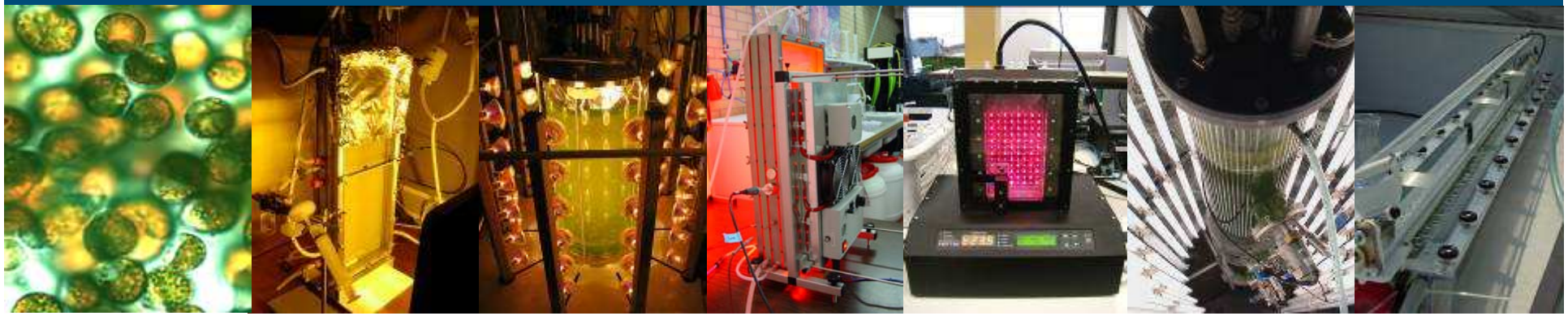
Microalgae for production of bulk chemicals and biofuels

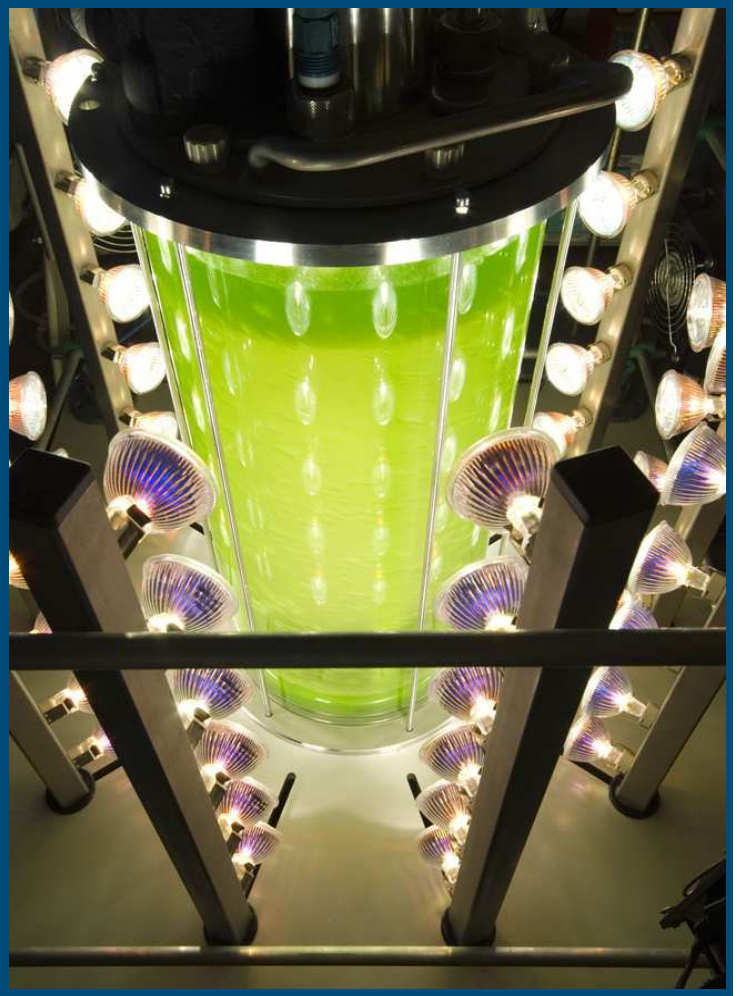
Maria Barbosa, Brenda Israel and René H. Wijffels
Wageningen University and Research Center



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Contents

- Introduction University/Business Unit
- Feasibility study
- Wageningen research agenda
  - Maximization biomass productivity/ yield
  - Reduction of energy input
  - Maximization productivity metabolites
  - New strains
  - Biorefinery and design scenarios
- Additional projects
- Initiatives for the future



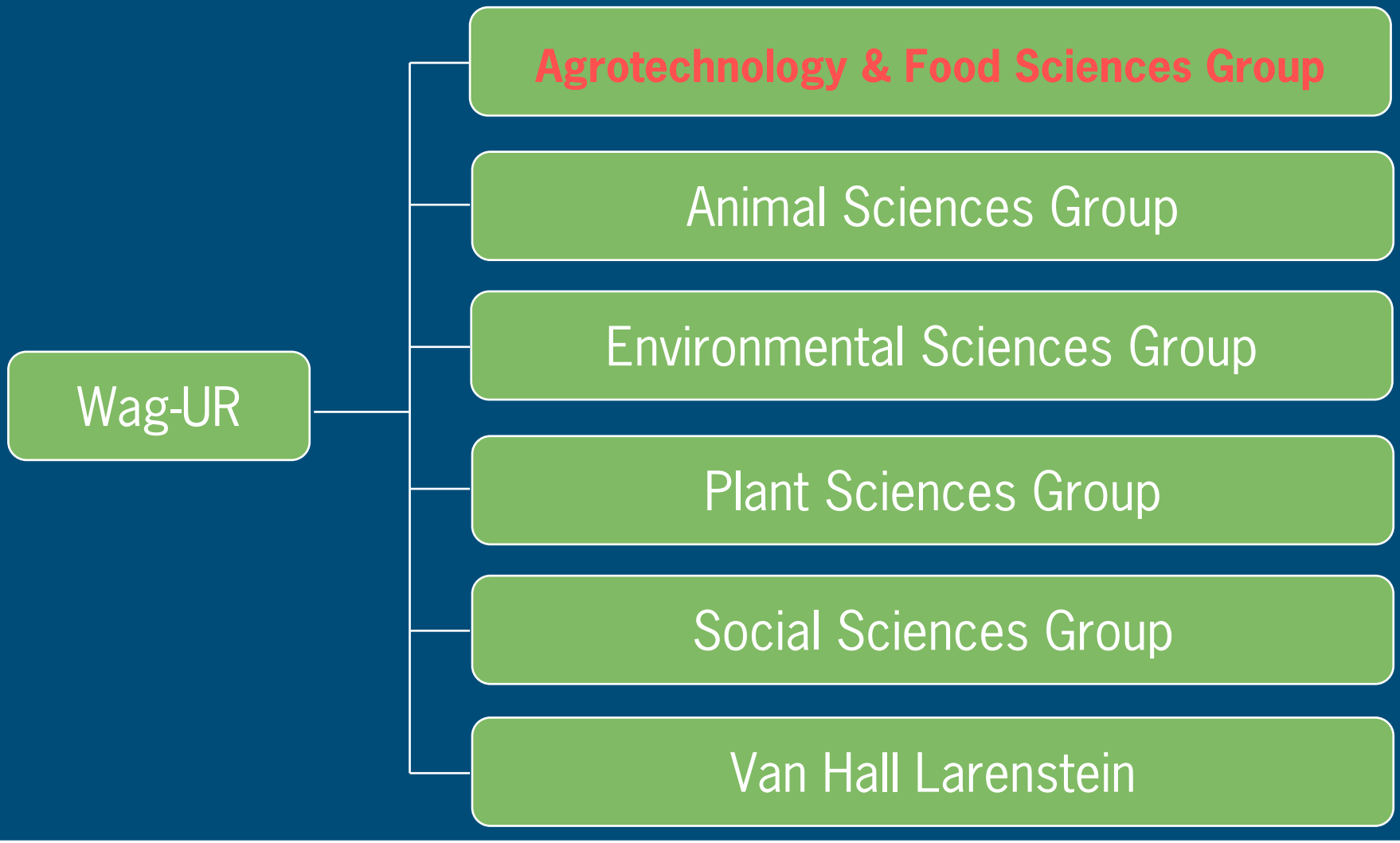
AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Wageningen UR

- Since 1918 Agricultural University
- 5400 employees
- 5 science groups + Van Hall Larenstein
- 590 million euro →
  DLO 315 million euro

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Wageningen UR and its Sciences Groups



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Biobased Products

- Development of:
  - Materials
  - Chemicals
  - Energy Carriers
- Based on:
  - renewable plant and animal resources
- 3 groups:
  - Bioconversion
  - Biomass Pretreatment and Fibre Technology
  - Sustainable Chemistry and Technology

Bioconversion

Conversion of biomass by bacteria, fungi, algae into:

- Fuels
  - Ethanol/Buthanol
  - Hydrogen
  - Diesel
- Bio-polymers
  - PLA
  - PHA
- Fine Chemicals
  - Poly Unsaturated Fatty Acids (PUFA)
  - Glycosamine glycanen
  - Protein Polymers (collagen, anti-fouling)

Biomass Pretreatment and Fibre Technology

- Biomass Pretreatment
- Paper and Board Technology → Dutch Centre of expertise
- Plastics reinforced with agrofibres
- Sustainable building materials
- Geotextiles
- Biorefinery

