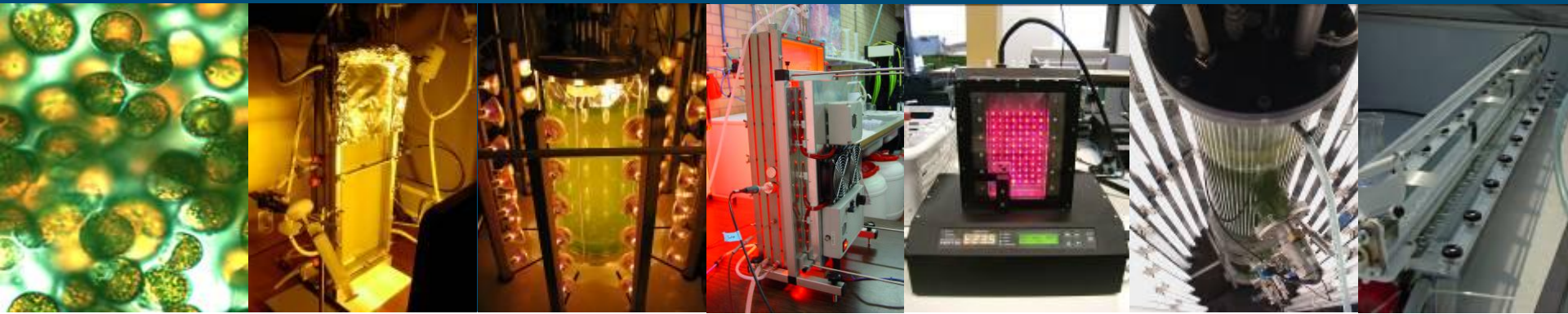


Algen: werkpaarden van de biobased economy?

Packo Lamers

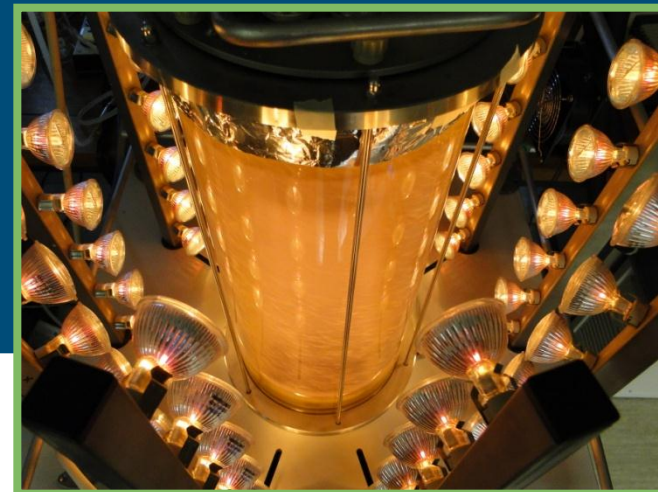
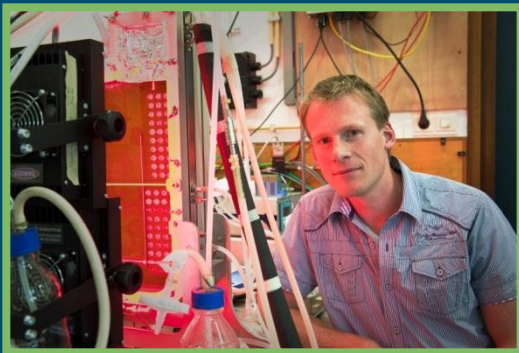
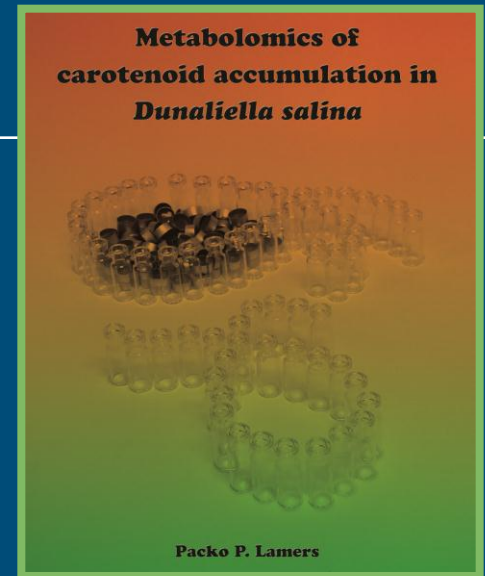
8 December 2011



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Even voorstellen:

- Universitair Docent Biotechnologie
- Daarvoor:
 - *Ir.: Bioprocestechnologie*
 - *Dr.: Pigmentproductie met algen*
 - *PostDoc: Metabole processen in algen*



De toekomst...een 'biobased economy'?



- Wat is dat precies?

5%

- 80% positief over biobased economy
- 40% overweegt carrière / opleiding

De wereld groeit...

World population development

Billio

MTOE

10

10,000

8

8,000

6

6,000

4

4,000

3

3,000

2

2,000

1

1,000

0

0

17

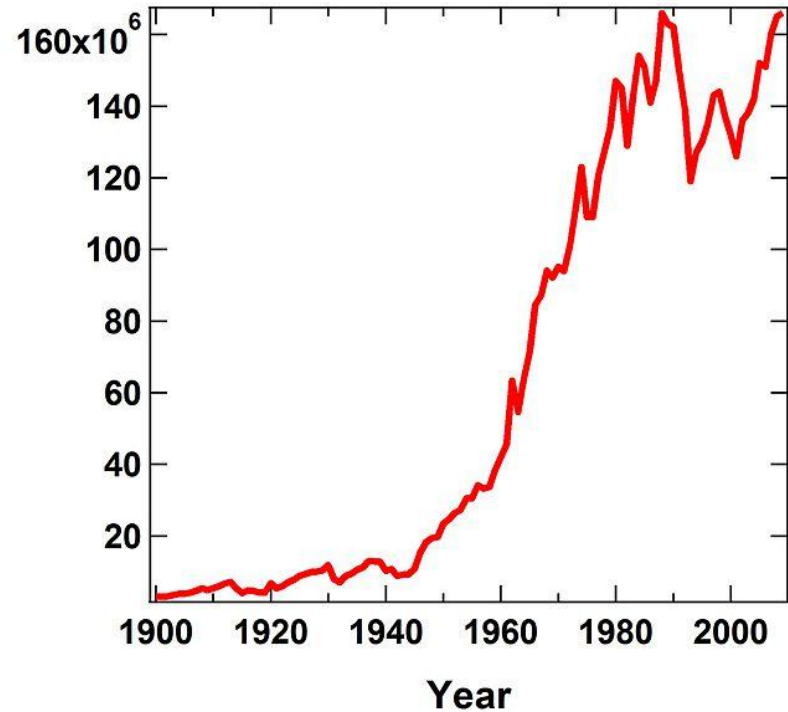
17,000

1860

Oil Palm in Malaysia and Indonesia production and exports. 1964-2006



World Phosphate Rock Production (metric tonne)



Natuurlijke grondstoffen zullen opraken



- Niet vandaag, of morgen...
...maar het gaat wel gebeuren

Oplossing?

■ Gebruik maken van hernieuwbare bronnen:

- Zon
- Water
- Wind



Elektriciteit alleen is niet genoeg

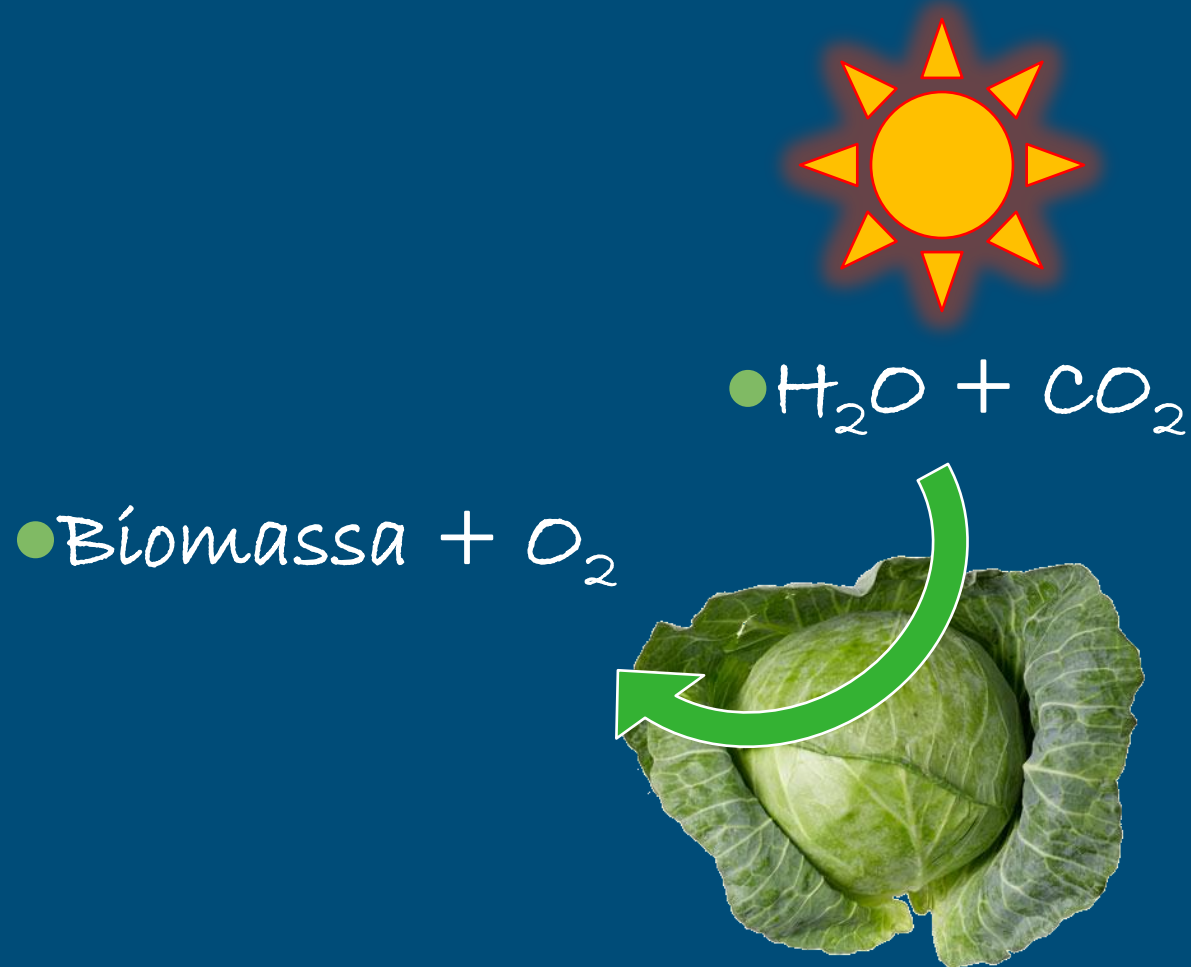


De biobased economy

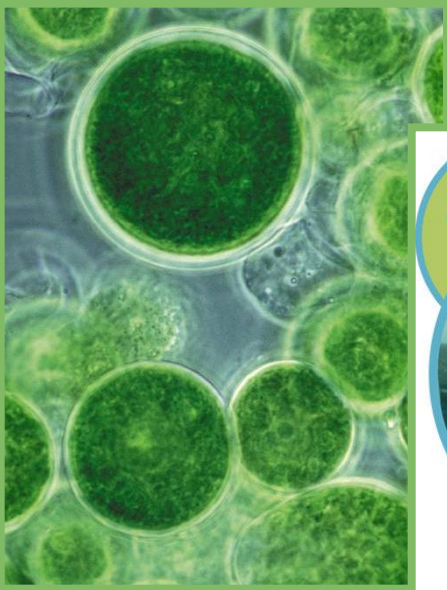
- Productie van
 - brandstoffen
 - humane en dierlijke voeding
 - bulk- en fijnchemicaliën
- waarbij gebruikt wordt gemaakt van
 - hernieuwbare grondstoffen
 - afvalstromen
 - biologische productie processen



Essentieel proces: fotosynthese



Microalgen vs. planten



vs.

