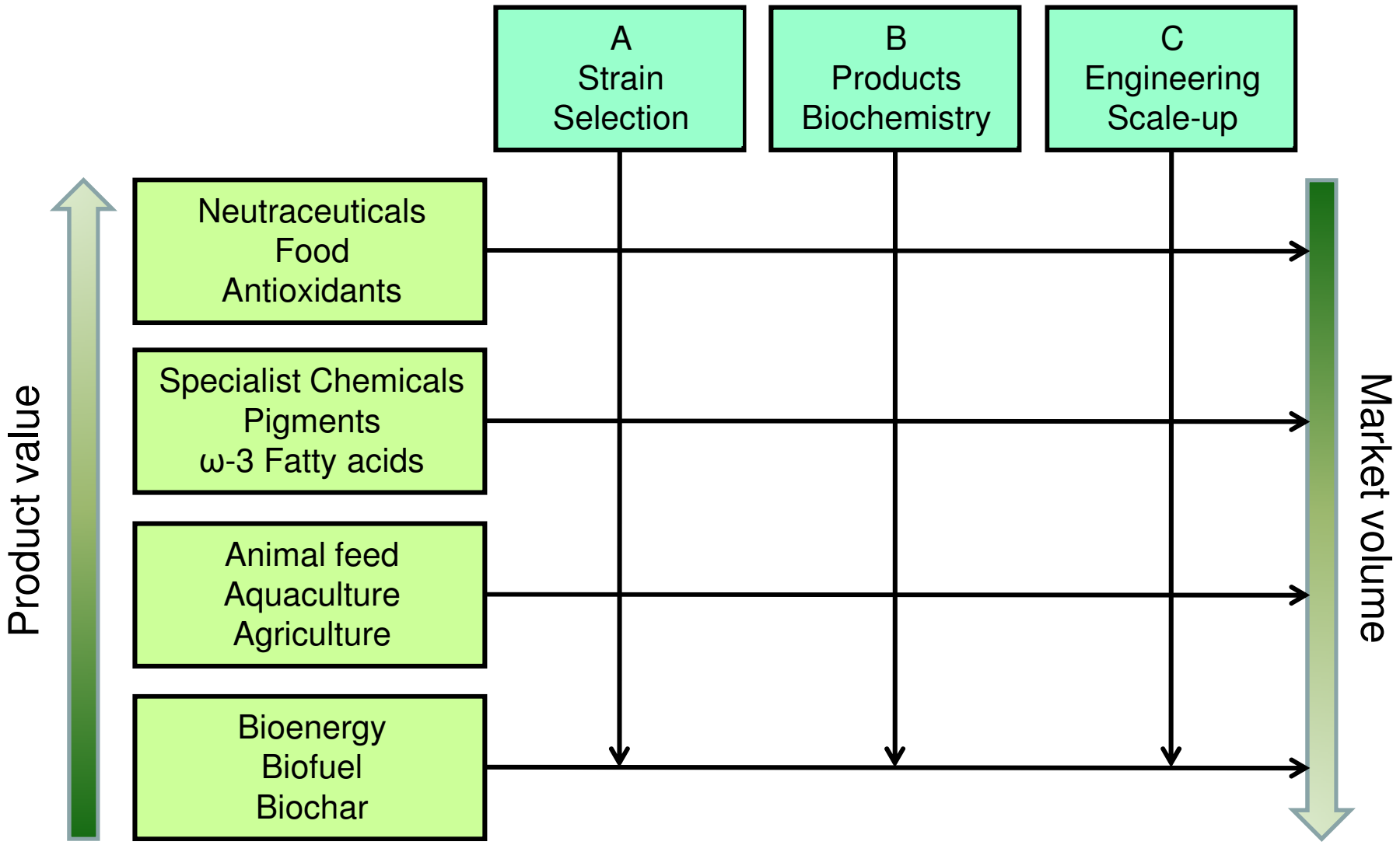
2006:
baby and infant food: 350 M USD

Alga	annual production (ton dry weight)	annual production (ton DHA oil)
Chlorella	2500	
Spirulina	4000	
Dunaliella salina	2000	
Haematococcus pluvialis	200-300	
Scizochytrium		10
Crypthecodinium cohnii		240

*excluding biomass for aquaculture feed

Source: Lucas and Southgate 2012

Microalgae from Domestication to Market



Microalgal Cultivation Methods Overview

Culture type	Advantages	Disadvantages
Indoors	High degree of control (predictable)	expensive
Outdoors	Cheaper	Less predictable
Closed	Contamination less likely	Expensive
Open	Cheaper	Contamination more likely
Axenic	Less prone to crashes	Expensive, difficult
Non-axenic	Cheaper, less difficult	Prone to crashes

Microalgal Cultivation Principles

Culture type	Advantages	Disadvantages
Continuous	Efficient, provides a consistent supply of high quality cells, automation, highest rate of production over extended periods of time	Difficult, usually only produces small quantities, complex, equipment costs may be high
Semi-continuous	Easier, somewhat efficient	Sporadic quality, less reliable
Batch	Easiest, most reliable	Least efficient, Quality can vary dramatically

Commercial Continuous Systems

Photo-bioreactors

Flat Panel

Tubular

Disadvantages:

Biomass fouling
(light limitation)