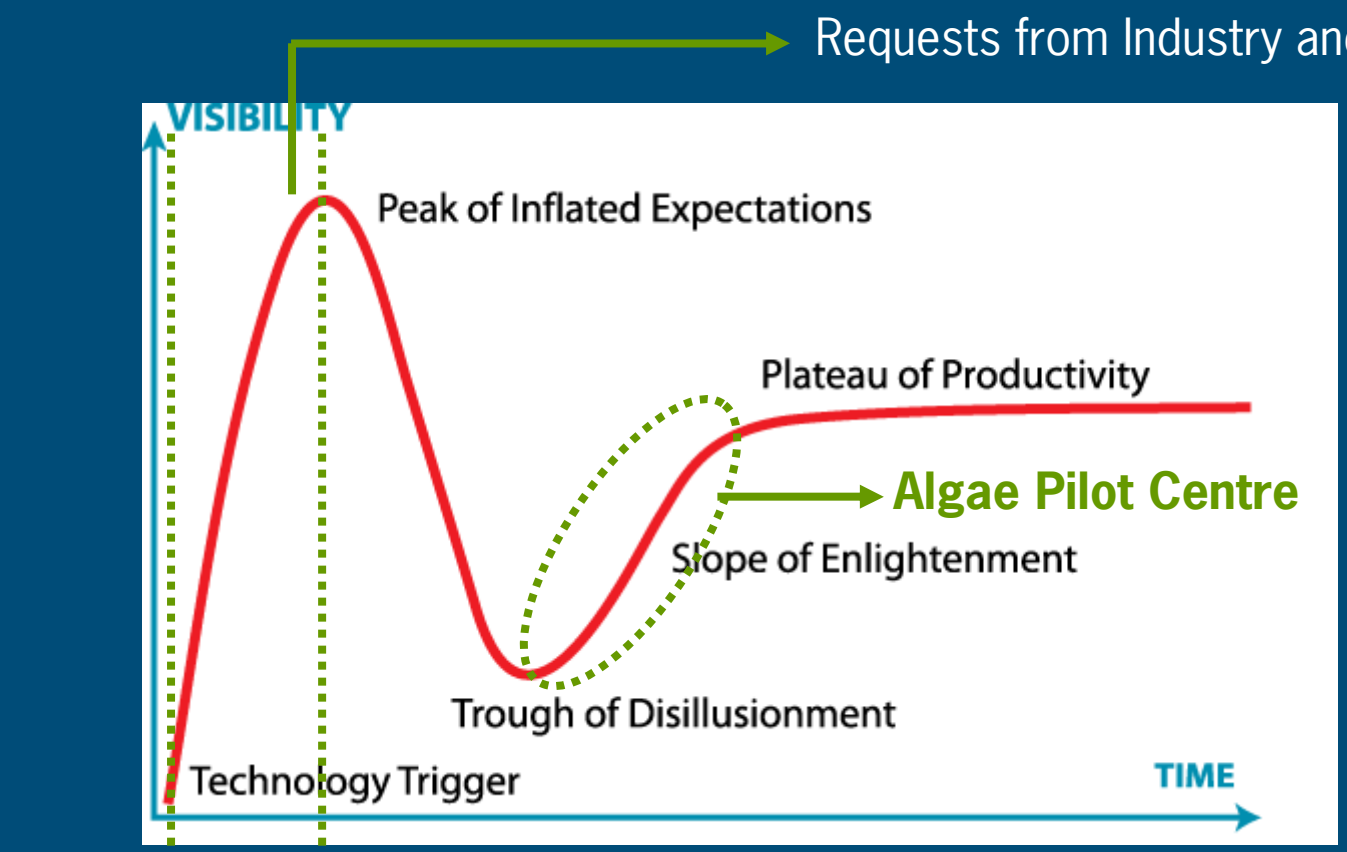
Fibres from: wood, hemp, flax, coconut

Sustainable Chemistry and Technology

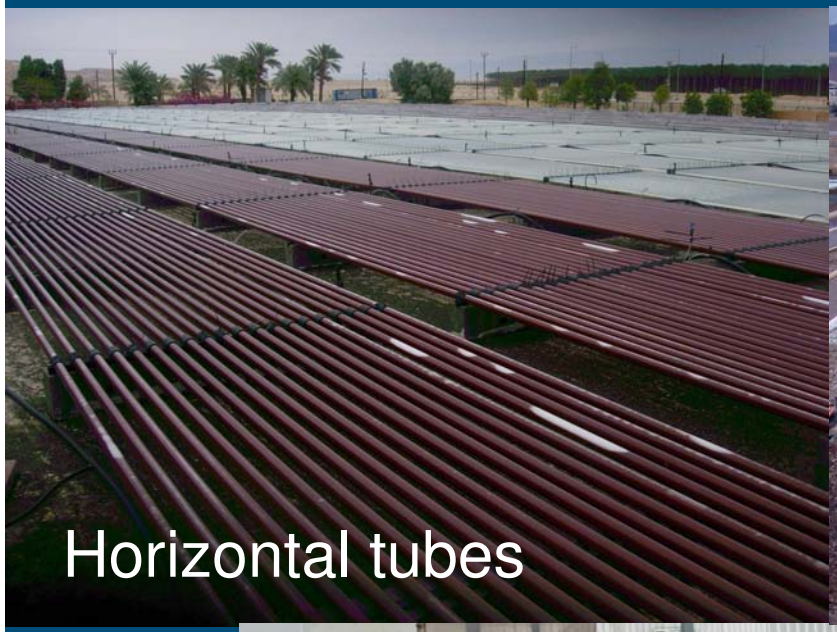
- Coatings and Adhesives
- Additives
- Biopolymers
- Biocatalysts
- Bioresins

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Development of algal technology



2007: Delta Feasibility Study



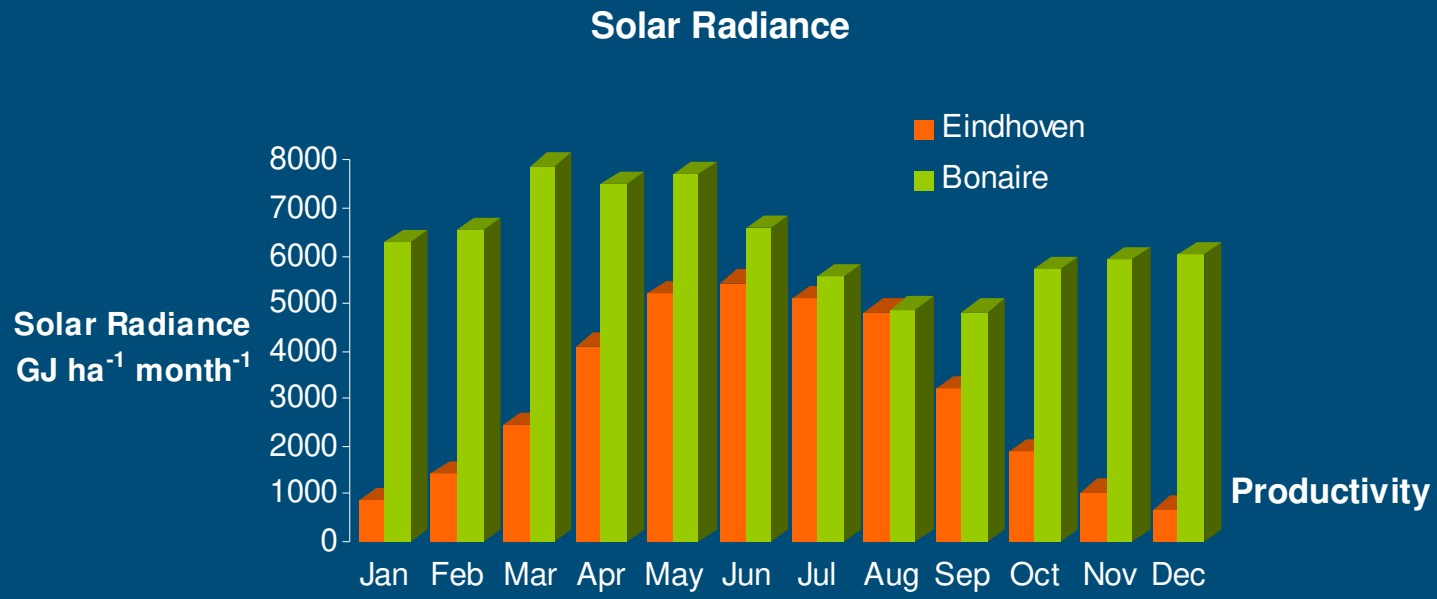
2007: Delta Feasibility Study

100 ha, the Netherlands

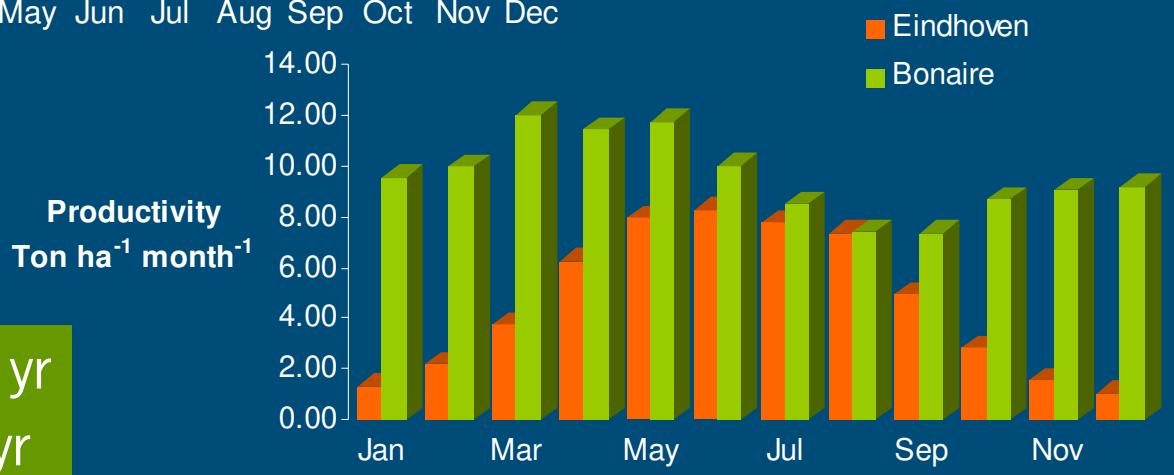
	Tubular	Flat panel	Pond
Biomass production (ton / yr)	4 141	6 363	2 071
Photosynthetic Efficiency (% on solar)	3	5	1.5
Light path (m)	0.034	0.030	0.20
Daily dilution rate (%)	30	30	10
Culture Volume (m^3)	29 671	57 692	180 180
Investment (€ / m^2)	34	94	65
Biomass production cost €/kg	**4.02**	**4.03**	**5.7**
Main contributor (%)	**Power 42%**	**Power 27%**	**Harvesting 15%**

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Different Locations = Different productivities