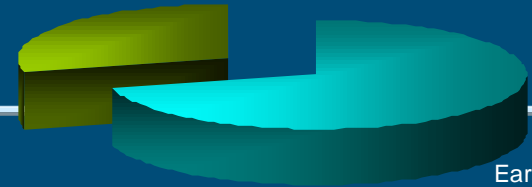


Drivers for aquatic Biomass

Biobased Economy

- World population growth and increase in prosperity -> higher energy demand
- High energy prices
- Security of energy supply
- Climate change due to greenhouse gasses
- Rural development

Earth land area
29%



Earth water area
71%

Specific aquatic biomass

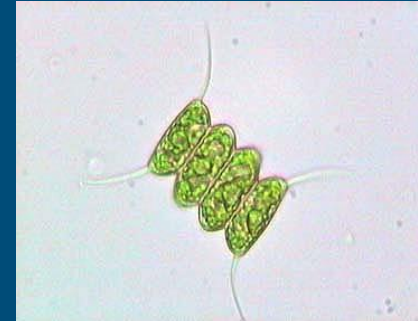
- Increased competition for land for the production of food, chemicals and energy
- Limitations of land for agriculture
- Impacts of global climate change on agricultural productivity

Wat zijn microalgen?

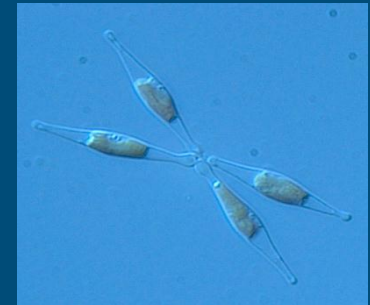
- Primitief plantaardig organisme
- ~0.001 – 0.1 mm groot
- Zout en zoutwater
- Fotoautotroof
- ≈ 80.000 soorten
 - Groene algen
 - Chromista
 - Diatomeeën
 - Bruine algen
 - Macro algen
 - Rode algen
 - Euglenophyta



● *Spirulina*



● *Scenedesmus*



● *Phaeodactylum*

Microalgen en hun producten

- Visvoer
- Biopolymeren
- Fijnchemicaliën (DHA, EPA)
- Functionele eiwitten
- Medicijnen
- Kleurstoffen
- Bemesting
- Olie



Waarom microalgen?

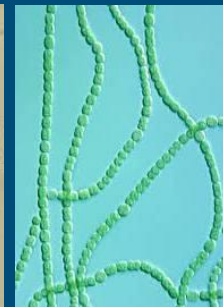
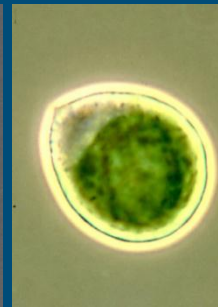
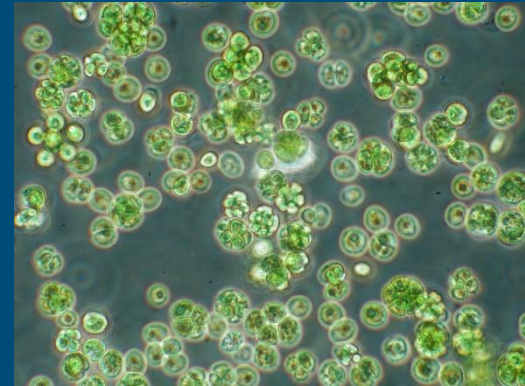
Feedstock	Oil Productivities L / ha /year
Corn	172
Soybeans	446
Sunflower	386
Rapeseed	1 250
Oil palm	5 950
Jatropha	1 892
Microalgae	
PE 3%; 30% lipids; NL	12 300
PE 3% ; 30% lipids; Bonaire	25 800
PE 6% ; 30% lipids; Bonaire	52 000

Hier zijn we

Potentie

Nog meer redenen:

- Hoge productiviteit per oppervlakte
- Groeit op zeewater
- Geen landbouwgrond nodig
- Minder water nodig
- Grote variëteit in soorten → en dus producten
- Olie ophoping to zeer hoge concentratie
- Stofwisseling is stuurbaar richting gewenst product
- Recyclen van nutriënten (N & P)
- CO₂ mitigatie

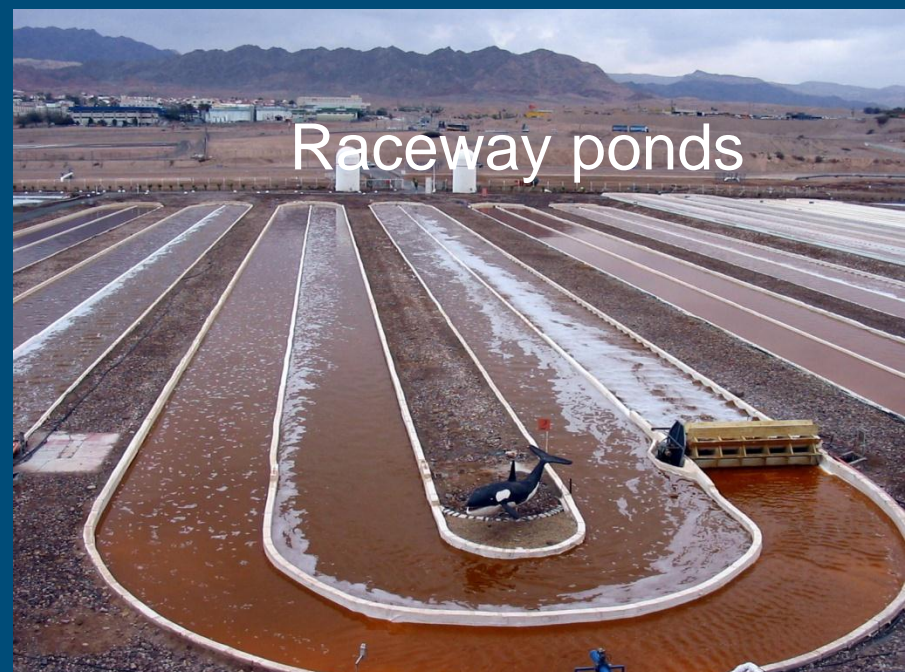


Van vakmanschap naar een industrieel proces...

- Huidige globale microalgen productie: ~5000 ton droge biomassa
- Hoogwaardige producten: pigmenten en ω -3 vetzuren
- Markt volume €1.25 miljard (gem. marktprijs €250/kg droge biomassa)
- Globale productie van palmolie ~40 miljoen ton; marktprijs van ~0.50 €/kg

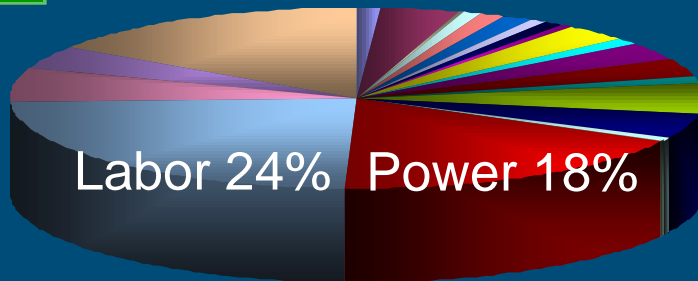


Studie economische haalbaarheid

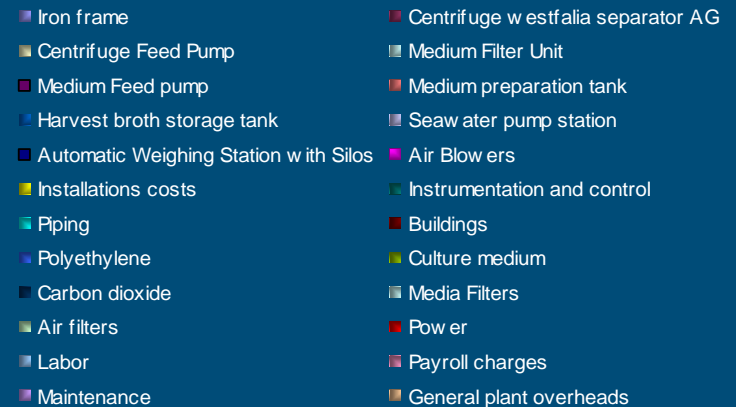
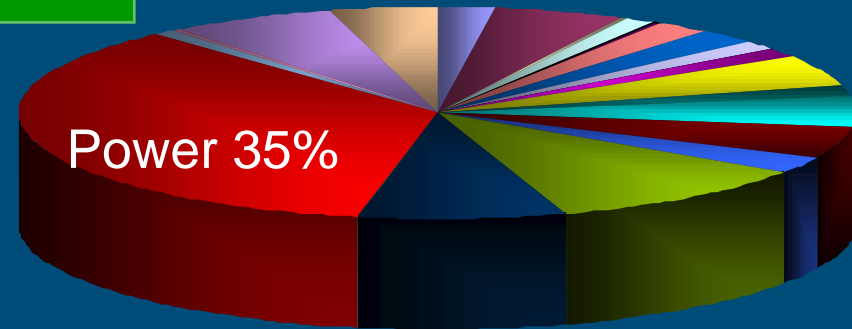


Delta feasibility study: production costs

1 ha



100 ha

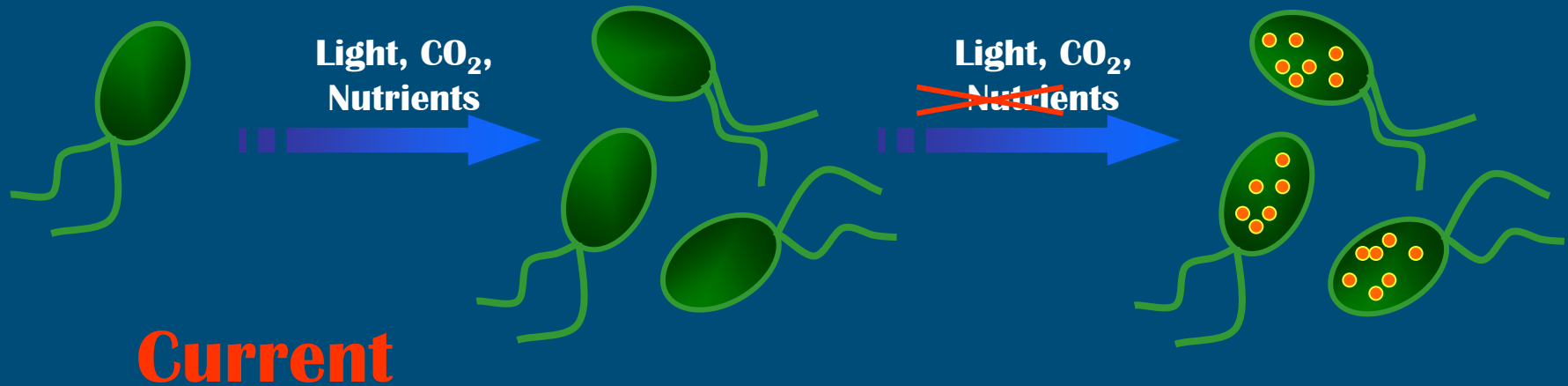


- At 1 ha scale today: 10 €/kg
- At 100 ha scale today: 4 €/kg
- What will be possible: 0.70 €/kg

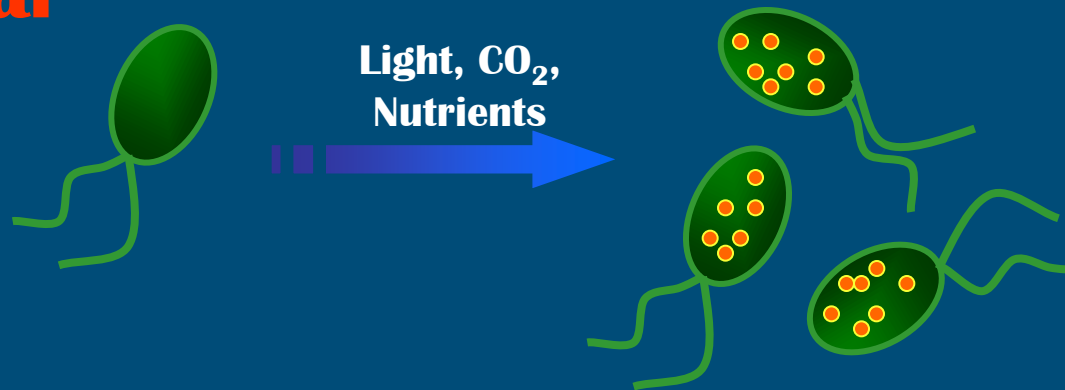
Why (not) microalgae? Present challenges!