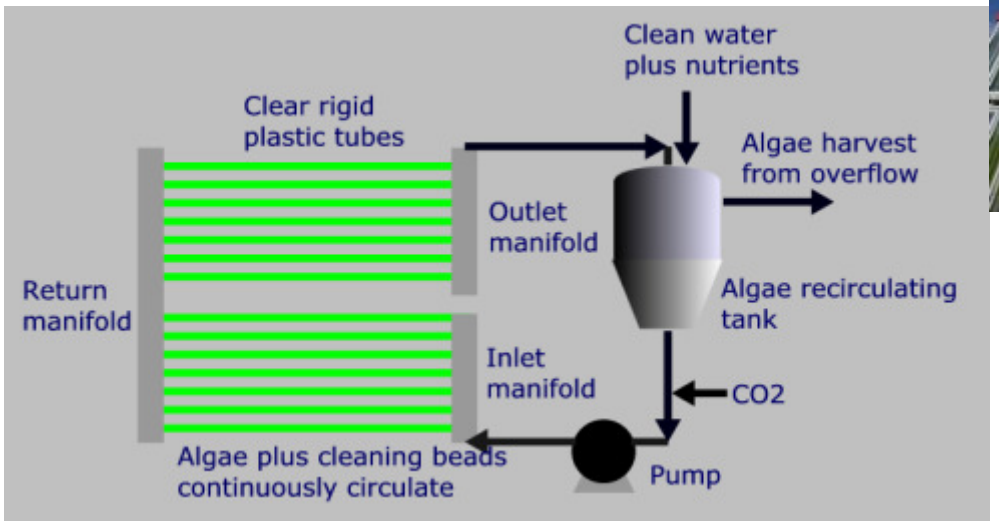
Oxygen build up in light compartment

Expensive









The BIQ House
Hamburg
flat panel facades

Heterotrophic Fermenter Cultivation

Dinophyta

Schizochytrium
Crypthecodinium
(Martek, USA)

Chlorophyta

Chlorella
Tetraselmis

Technology Advantages

large prior knowledge
existing hardware for automation
large scale and globally available
low unit operation costs
high culture densities (>50 g L^{-1})

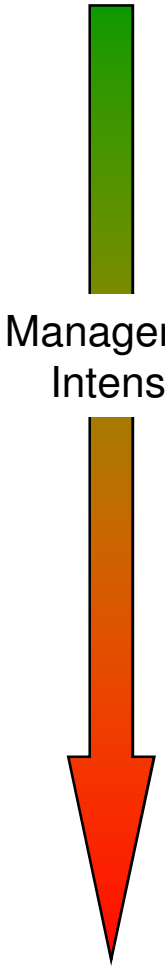
Challenges

axenic cultures (sterile, no bacteria)
oxygen demand





Microalgal Cultivation Technology

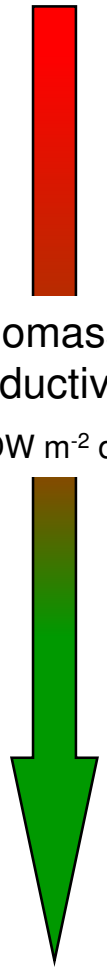


<u>Ponds</u>
Aquaculture production
Low control
Optional nutrient addition

<u>Raceways</u>
Aquaculture production
Control over mixing
Optional nutrient addition

<u>Vertical bags</u>
Aquaculture feed production
High control

<u>PBRs/fermenters</u>
Full environment control
Axenic cultures
Genetically modified organisms



- Light
- Temperature
- Nutrients
- Carbon (pH)

Factors Affecting Biochemical Profiles

Factors

Light (photo-period and intensity)

Temperature

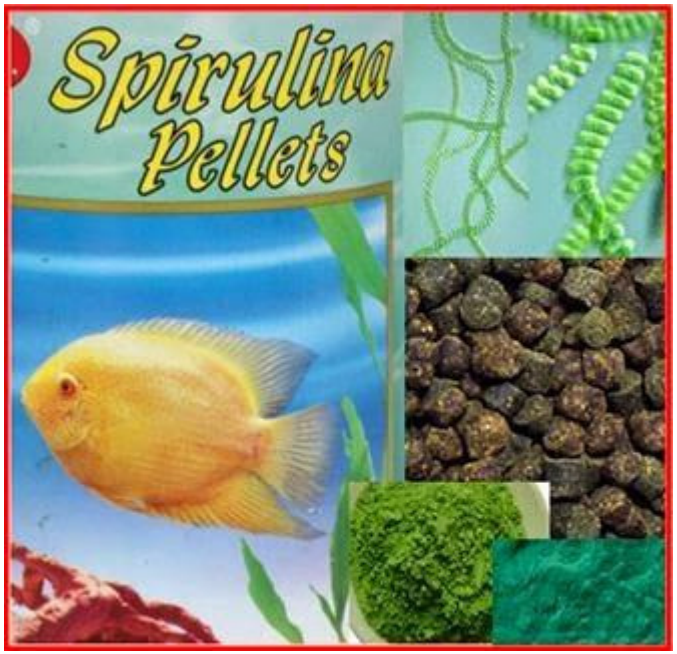
Nutrient-status (nitrogen availability)

Nutrition (media)

Salinity

Carbon availability (CO_2)

Growth phase



Affect the biochemical composition and therefore bioproduct potential of microalgae

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