Productivity

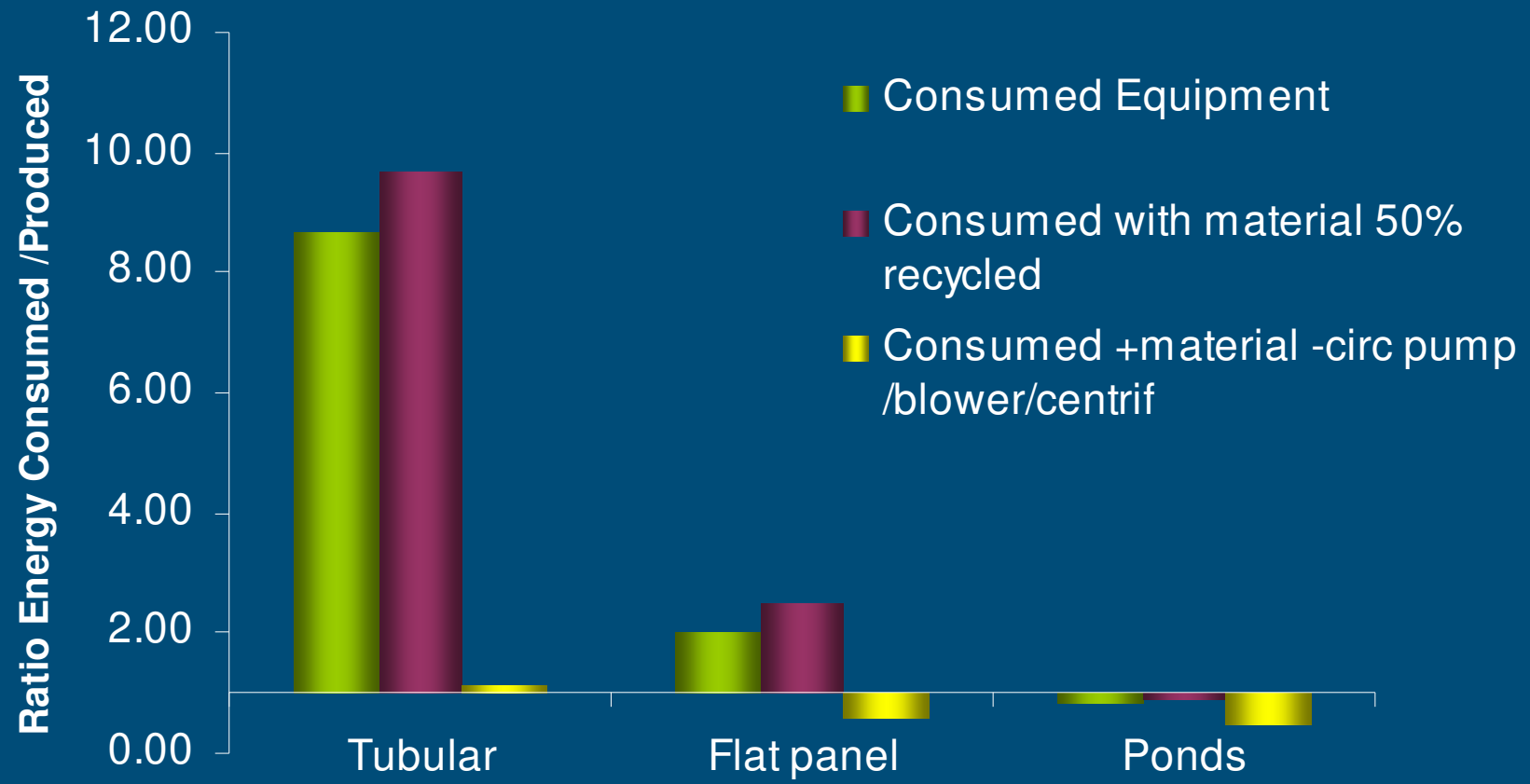


Eindhoven 55 ton /ha/ yr
Bonaire 105 ton /ha/yr

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

2007: Delta Feasibility Study

Energy Balance

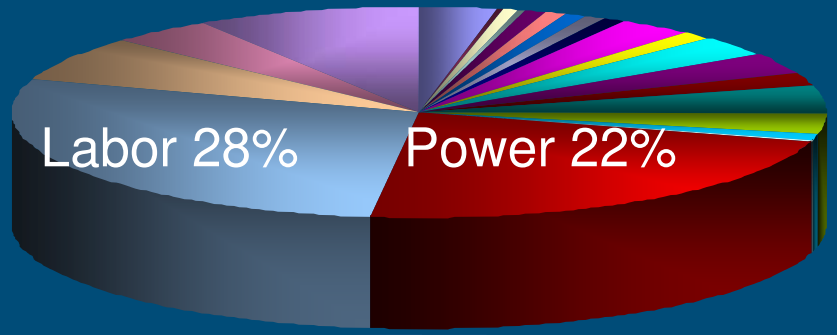


AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

2007: Delta Feasibility Study

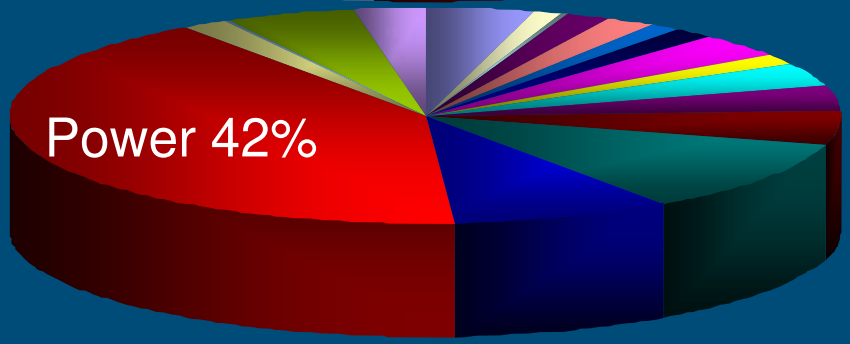
Biomass production cost

1 ha



10.62 € / kg biomass

100 ha



4.02 € / kg biomass

89% decrease

potential

- Centrifuge westfalia separator AG
- Centrifuge Feed Pump
- Medium Filter Unit
- Medium Feed pump
- Medium preparation tank
- Harvest broth storage tank
- Seaw ater pump station
- Automatic Weighing Station w ith Silos
- Culture circulation pump
- Installations costs
- Instrumentation and control
- Piping
- Buildings
- Polyethylene tubes Photobioreactor
- Culture medium
- Carbon dioxide
- Media Filters
- Air filters
- Pow er
- Labor
- Payroll charges
- Maintenance
- General plant overheads

0.4 € / kg biomass
15 €/GJ

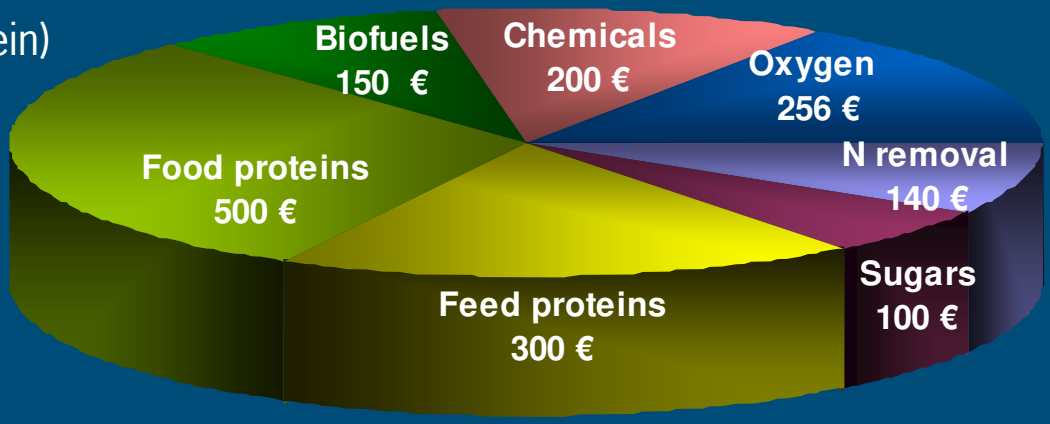
AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Conclusions Delta report: economical viability

- Power input is the main constrain in photobioreactors
- Sensitivity analysis show that biomass production costs can be further decreased from 4 to 0.4 €/kg
- Parameters that need improvement
  - Mixing system / efficiency
  - Photosynthetic efficiency
    - reactor design
    - cultivation conditions
    - strain improvement / screening
  - Integrate processes
- Positive energy balance still needs to be reached

Bulk chemicals and biofuels in 1,000 kg microalgae

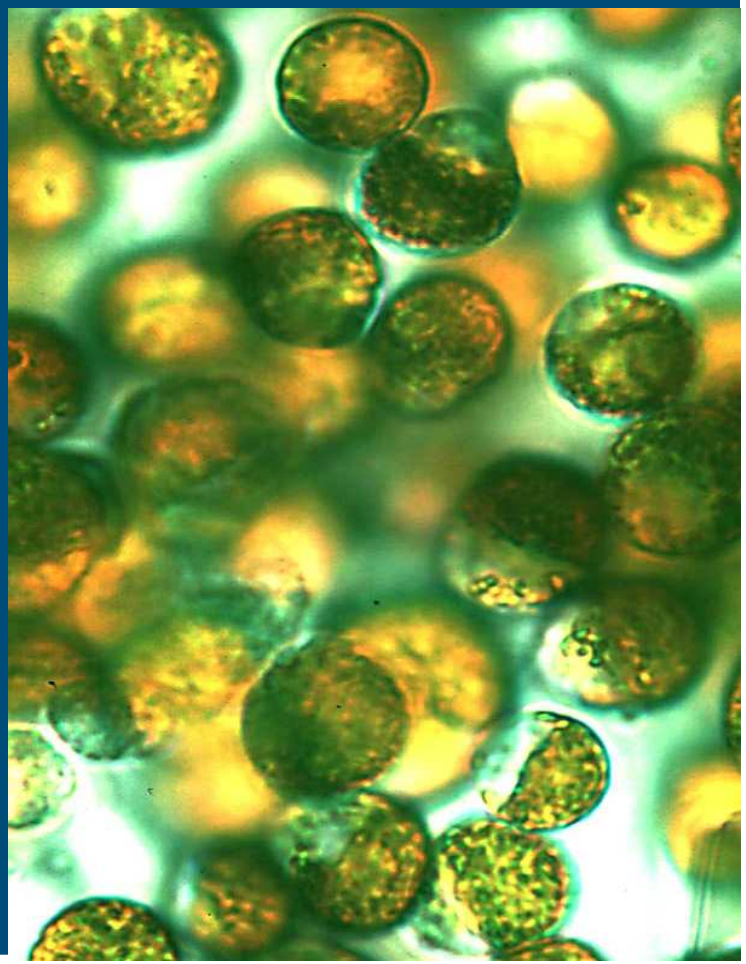
- 400 kg lipids
  - 100 kg as feedstock chemical industry (2 €/kg lipids)
  - 300 kg as transport fuel (0.50 €/kg lipids)
- 500 kg proteins
  - 100 kg for food (5 €/kg protein)
  - 400 kg for feed (0.75 €/kg protein)
- 100 kg polysaccharides
  - 1 €/kg polysaccharides
- 70 kg of N removed
  - 2 €/kg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