The choice of algae

Lipid production

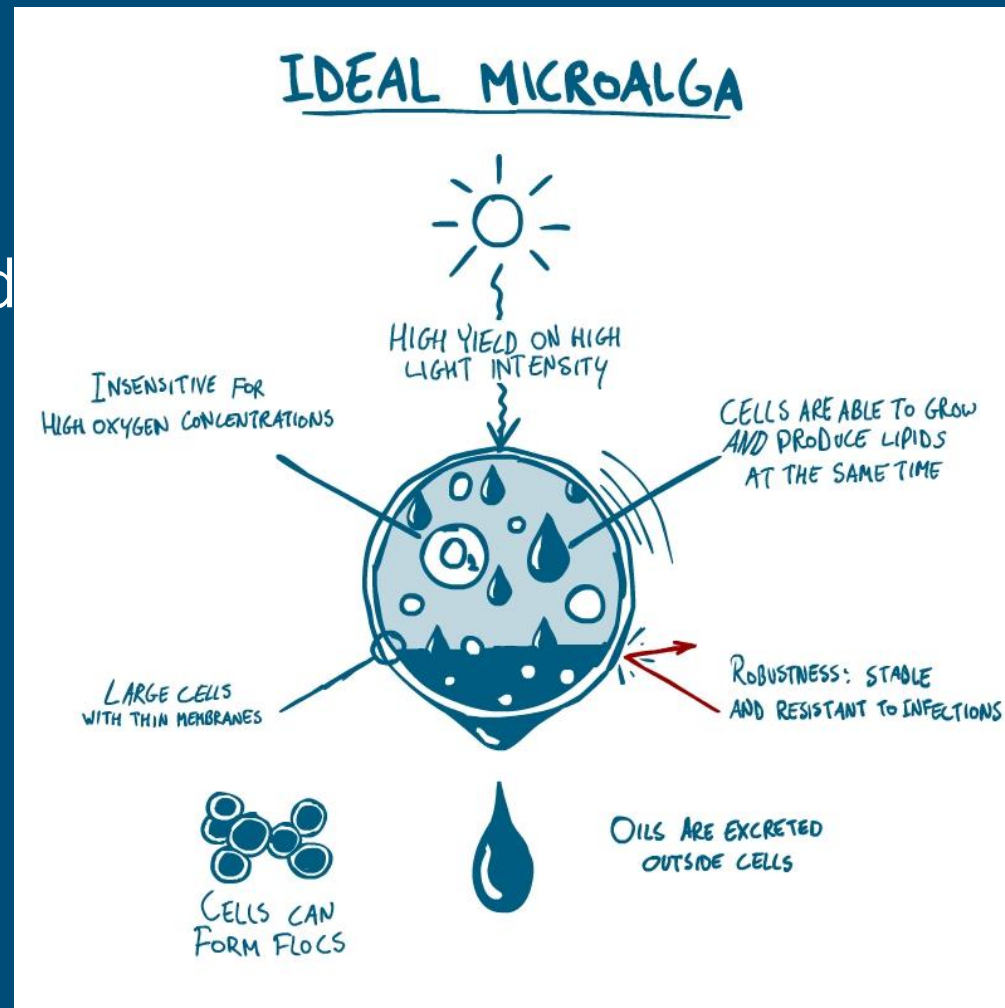


Goal



The alga: no optimization on a single parameter

- High biomass productivity
- High productivity in required molecules (proteins, saturated neutral, lipids, unsaturated fatty acids)
- Insensitive to high oxygen concentrations
- Possibility to grow under selective conditions
- Easy to harvest
- Mild extraction



Why (not) microalgae? Present challenges!