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Wageningen research agenda

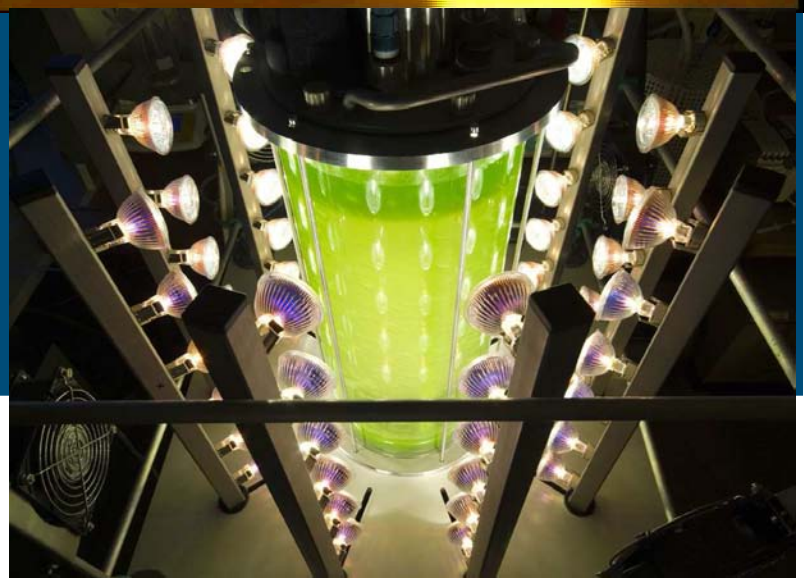
- Maximization biomass productivity/ yield
- Reduction of energy input
- Maximization metabolites productivity
- New strains
- Biorefinery and design scenarios



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Maximization biomass productivity/ yield

- Control primary metabolism
  - Annette Kliphuis (STW)
  - Carsten Vejrazka (EU)
- High-cell density cultures
  - Rouke Bosma, SenterNovem
  - Jan-Willem Zijffers (SenterNovem/EU)
  - Maria Cuaresma (SenterNovem and EU)
  - Niels-Henrik Norsker (Proviron)
  - Vacancy (Wetsus)
  - Michiel Michels (Hogeschool Zeeland)

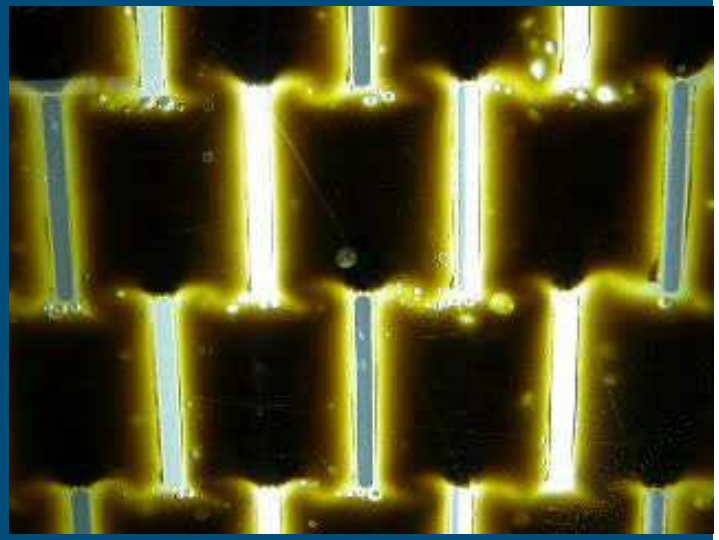


AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Maximization biomass productivity/ yield

Evaluation and modeling new photobioreactor design

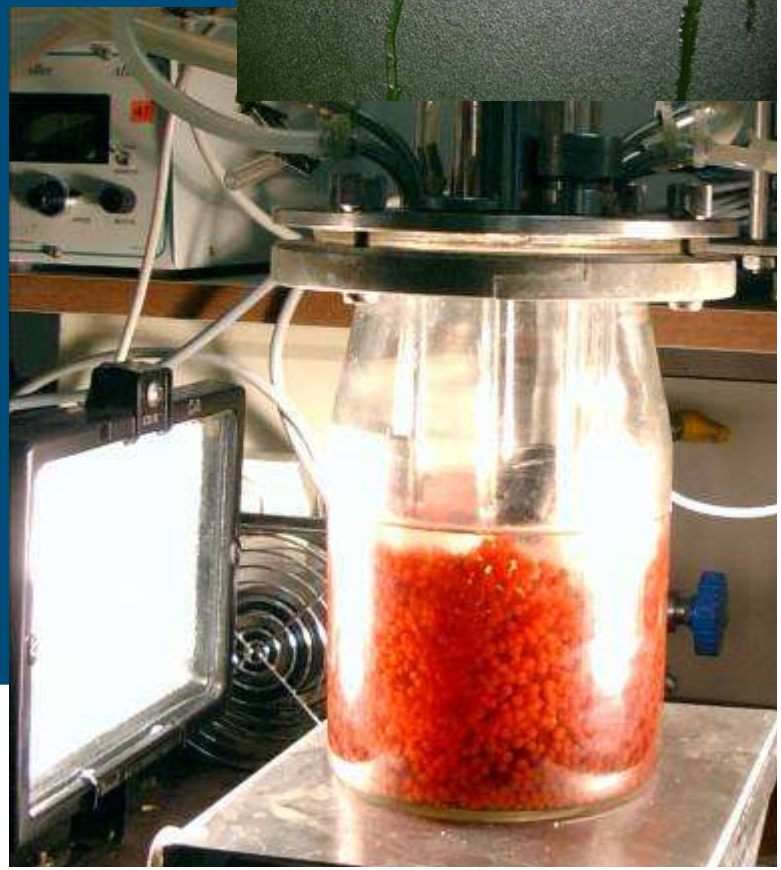
- Industrial collaboration with Proviron
- Testing evaluating and modeling of new PBR design
  - Cheap and scaleable…



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Reduction of energy input

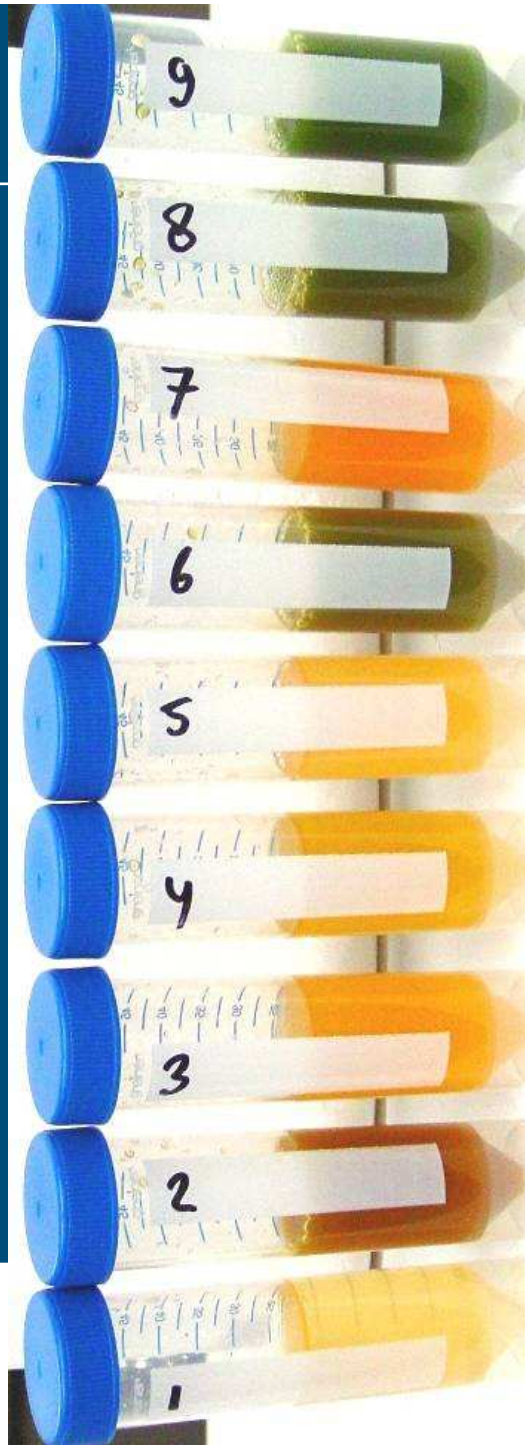
- Effective CO_2 supply
  - Ana Santos (Wetsus)
  - Vacancy (SenterNovem)
- Systems without degassing
  - Sayam Raso (grant from Thailand)
  - Claudia da Sousa (Wetsus)
- Harvesting and processes with biofilms
  - Nadine Boelee (Wetsus)
  - Sina Salim (Wetsus)



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Maximization productivity metabolites

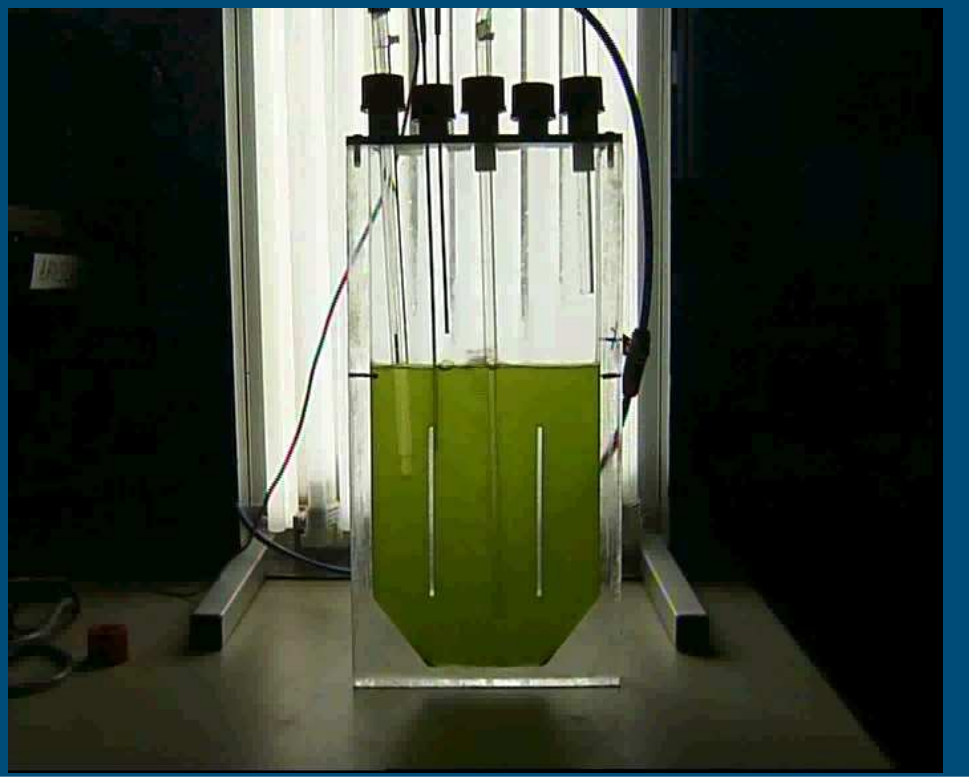
- Carotenoids
  - Packo Lamers, STW
- Lipids
  - Rouke Bosma (SenterNovem)
  - Vacancy (Wetsus)
  - Vacancy (IWT)
- Milking
  - Dorinde Kleinegris (STW)



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

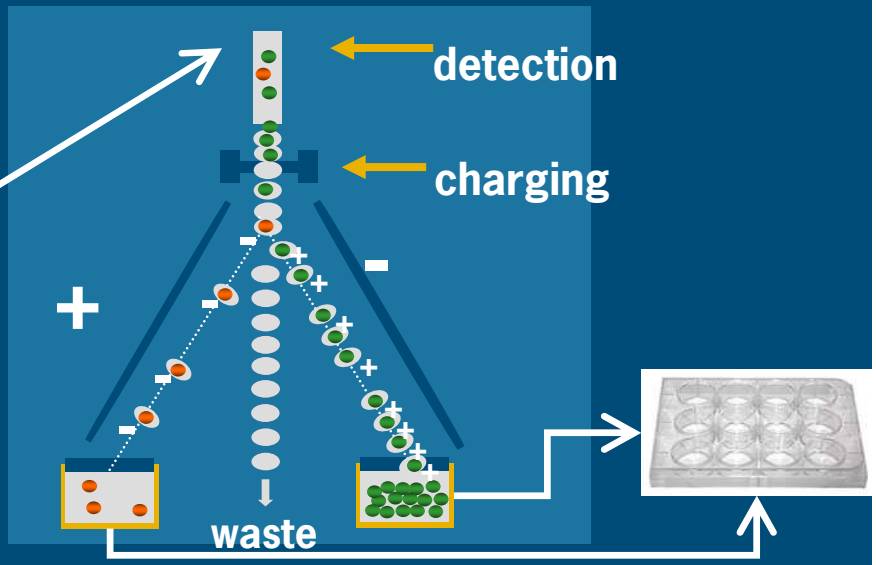
Maximization productivity metabolites: Milking of microalgae

- Development of *in situ* extraction process
- Selection of production strains
- Improvement of strains



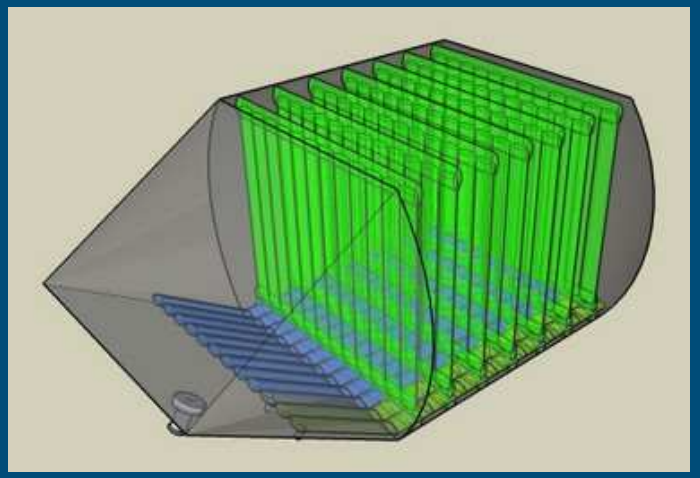
New strains

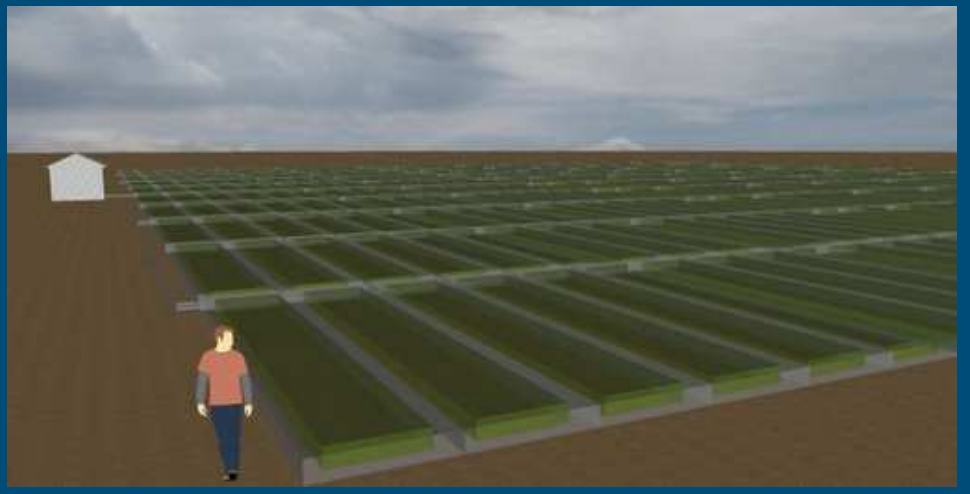
- Strain selection and milking (Dorinde Kleinegris, STW)
- Selection of robust algae for oil production (Rouke Bosma, SenterNovem)



Biorefinery and Design scenarios

- Biorefinery
  - Anja Schwensfeier (Wetsus)
- Design Scenarios
  - Ellen Slegers (Wetsus)





Designs: Proviron

Design scenarios - Ellen Slegers

- Objective
  - Develop scenarios for production of energy carriers at very large scale
- Why
  - Logistics: complexity and energy use of supply of materials
- Research issues
  - Which scale is most economic? 1-10-100-…>10,000 ha?
  - Logistics of a large scale facility are very complex
  - Energy
  - Mixing, degassing, CO_2 supply, harvesting, materials
  - Industrialized areas, desert, floating, local
  - Day / night / summer / winter
  - Storage

Additional Running Projects

- AlgiCoat (EOS LT)
  Selection of algae strains for the production of precursors and their conversion to coatings. Biodiesel is a byproduct.
  (Akzo-Nobel, Essent, Ingrepro, WU-Bioprocestechnologie, WUR-A&F)

- Diatom growth, lipid production and their regulation under simulated process conditions in photobioreactors (IWT)
  (Universiteit Gent, Proviron, WU-Bioprocestechnologie)

- Solar-H2 (EU-FP7)
  Fundamental research on the field of photobiological production of hydrogen by algae. Netherlands brings in the modelling of photosynthesis dynamics Uppsala U., CEA Frankrijk, Max Planck, U. Turku, U. Berlin, U. Bochum, Biol. Research Center Szeged, U.. Geneve, U. Bielefeld, Centre Nat. De Recherche Scientifique, WU-Bioprocestechnologie

- Optimization of microalgae cultivation, using nutrients (digestate and CO_2) and waste heat from a biogas installation (EOS demonstratieproject) in a milk and meat farm.
  (Melkveebedrijf Kelstein, DLV-Plant, Crassus Advisce4you)

Initiatives for the future

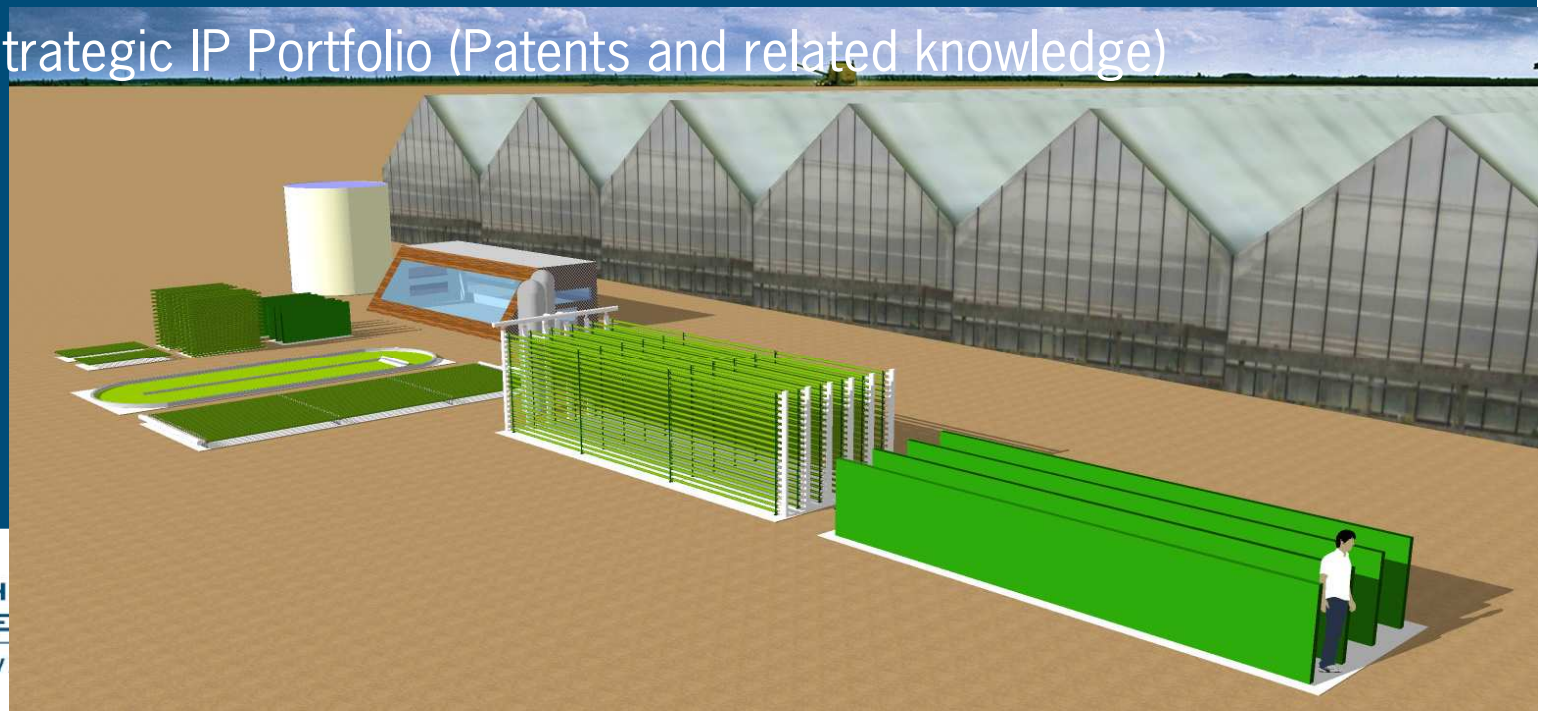
- Algae Pilot Production and Development Center
- Dutch Biorefinery Roadmap
- FP7- Biorefinery call (coordination)
- FP7-KBBE-2009-3 (Area 2.3.2: Marine and Fresh-water Biotechnology (blue biotechnology))

Algae Pilot Production and Development Center: Why?