The process: efficiency in supply of nutrients and resources

Efficiency in supply and use of nutrients and resources

Sunlight

Water

CO₂, Nitrogen and Phosphorus

Efficiency in supply and use of nutrients and resources

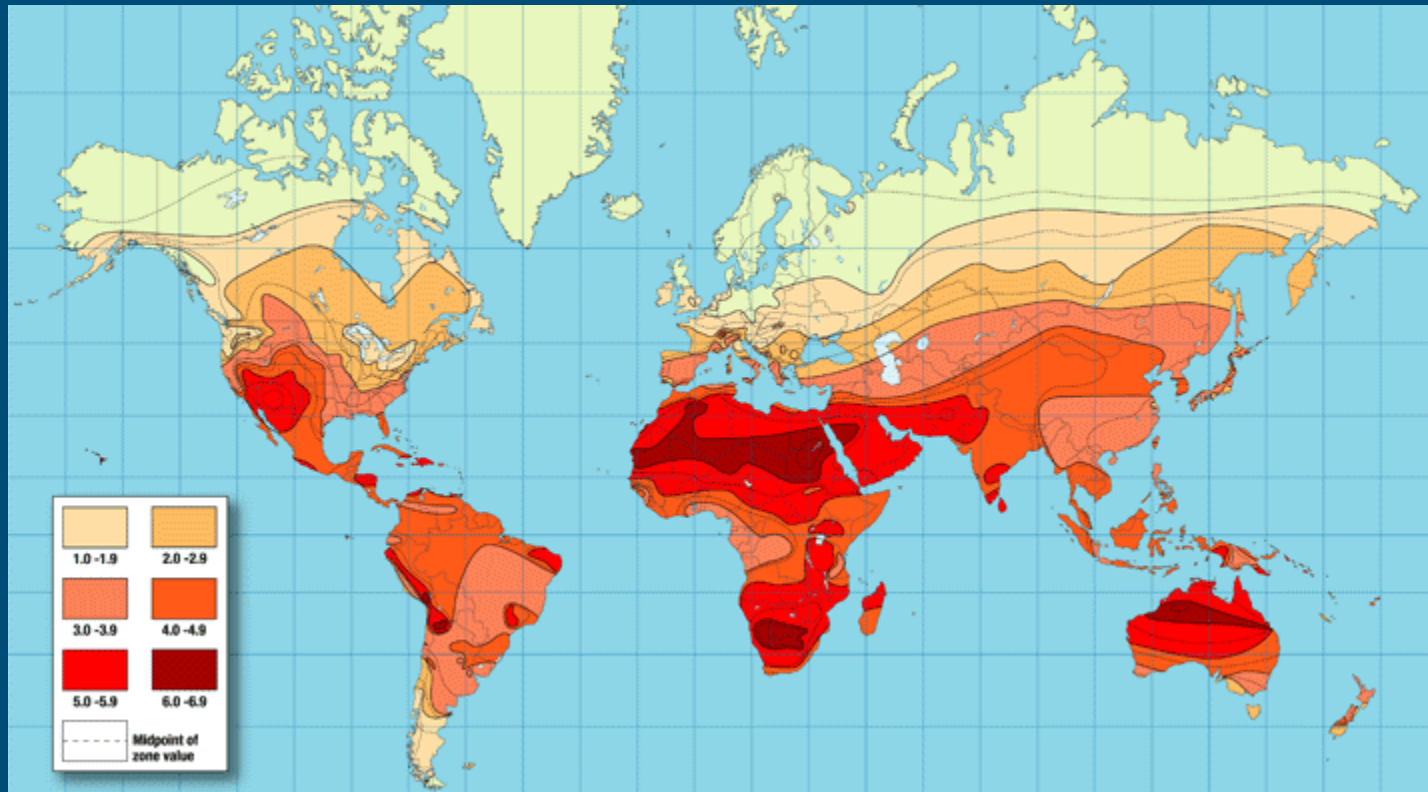


Sunlight

Water

CO₂, Nitrogen and Phosphorus

Locatie en zonnestraling





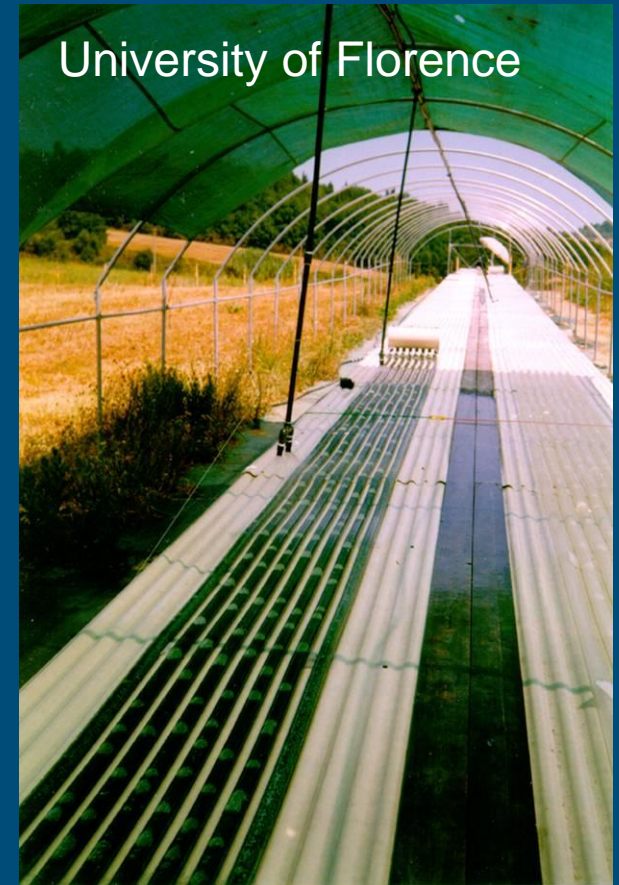
Tubular photobioreactors



LGem, Netherlands



AlgaTechnologies, Israel

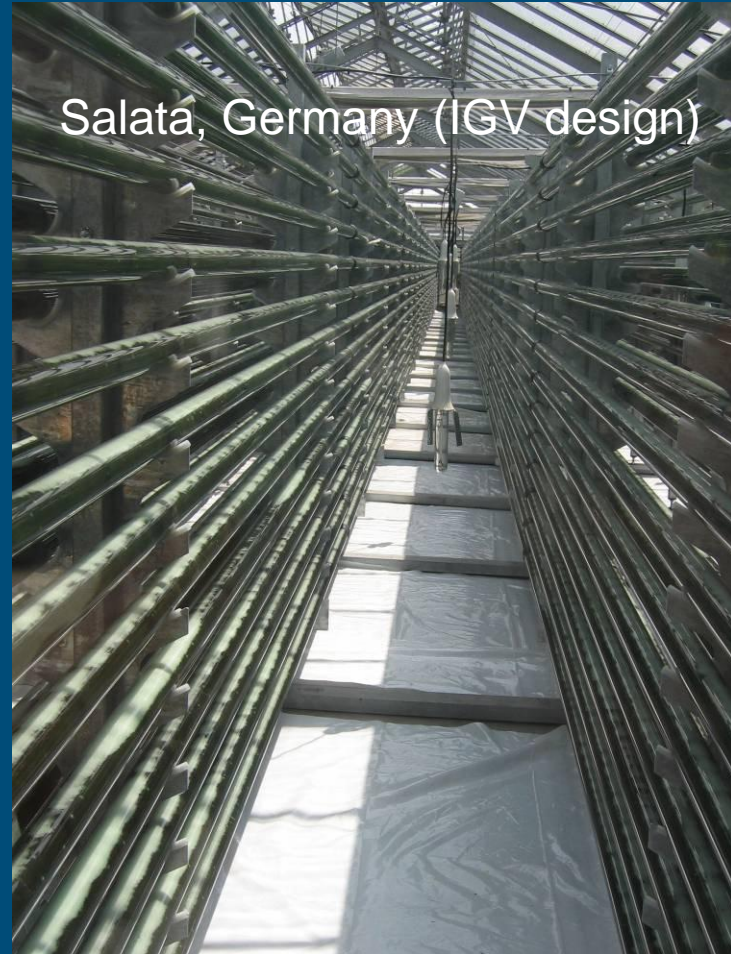


University of Florence



Vertical tubular photobioreactor

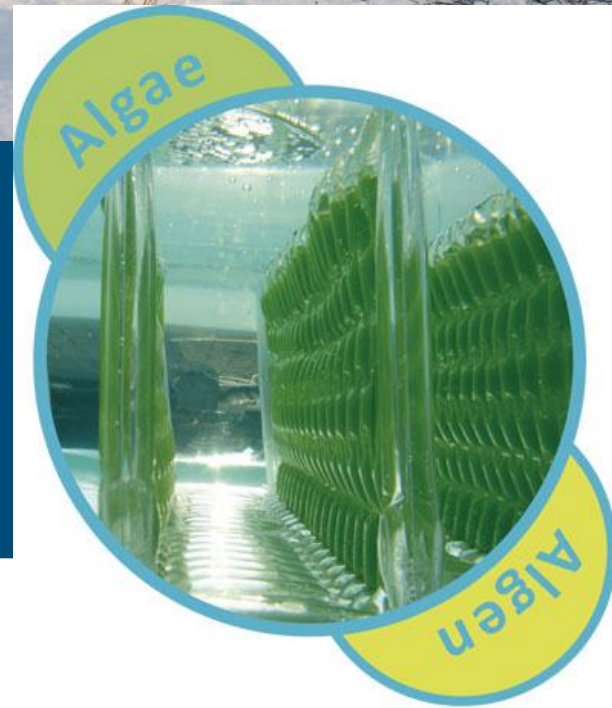
- Tubular fences



Plastic film photobioreactors



Proviron
a human and ecological approach to chemistry



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Open ponds



NBT Ltd., Israel



Ingrepo, Netherlands

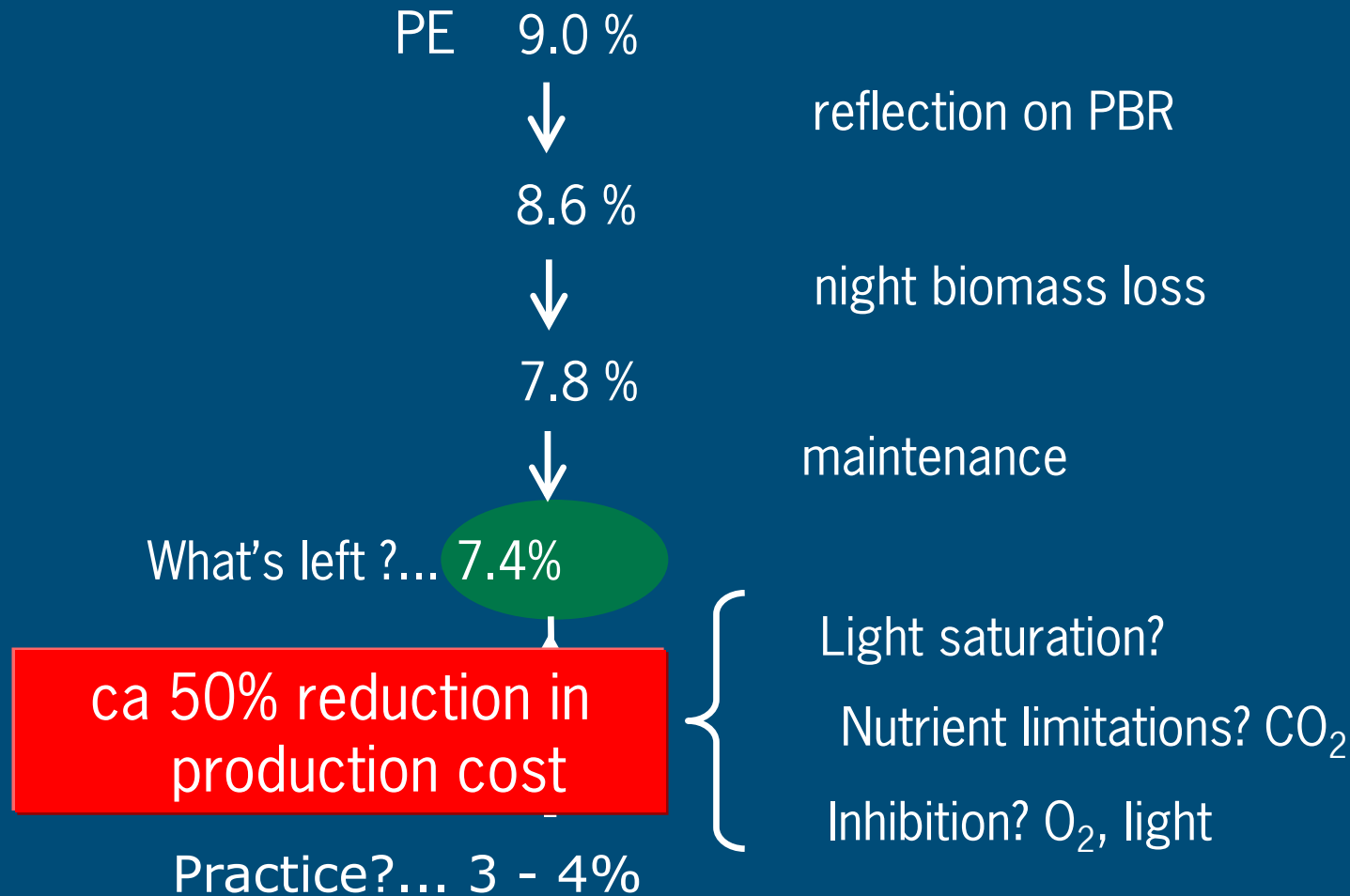


Comparison

	Raceway	Hor. tube	Vert. tube	Vert. panel	Vert. panel
Characteristics	Depth: 0.3 m	Diameter: 0.05 m Length: 50 – 100 m	Diameter: 0.05 m Length: 50 – 100 m	Depth: 0.1 m Height: 0.5 m Length: 10 m	Depth: 0.5 m Height: 1.0 m Length: 10 m
Ground coverage	Full ground coverage	Full ground coverage 20 tubes/m ²	40 tubes/m ²	5 panels/m ²	2 panels/m ²
Biomass concentration	0.1 – 0.5 g/L	1.0 – 5.0 g/L	0.5 – 2.5 g/L	1.5 – 7.5 g/L	0.5 – 2.5 g/L
PE	1.5%	3 – 4 %	4 – 6 %	4 – 6 %	4 – 6 %

Production costs:

Increasing Photosynthetic Efficiency – what margin do we have?



What's determining photosynthetic efficiency outdoors?

Measured / controlled parameters

- Incident light intensity
- Temperature
- O₂ partial pressure
- CO₂ partial pressure
- Gas flow rate / Liquid velocity
- Dilution rate
- pH
- Nutrients