- Research agenda is present
- Translate research towards applications
- Need to lower biomass production costs for low value products
- Need for progress
- Need for demonstration
- No experience in practice
- Need for know how
- Fastest way to go to full scale?
- Need for intermediate phase
  - Systems
  - Process chains

Algae Pilot Production and Development Center: Objectives

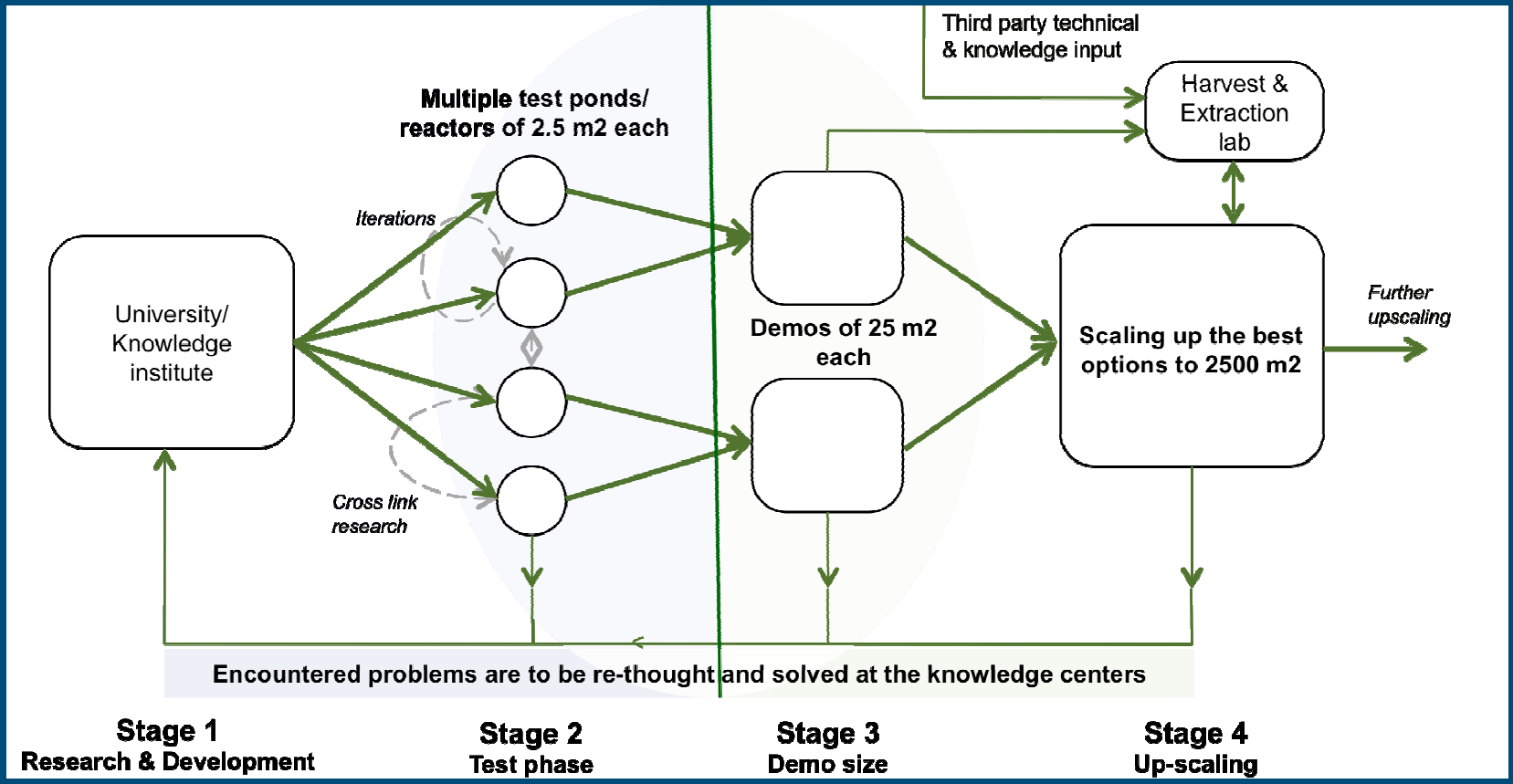
- Build up an international , open and independent centre for applied research
- Production of algal biomass for food, feed, bulk chemicals and biofuels
- Cradle to Cradle: Closing material loops - CO_2, N, P
- Technology with a positive energy balance
- Competitive technology
- To be applied in and outside the Netherlands
- Pilot as intermediate between lab and demo
- Build up a strategic IP Portfolio (Patents and related knowledge)



AGROTECH
FOOD SCIE
W

Algae Pilot Production and Development Center

From fundamental research to pre-commercial development *



WUR / WETSUS

Algae Pilot Production and Development Center

BioFuel Venture

AGROTECHNOLOGY & FOOD SCIENCES GROUP WAGENINGEN UR

*Spring Associates/WUR

Possible companies to collaborate with

- Proviron*
- Friesland Foods*
- Delta*
- Essent*
- Eneco*
- Nuon*
- DOW Chemicals*
- Syngenta*
- AF&F*
- Hubert*
- Total
- Necton (Portugal, SME Algae)
- Algaelink (NL , SME, Algae)
- Paques
- LGem* (NL, SME, Algae)
- Itochu
- Grondkapitaal*
- KLM
- VAR
- Haven Rotterdam
- Neste Oil*
- Hednesford*
- Unilever*
- Rosendaal Energy*
- Ingrepro* (NL, SME, Algae)
- Akzo*
- Grow
- STOWA*
- Waternet
- Global Foods

*ongoing collaborations

Algae Producers: Proviron, Roquette, SBAE, Aquaphyto, www.maris-projects.nl, Technogrow, SUBITEC GmbH (Duitsland)

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Algae Pilot Production and Development Center: layout

- Research plan and Contract Research
- 4 outdoor systems of 25 m^2 each
  - Open pond: reference
  - Horizontal tubular system: high light intensity, oxygen accumulation
  - Vertical tubular system: low light intensity, oxygen accumulation
  - Flat panel system: low light intensity, no oxygen accumulation
- 4-8 systems of 2.5 m^2
- Specific requirements: extra systems
- In greenhouse?

AGROTECHNOLO
FOOD SCIENCES
WAGENI

Algae Pilot Production and Development Center

Strong points

Uniqueness - 4 different systems that can run in parallel (minimum)

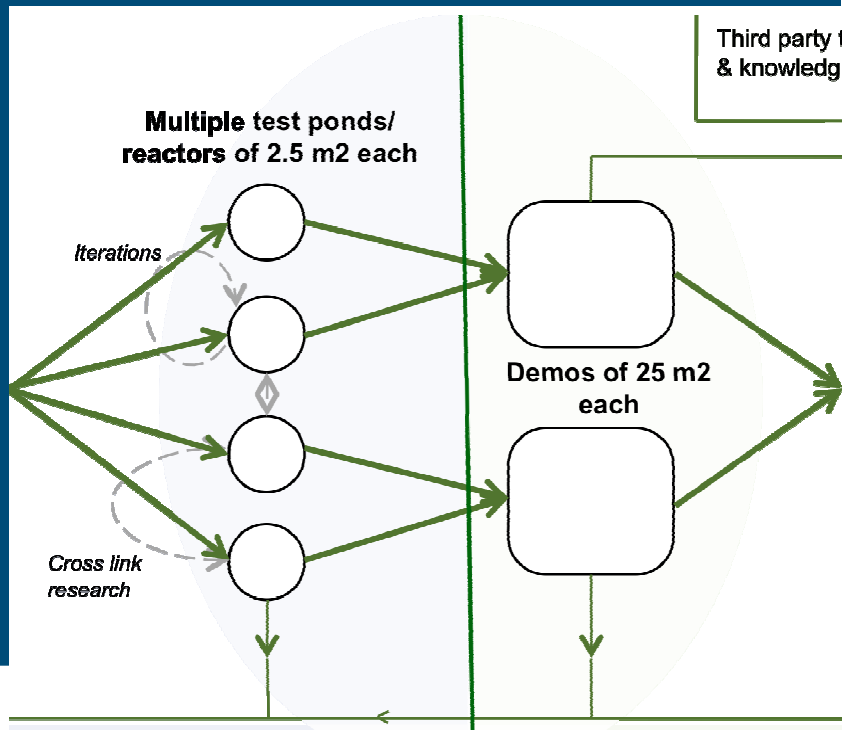
Fundamental aspects for successful operation and scale up of photobioreactors to commercial plants

Control Units: accurate online measurements and control of a wide range of metabolic and environmental parameters

Flexibility: The reactors should be easily changeable to allow fast testing of different systems

Research Programme

- Development of a process chain
- Experience with systems
- Comparison of systems
- Information for design of full scale plants
- Comparison of strains
- Comparison of feeds (nutrients, CO_2, sunlight…)
- Supply of biomass for further processing
- Further processing