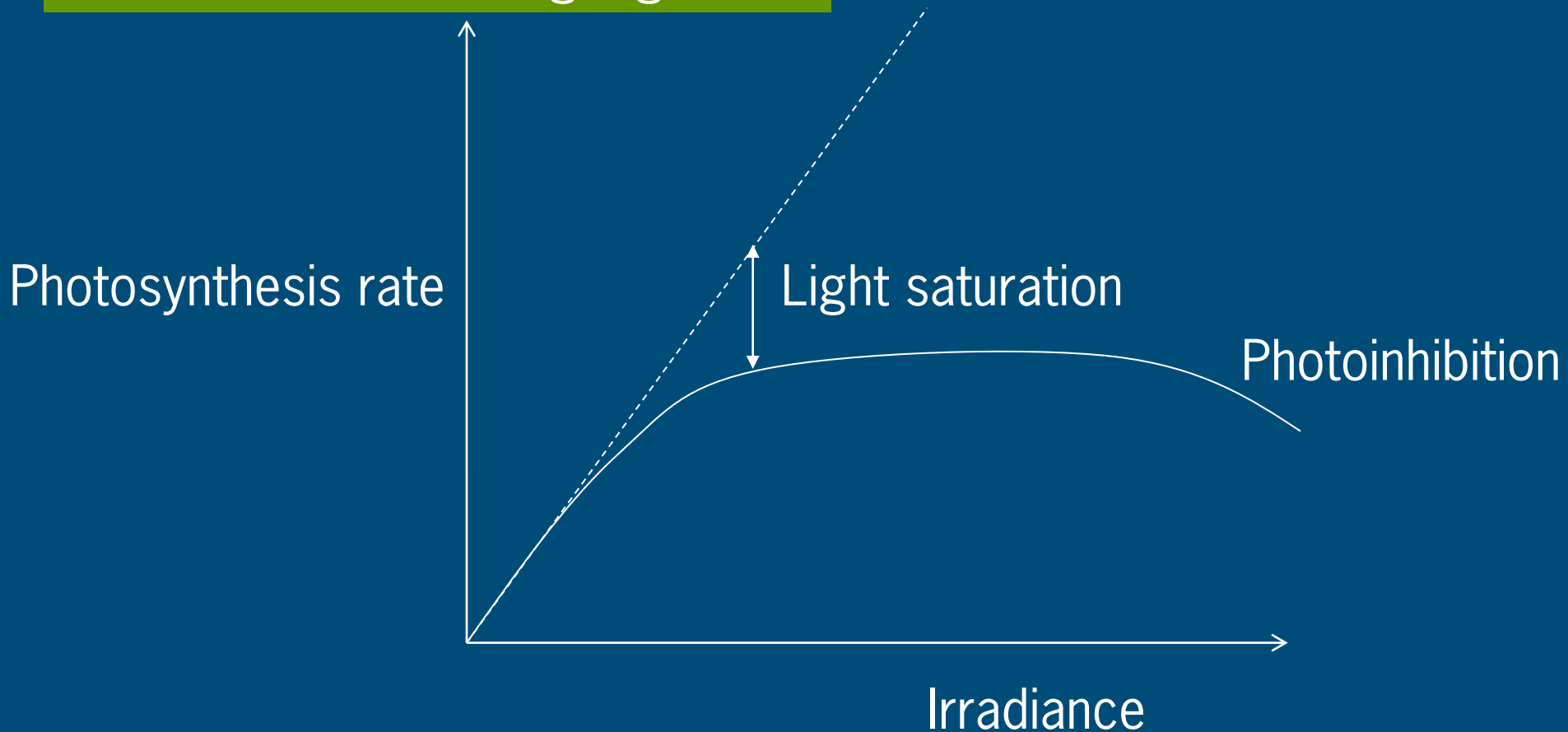
Low controllability



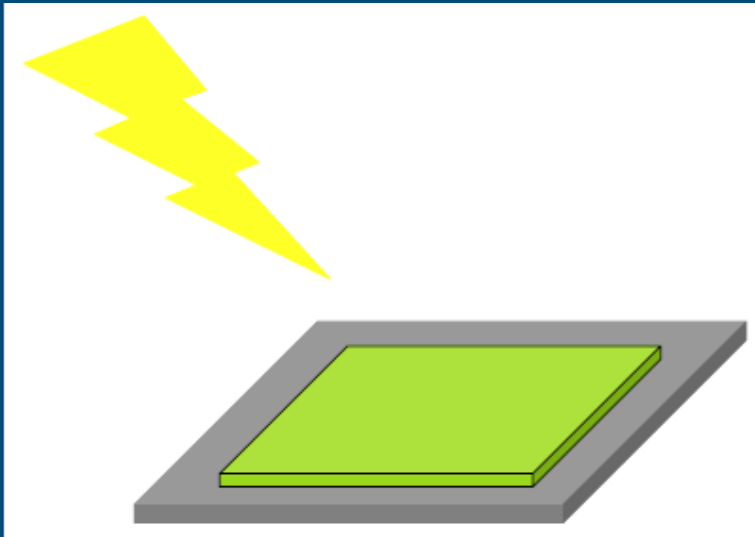
High controllability

Photosaturation and photoinhibition

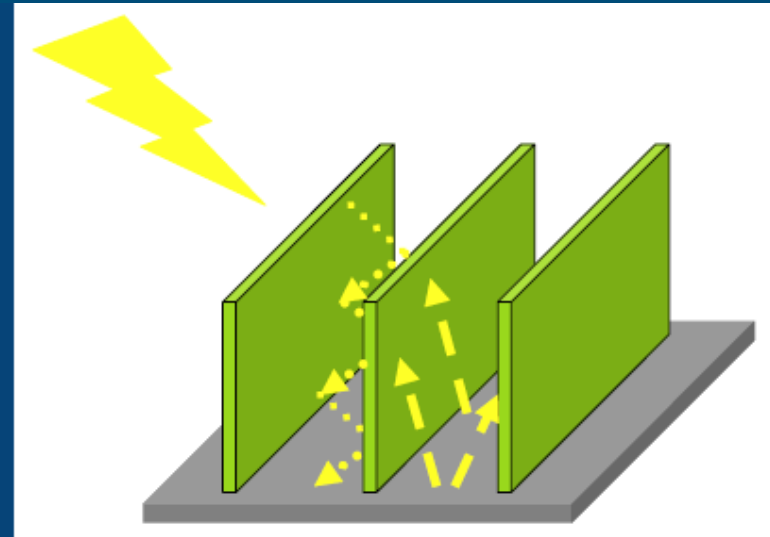
Diluted cultures – no light gradient



The principle of light dilution – go vertical!



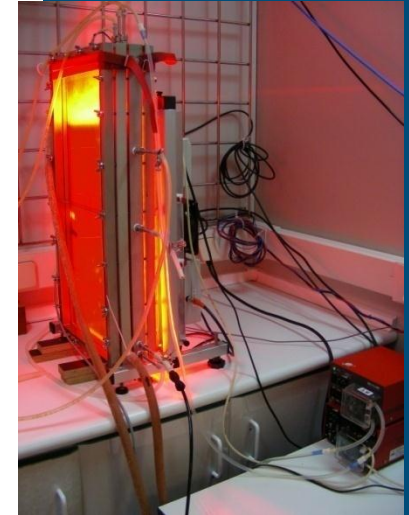
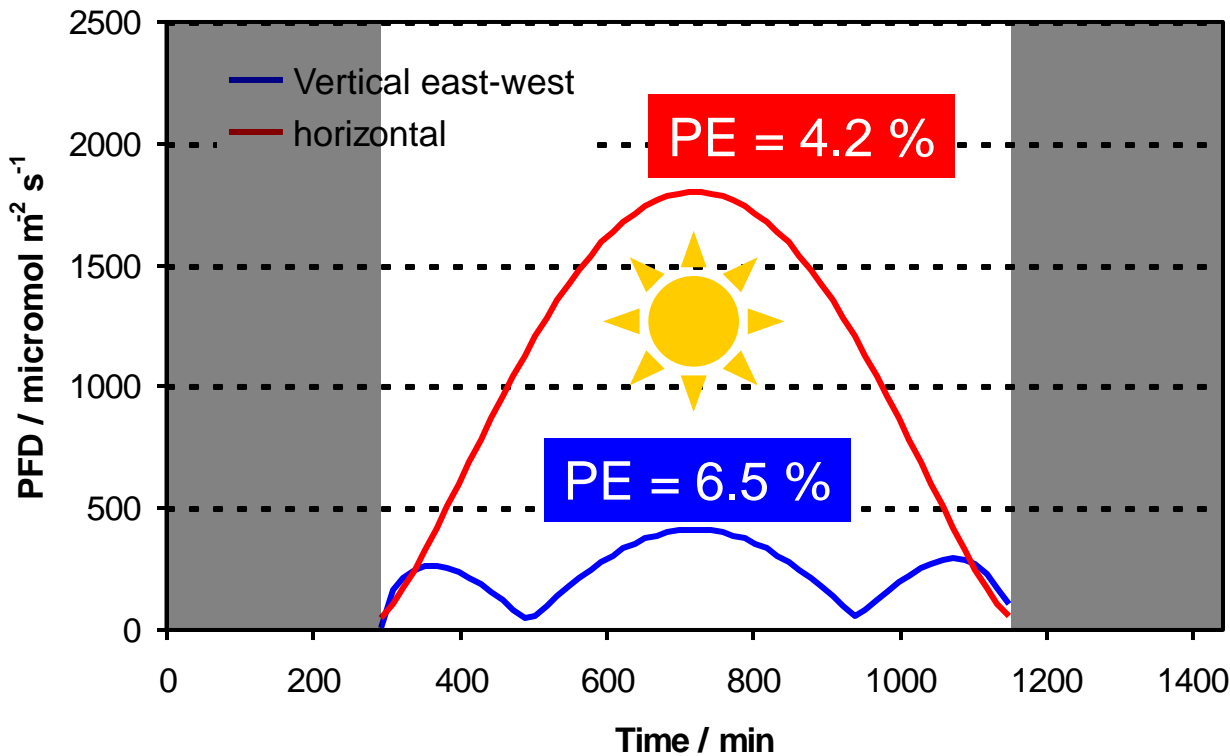
I_{\max} : 1800 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$
(direct sunlight)



I_{\max} : 400 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$
(diluting effect)



Light dilution in the lab



- At lab scale a photosynthetic efficiency of 6% seems to be within reach
Cuaresma et al., 2010

What about:

- Pilot scale 10 – 100 m^2
- Extended time > 1 yr

Light dilution in practice

Challenges

- Material lifetime
- Cleanability
- Reducet energy input (e.g reflect IR)

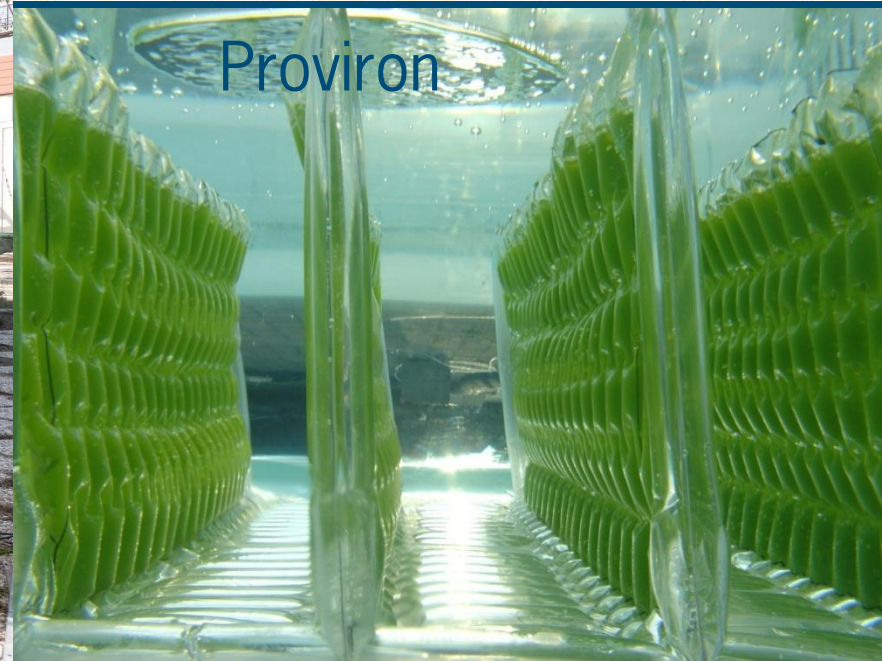
Solix Biofuels)



Fotosintetica & Microbiologica



Proviron



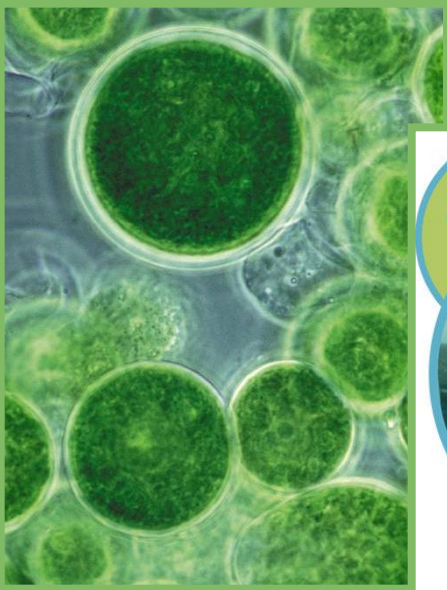
Efficiency in supply and use of nutrients and resources

Sunlight

Water

CO₂, Nitrogen and Phosphorus

Microalgen vs. planten



VS.



Main inputs in the process: Water

Photosynthesis : ~0.75 liter of water / kg of biomass

1.5 liters of water / liter of oil (50 % lipid content)

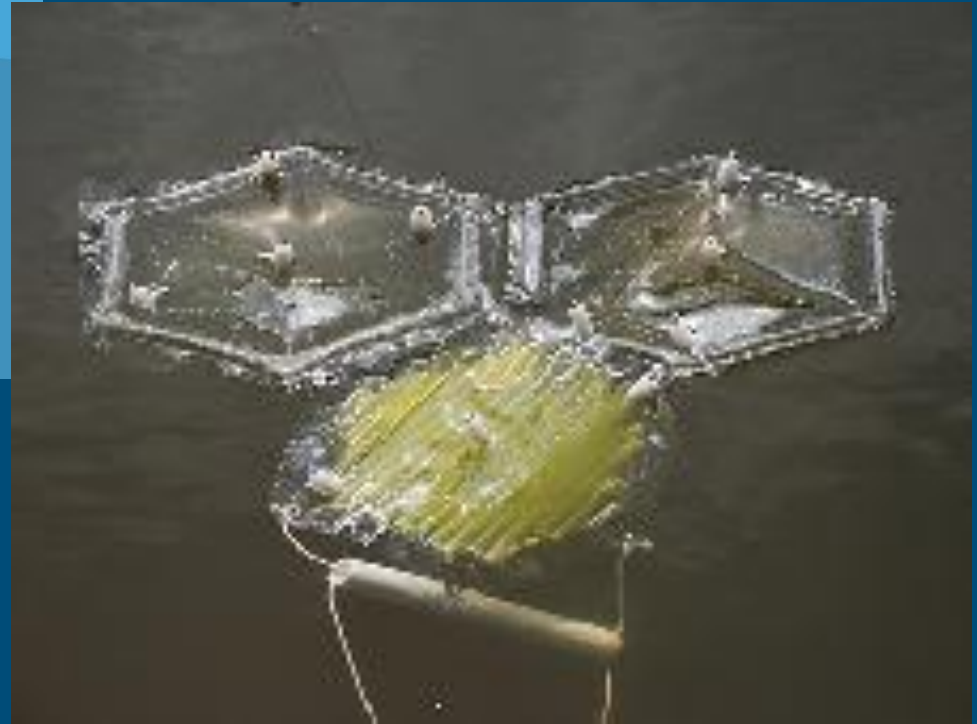
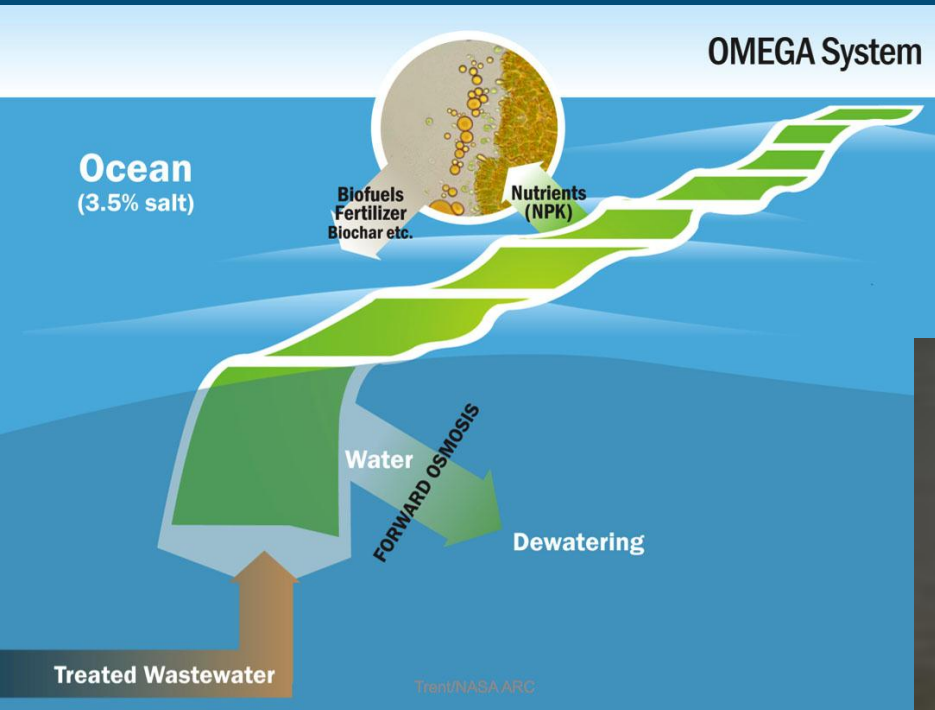


In practice consumption is much larger:

- cooling closed systems
- fresh water needs to be added to open ponds to compensate for evaporation.

- Cooling with large saltwater buffer
- Seawater species
- Growth on large water surfaces (lakes and seas)

NASA OMEGA Systems



Efficiency in supply and use of nutrients and resources

Sunlight

Water

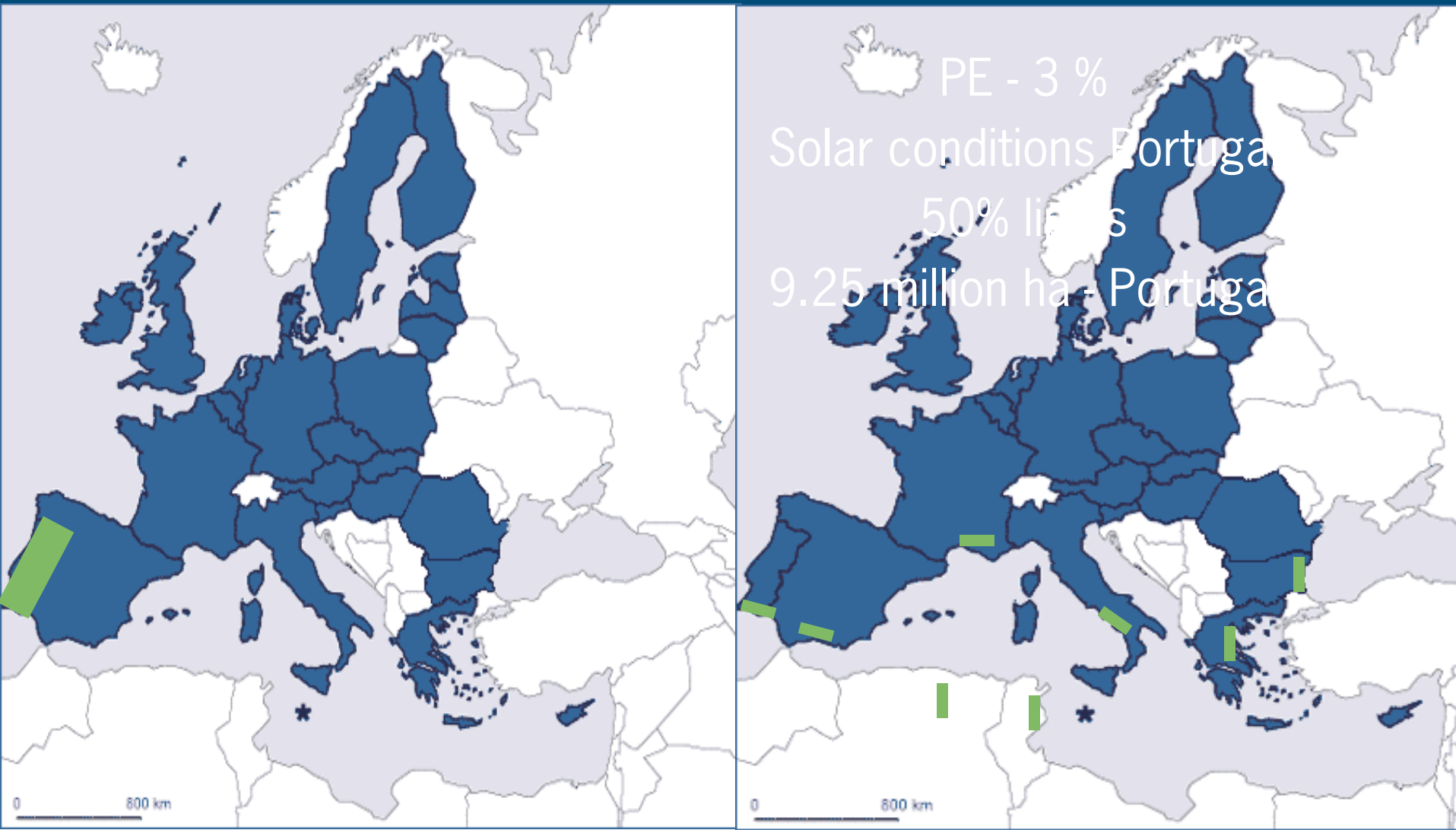
CO₂, Nitrogen and Phosphorus

Main inputs in the process

To produce 1 ton of algal biomass:

- 1.8 tons of CO₂ is needed
- 0.07 ton N
- 0.01 ton P

Transport Fuels in Europe - 0.4 billion m³



Main inputs in the process CO₂

- 1.8 tons of CO₂ is needed to produce 1 ton of algal biomass



- 1.3 billion tons of CO₂ for 0.4 billion m³ of biodiesel
- EU CO₂ production 4 billion tons of CO₂

Logistics?

Main inputs in the process N & P



Biomass: 7% N
1 % P

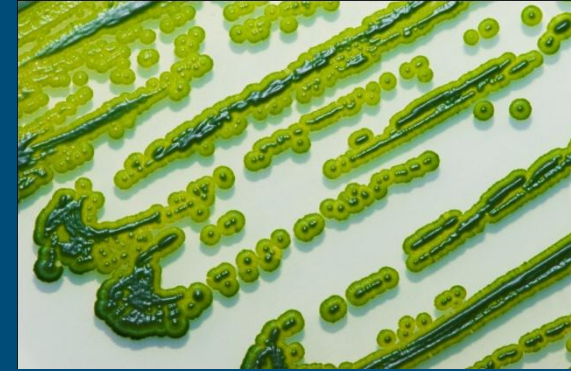
- ~25 million tons of nitrogen
- 4 million tons of phosphorus

Twice the amount that is presently produced as fertilizer in Europe

- Use residual nutrient sources (ca 8 million ton N in Europe)
- Recycle nutrients

How ?

- Increasing photosynthetic efficiency
- Integrate processes (free nutrients)
- Decreasing mixing
- Developing cheaper and less energy consuming harvesting technologies
- Choosing locations with higher irradianations



Scale-up

Production costs

Energy
requirement

AlgaePARC

Algae Production And Research Center

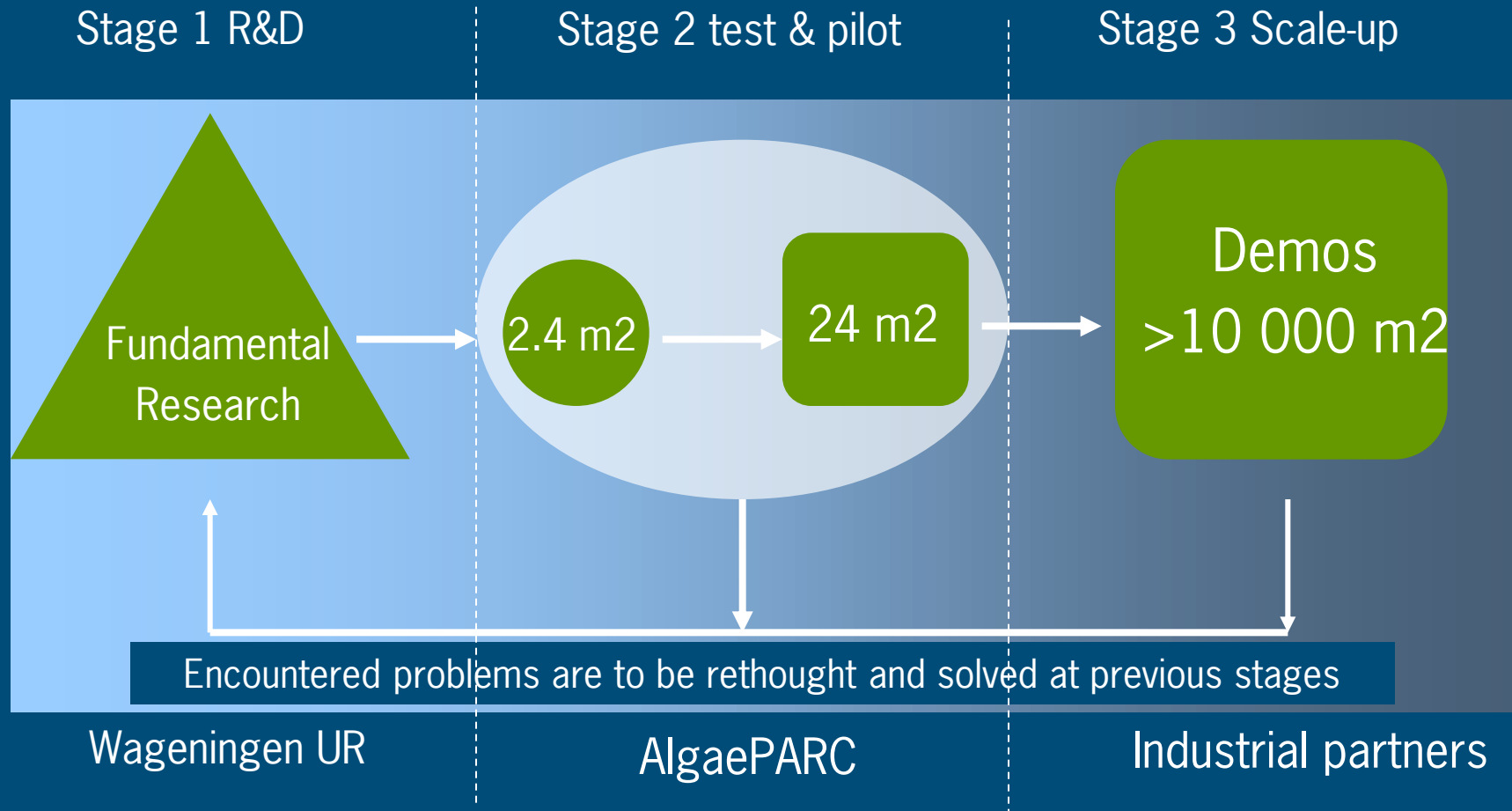


AlgaePARC

The main focus of AlgaePARC is to develop knowledge, technology and processes strategies to **scale up** microalgae facilities **under industrial settings** and to optimise product productivities under stress and controlled conditions outdoors.