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Research Programme

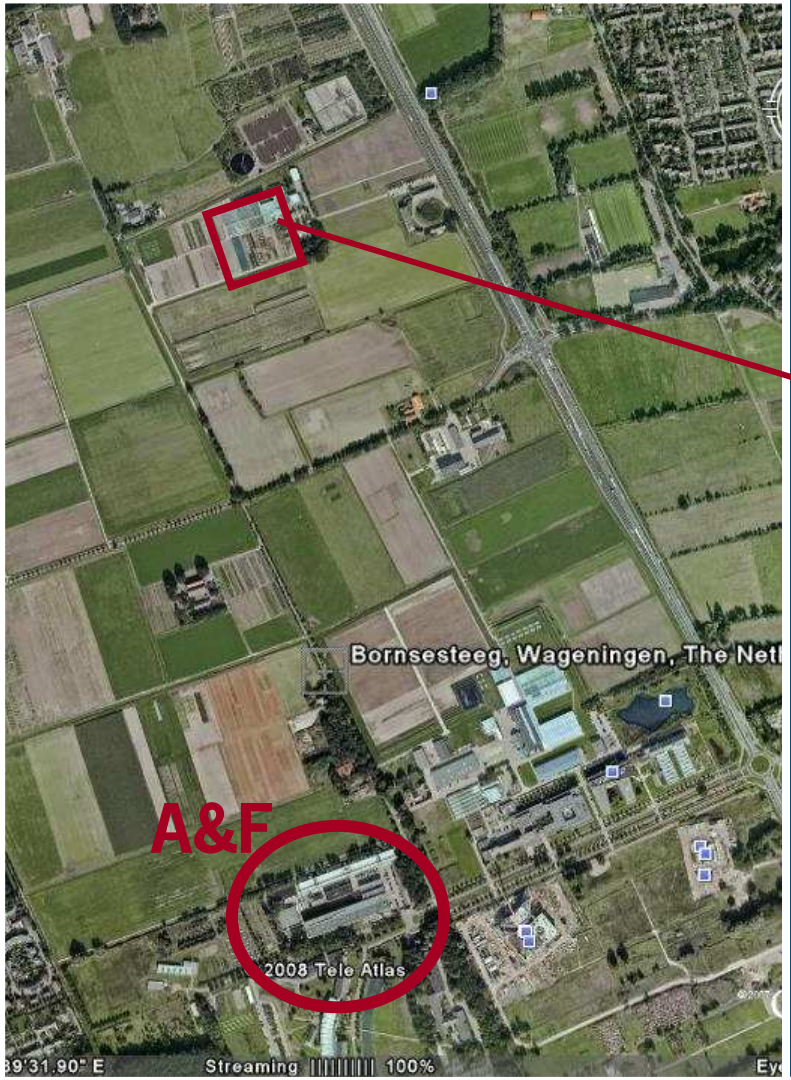
- Comparison of feeds

CO_2 – Power plants, biogas installations, fermentative processes

P – wastewater treatment, by products from chemical companies

N – wastewater treatment, digestate from fermentative processes

Location



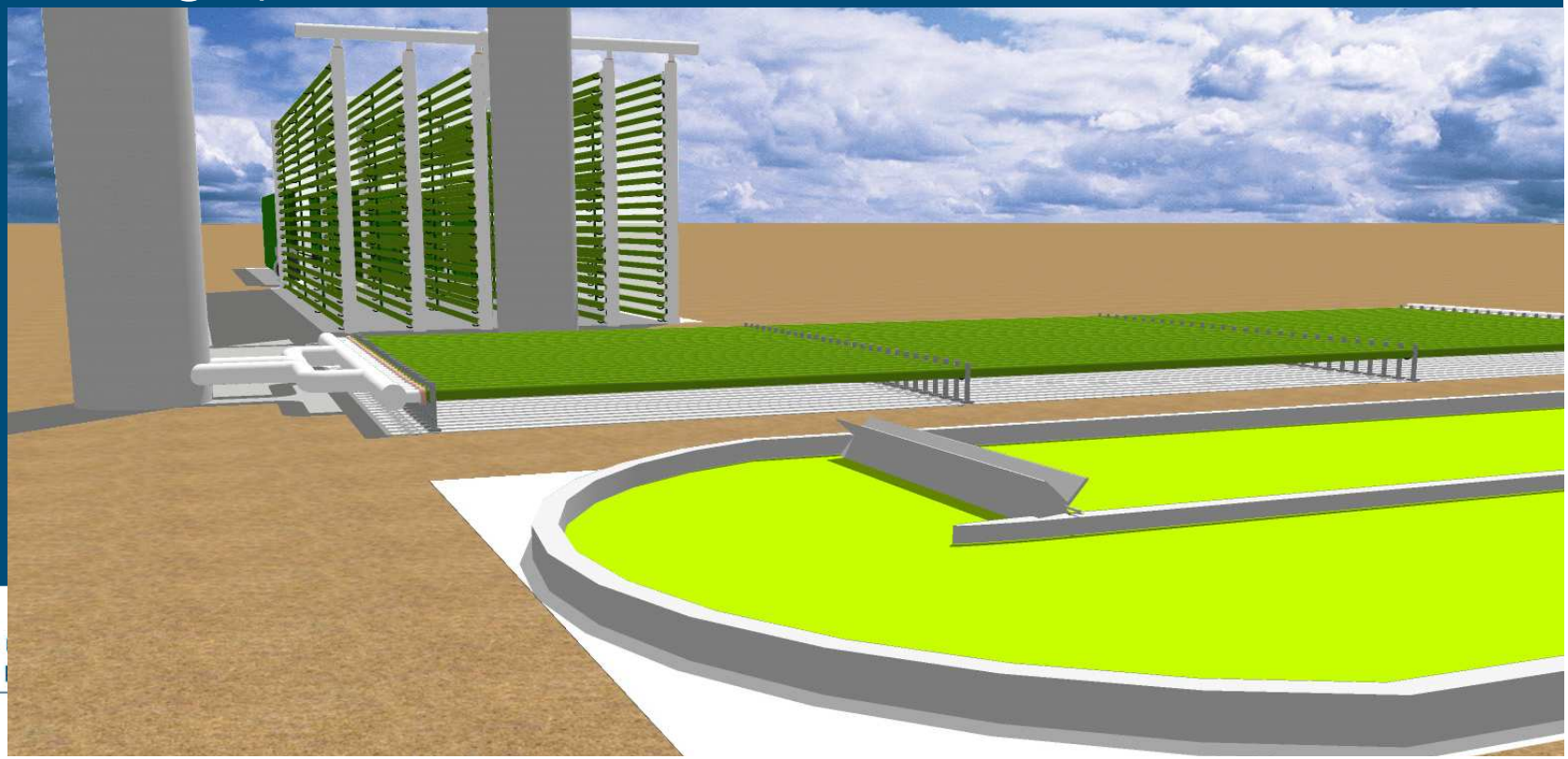
AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

The pilot facility

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

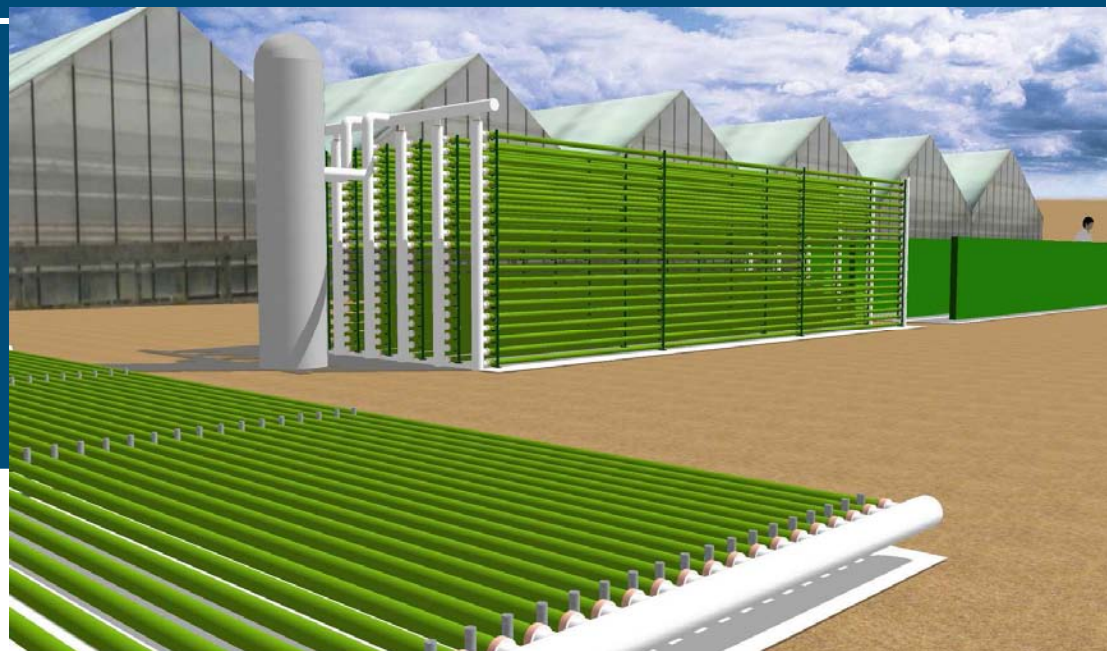
25 m^2 systems

- Long time performance (1 year)
- 4 systems run parallel
- Problems: solve in lab
- Representative productivities for full scale
- Information for design of full scale plants (Layout, Distance between tubes or plates, Light path, Orientation)



General reactor parameters

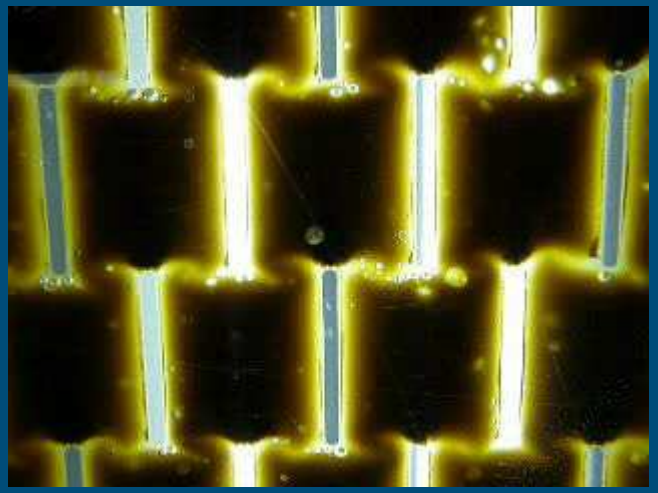
	Horizontal Tubular	Vertical Tubular	Flat panel	Open pond
Photosynthetic Efficiency on solar (%)	3	5	5	1.5
Production capacity (Kg / year)	99.4	165.6	152.7	49.7
Culture volume (m3)	1.0	1.9	2.0	4.8
Volumetric Productivity (g/L/h)	0.024	0.022	0.017	0.002



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

2.5 m^2 systems

- Phase between lab and pilot
- Test things where you are not sure of
- Different strains
- Different feed stocks
- Adaptations in design
- New systems
- If successful
  - To 25 m^2 scale
- If not successful
  - More experiments
  - Reject



Time Schedule

- Funding Commitment and Contracts Q1 & Q2 2009

Governmental subsidy + Industry participation
(200 k€ /company / 4 years)