Translate research towards applications



AlgaePARC objectives

- International center of applied research
- Intermediate between basic research and applications
- Development of competitive technology (economics, sustainability)
- Acquire information for full scale plants
- Algal biomass for food, feed, chemicals and fuels



24 m² systems

- Long time performance (1 yr)
- High level of measurement and control
- Representative productivities for full scale
- Information for design of full scale plants

2.4 m² systems

- Phase between lab and pilot
- Testing – short term experiments
- Different strains
- Different feed stocks
- Adaptations in design and process
- If successful
 - To 25 m² scale
- If not successful
 - More experiments
 - Reject

Cultivations systems (24 m²)

Open pond

- Reference

Horizontal tubes

- high light intensity
- oxygen accumulation

Vertical stacked hor. tubes

- light dilution
- oxygen accumulation

Flat panels (Proviapt)

- light dilution
- no oxygen accumulation



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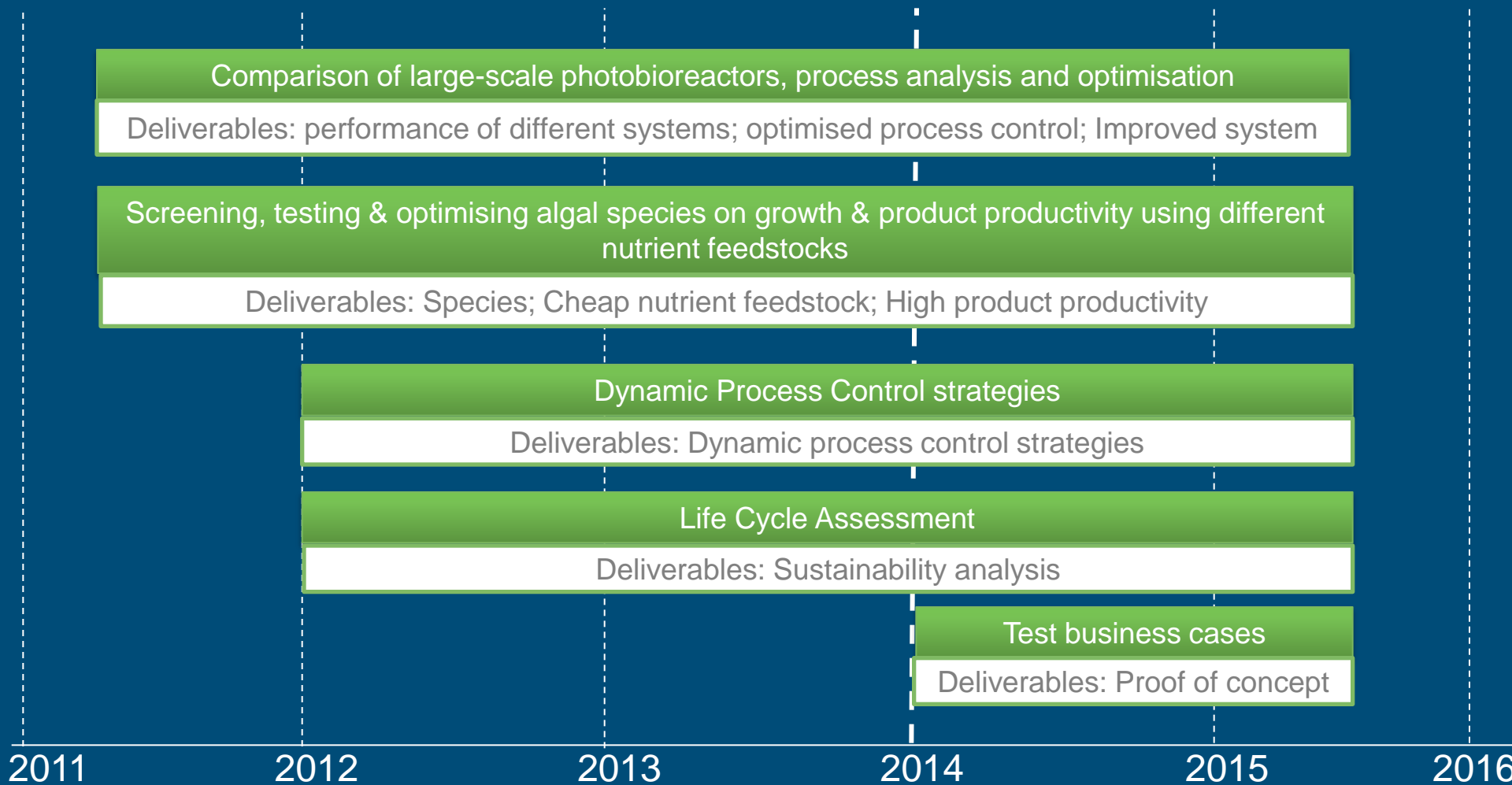
- light dilution
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Flat panels (Proviapt)

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- no oxygen accumulation



R&D activities AlgaePARC



Funding AlgaePARC

■ Facility financed by

- Ministry EL&I
- Province Gelderland
- Wageningen UR

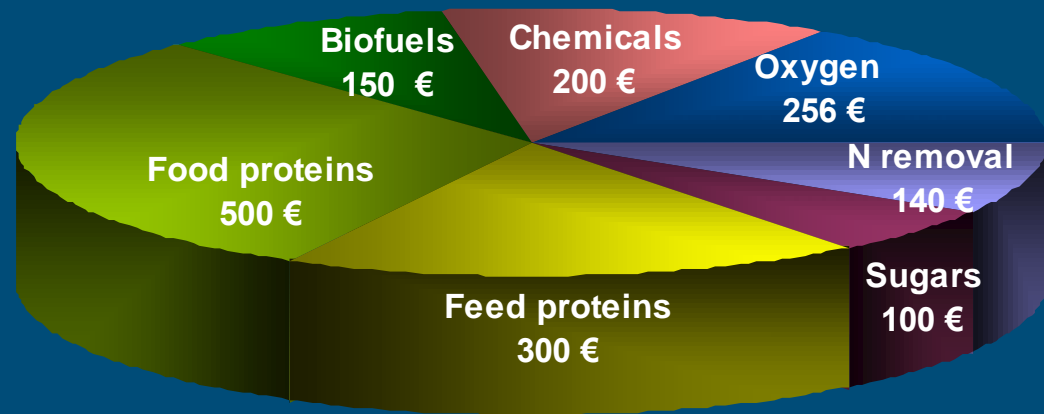


■ Research program financed by



Next steps

- Development of demo projects
- Biorefinery
 - Mild cell disruption techniques
 - Fractionation biomass with maintainance of functionality of proteins
- From cell physiology to process strategies



Mircoalgae in a biobased economy?



- Possibly
- 10-15 years R&D
- Need for trained personnel

De Algenieurs: een groene generatie met energie voor de toekomst



PhD students & young professionals

- Conference (June '12)
- Course (2012/2013) Photobioreactor design

Middelbare scholen

- Algen-practicum
- Design challenge
- Digitaal leermateriaal
- PWS platform

AlgaePARC excursies

www.algae.wur.nl
www.AlgaePARC.com



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Packo.Lamers@wur.nl

Why (not) microalgae? Present challenges!

The process: harvesting

Harvesting techniques

- Centrifugation
 - Energy consumption is high
- Filtration
 - Only possible with large algae species (e.g. Spirulina)
- Flocculation
 - Good alternative for removal of water as first step

Flocculation

Chemical flocculation

- Multivalent metal salts
- Cationic polymers
- Chitosan

Autoflocculation

- Extreme pH
- Temperature
- Nutrient depletion

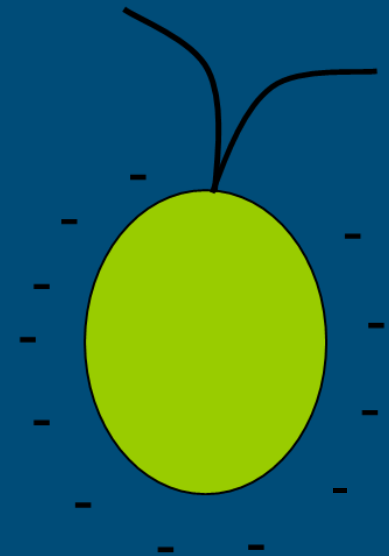
Bioflocculation

- Exopolysaccharides produced by microorganism

Dissolved/dispersed air flotation

Chemical flocculation

1. Multivalent metal salts
2. Cationic polymers
3. Chitosan



Important:

- Case 1, 2 and 3: Negative effect for downstream processing for production of biodiesel
- Case 2: flocculation using cationic polymers is inhibited by high ionic strength of sea water
- Case 1, 2, and 3: cost price too expensive for biodiesel production

Autoflocculation

1. Extreme pH
2. Temperature
3. Nutrient depletion

Important:

- Case 1: supposedly works for all algae
 - Time needed ranges from hours to days
 - pH range where flocculation occurs depends on strain
 - Effectiveness depends partially on growth phase
- Case 1: Much used in waste water plants
- Case 1, 2, 3: may cause cell composition changes
- Case 2, 3: generally considered too unreliable to be economical on a commercial scale

Bioflocculation

1. Capability of production of exopolysaccharides

Important:

- Environmental conditions are of influence
- Production strain is flocculating strain
- Other microalgal strain can be added to reactor as flocculant
- Other microorganisms (bacteria etc.) can be added to reactor as flocculant

Dissolved/disperged air flotation

1. Electrostatic interaction between cell and gas bubble/'collector'

Important:

- Strain dependent
- Usually use of added chemicals (inorganic coagulants)
- Often used in waste water treatment plants

Why (not) microalgae? Present challenges!

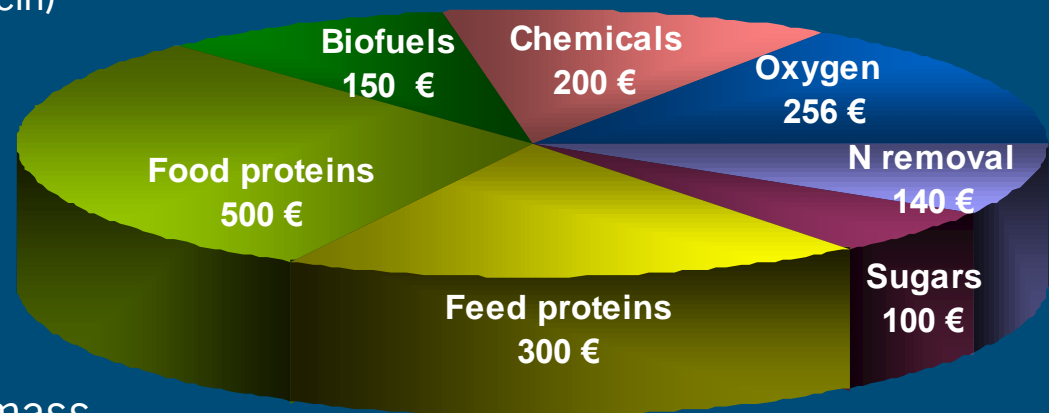
The process: what to do with the biomass

Microalgae: Importance of a biorefinery approach

- Varied and high quality composition of biomass
- Economic need to optimise valorization of the biomass by extraction of multiple products in addition to e.g fuels

Bulk chemicals and biofuels in 1,000 kg microalgae

- 400 kg lipids
 - 100 kg as feedstock chemical industry (2 €/kg lipids)
 - 300 kg as transport fuel (0.50 €/kg lipids)
- 500 kg proteins
 - 100 kg for food (5 €/kg protein)
 - 400 kg for feed (0.75 €/kg protein)
- 100 kg polysaccharides
 - 1 €/kg polysaccharides
- 70 kg of N removed
 - 2 €/kg nitrogen
- 1,600 kg oxygen produced
 - 0.16 €/kg oxygen
- Production costs: 0.40 €/kg biomass
- Value: 1.65 €/kg biomass



Complexity of biorefinery

- Business model in which different end users need to collaborate
- Market volumes must fit
- Highest value is obtained if functionality of molecules is maintained
- Biomass production and biorefinery depend on each other

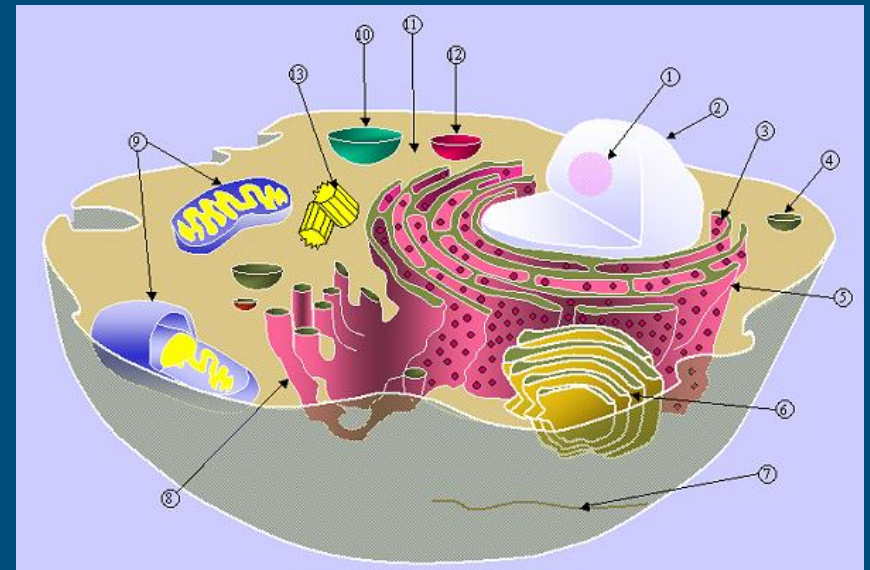
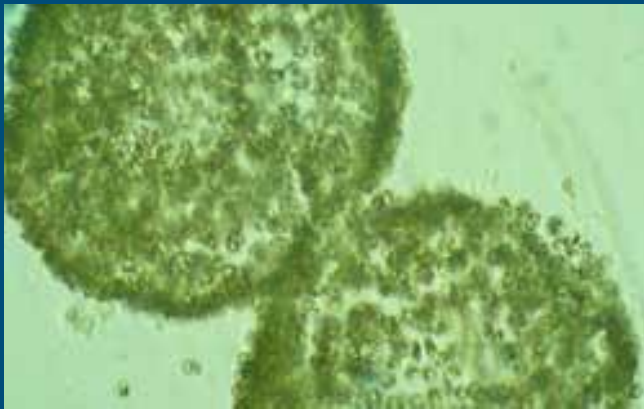
To replace all transport fuels in Europe

- 400 million m³ lipids needed
- 9.25 million ha surface area
- Equivalent to surface area of Portugal
- 400 million tons of proteins produced
- 20 times the amount of soy protein imported in Europe

How can we make a more structure based approach for biorefinery?

- To fractionate all components
- Maintain their functionality
- At low energy input

Localization of components in different organelles in the cell



Molecular and Technological knowledge both needed

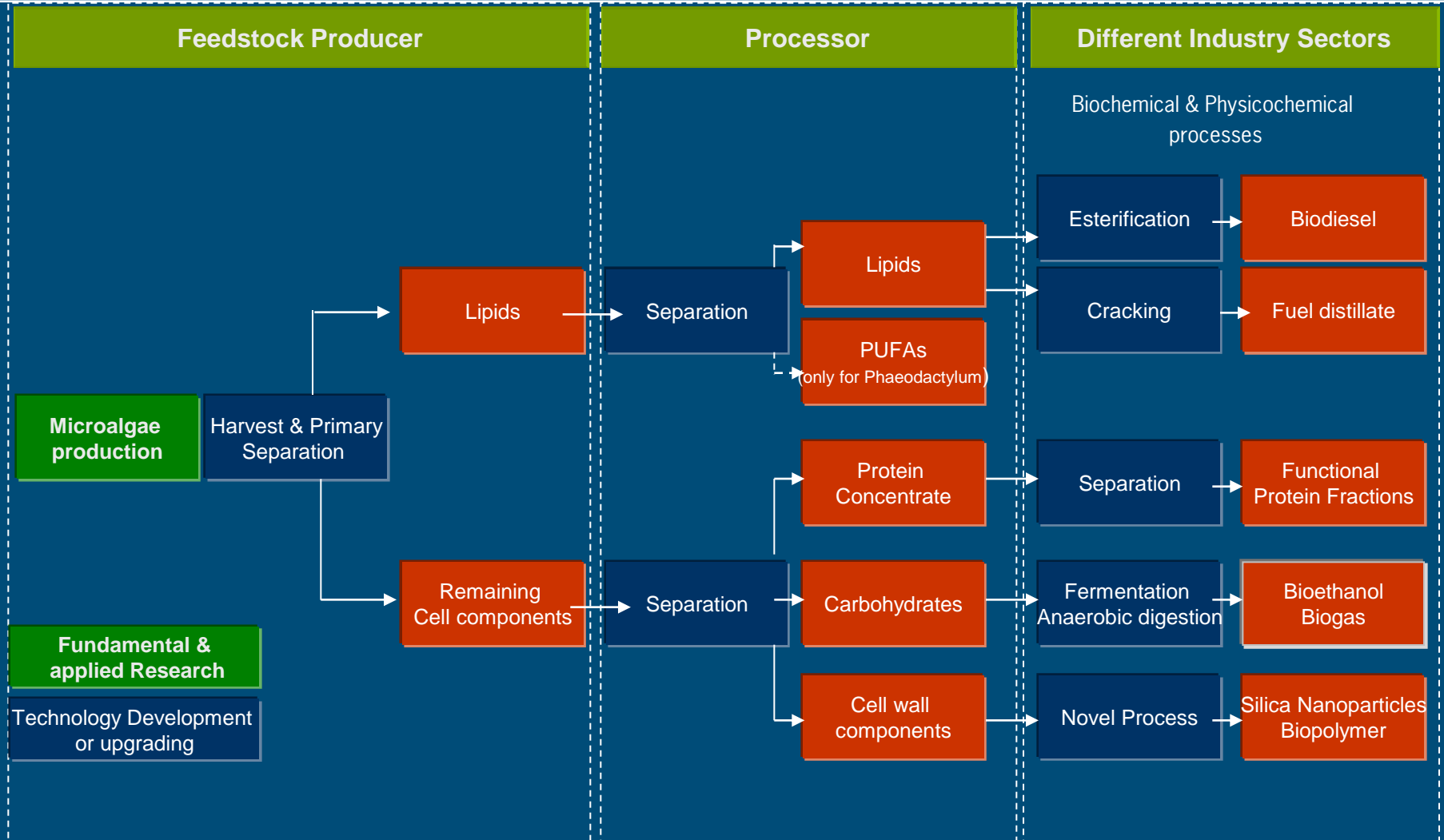
Specific developments required for a microalgae biorefinery

- Development of mild and efficient cell disruption, extraction and fractionation technologies
- Effective technologies for separation of carbohydrates, proteins and lipids
- Lipid/oil refining technologies
- Improvement of environmental performance, decrease in energy consumption and decrease of capital costs
- Integrate knowledge & facilities for oil, food and fine chemical industry
- Biomass provision (quantity and quality)

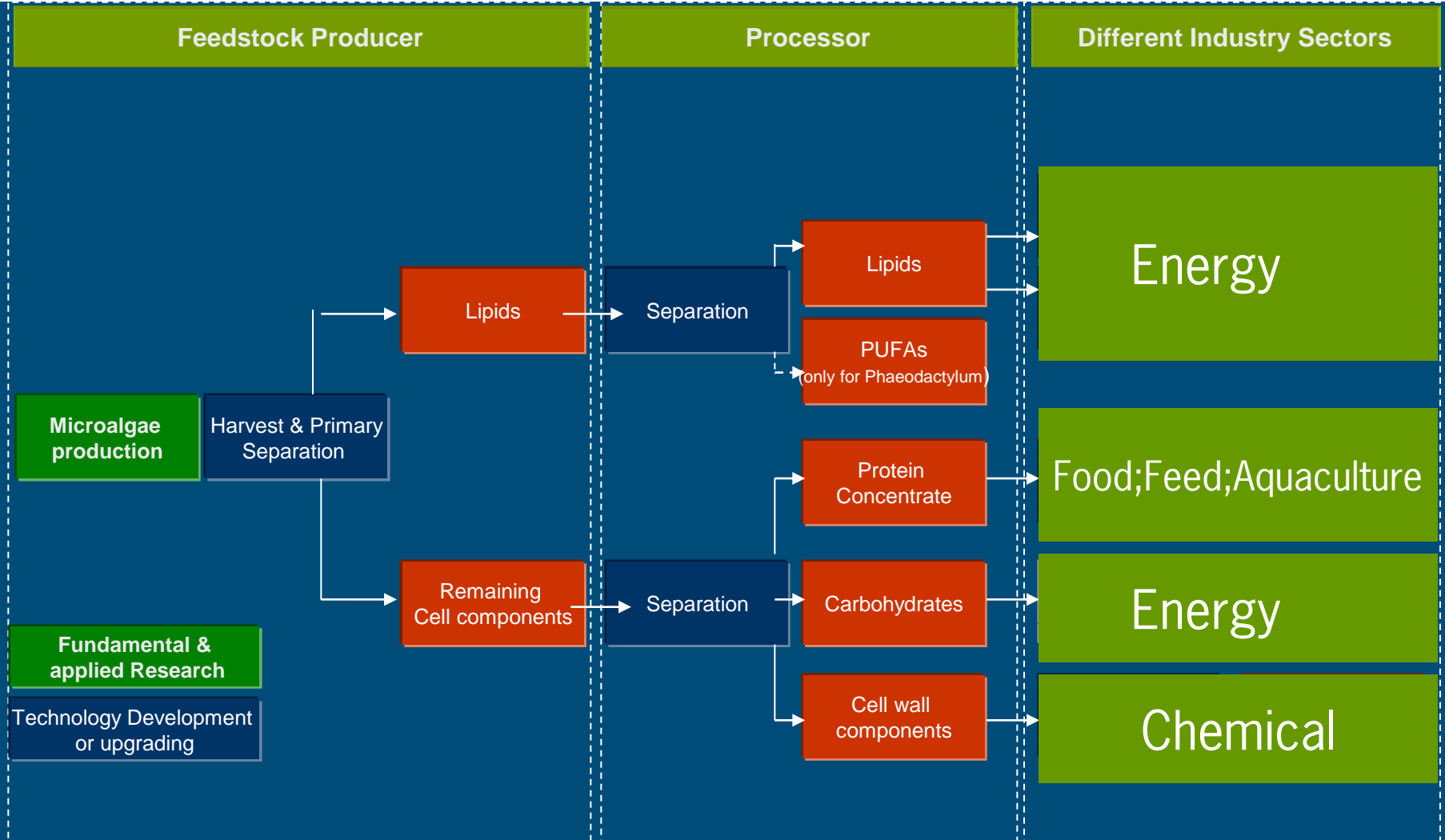
Present

- One process for one product

Chain Approach: from feedstock to end products



Chain Approach: from feedstock to end products



Why (not) microalgae? Present challenges!

Furthermore....

Challenges in the entire chain

- High CAPEX, high running costs and energy consumption for cultivation, harvesting and product separation
- Large-scale cultivation of microalgae
- Current process technology does not allow the production of multiple products
- Lack of trained personnel
- Product development to commercial applications
 - Regulatory approval for use of algae in feed/food is lacking
 - Broad consumer acceptance of algae and seaweeds in food
 - The full range of potential products, best combinations and their market values is unclear