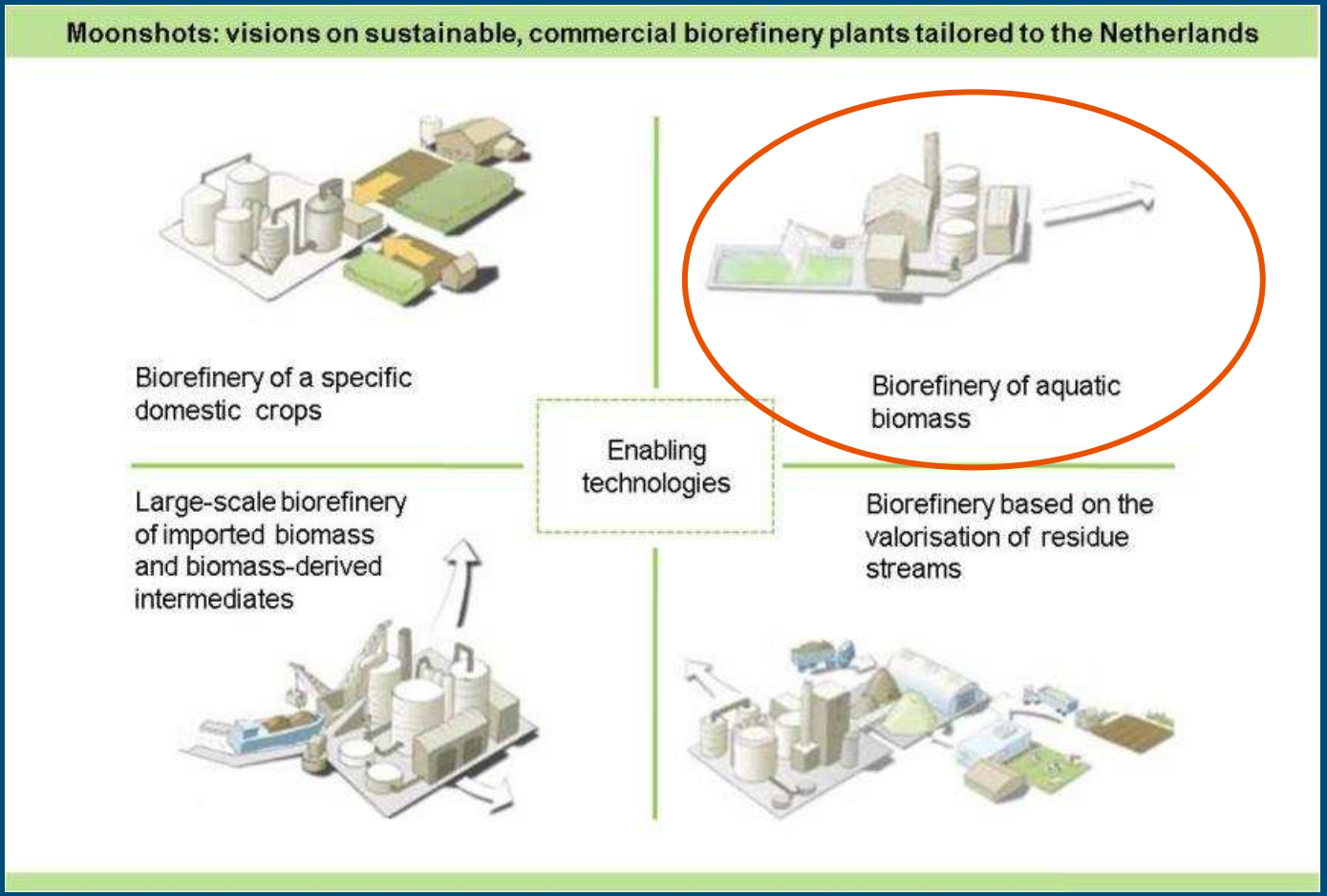
- Building pilot facilities Q4 2009
- Commence Research Programme Q1 2010

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Benefits for partners

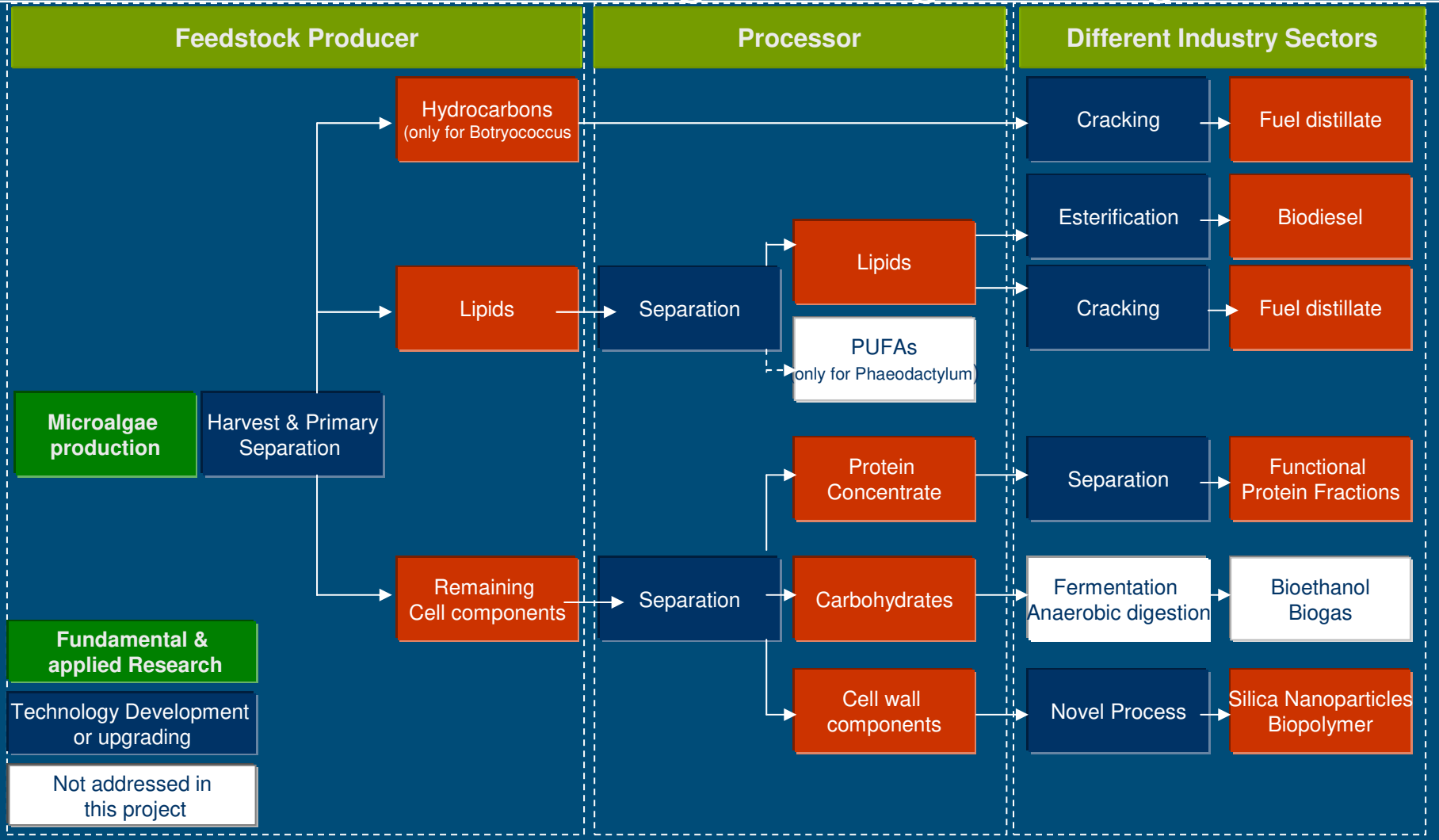
- *Industry*: A solution to the present queries, development of new processes and products, IPR
- *Government*: An international high quality research centre which will provide for economical spin-off of the region. Further establishment of The Netherlands as a knowledge based economy by the development of innovative and sustainable biobased processes and products.
- *Wageningen UR*: Increase the expertise. Ambition to contribute to developments in society.

Initiatives for the future: Dutch Biorefinery Roadmap



Initiatives for the future: LG-SMART (EU FP7)

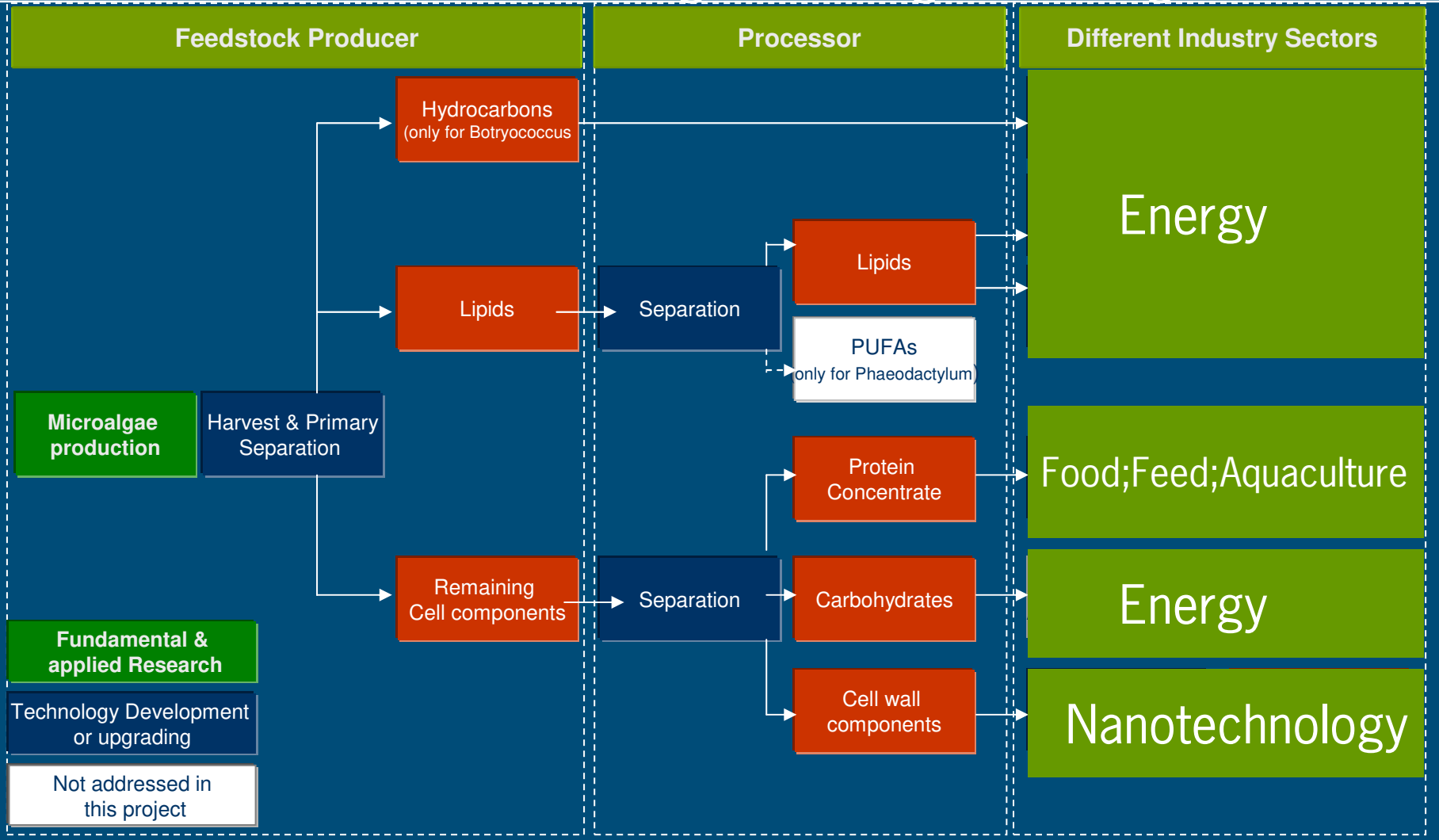
Let's Get Smart with Micro-Algae Refining Technologies



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Initiatives for the future: LG-SMART (EU FP7)

Let's Get Smart with Micro-Algae Refining Technologies



AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Thank you for your attention

AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR