Energy efficiency and economics of the production of microalgae biomass with a flat panel-airlift photobioreactor

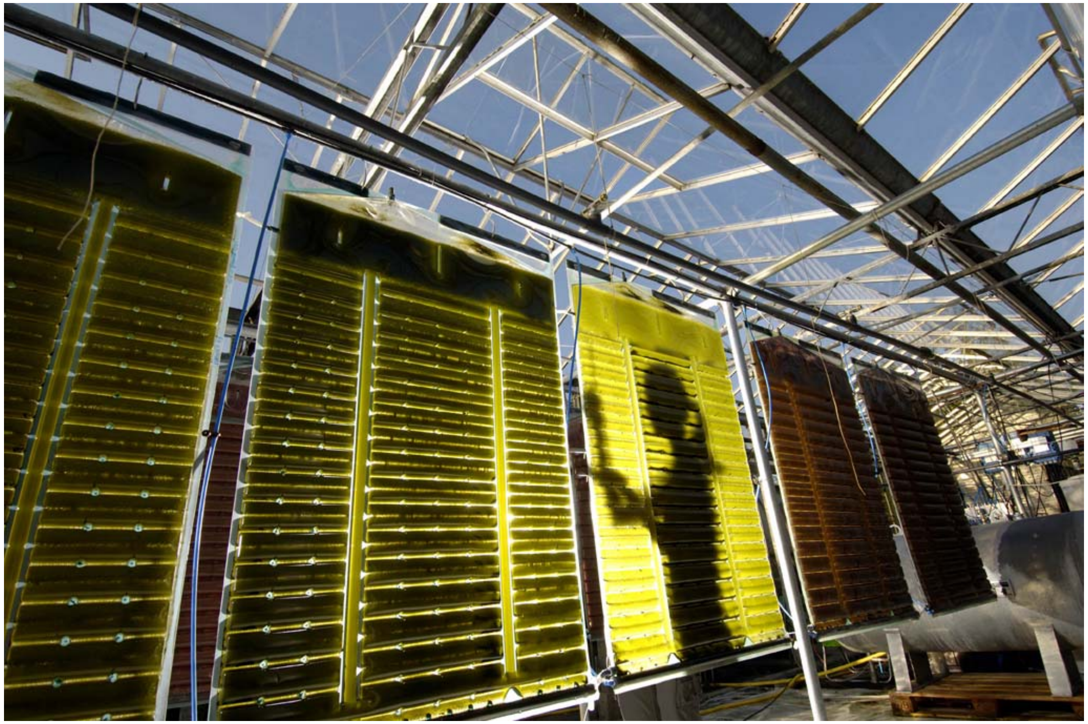
Dr. Peter Ripplinger

Subitec GmbH

Content

- Subitec GmbH: the company
- Flat Panel Airlift (FPA) – Photobioreactor
- Pilot plants
- Integrated production process including Biorefinery
- Comparison of different production systems
- Economics of biomass production in industrial scale
- Summary

Subitec GmbH: the company



Pilot plant, Subitec GmbH, in Stuttgart-Vaihingen (2005)

Subitec GmbH: the company

- Spin-off from the „Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik“ (IGB) in Stuttgart
- Two patent families regarding the Flat Panel Airlift-Photobioreactor granted wordwide
- Pilot plants with E.ON Hanse AG (in Hamburg) and EnBW AG (near Stuttgart)
- Projects funded by DBU (Deutsche Bundesstiftung Umwelt) the state Baden-Württemberg

Position in the value chain

Product development with academic and industrial partners

Cultivation

- Development of Photobioreactors
- Process optimization
- Engineering of production plants

Downstream processing

- Harvesting/Separation
- ulping
- Extraction
- Conversion

Products

- Pharma
- Cosmetics
- Food supplements
- Feed
- Energy

Subitec
Core competence

Subitec with industriell
and academic partners

Markets

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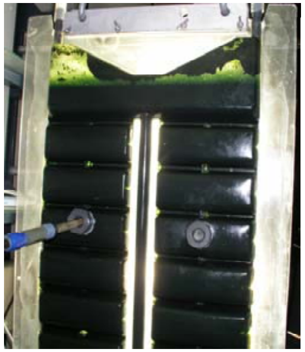
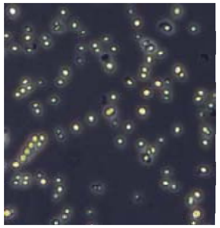
Products and Services

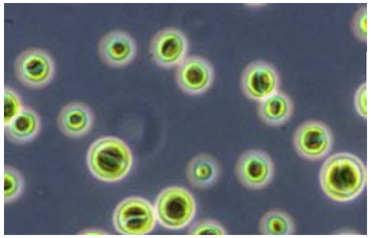
- Systems for the cultivation of microalgae based on 5 L, 9 L, 33 L und 180 L-FPA-Reactors
- R&D partner for biorefinery concepts based on algae biomass
- Production of algae biomass for the cosmetic and pharma industry and for product development

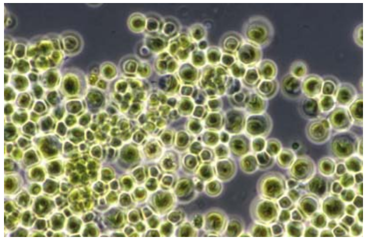
Microalgae cultivated in the FPA-Reactor

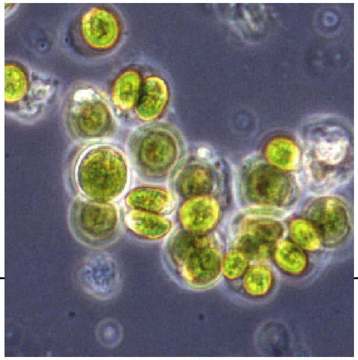
	Lab scale	
Marine algae	max. DW (g/l)	ø Prod. (g DW/l*d)
Isochrysis spec. (clone T.iso)	10	0,5
Nannochloropsis oculata	13	1
Tetraselmis suecica	16	0,6
Platymonas subcordiformis	12	0,5
Other algae (sweet water)		
Chlorella vulgaris	12	0,8
Chlorella sorokiniana	12	1,3
Eigenisolat DSN 5.1	16	0,7
Haematococcus pluvialis	2,5[a]	0,5
	5[b]	0,3
Phaeodactylum tricornutum	25[d]	1,5
	12[e]	0,9











Flat Panel Airlift (FPA) – Photobioreactor

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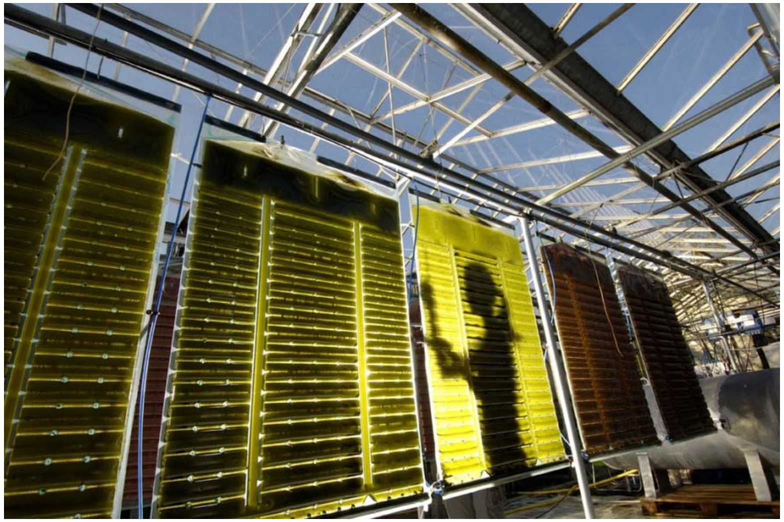

Pilotanlage der Subitec GmbH in Stuttgart-Vaihingen (2005)

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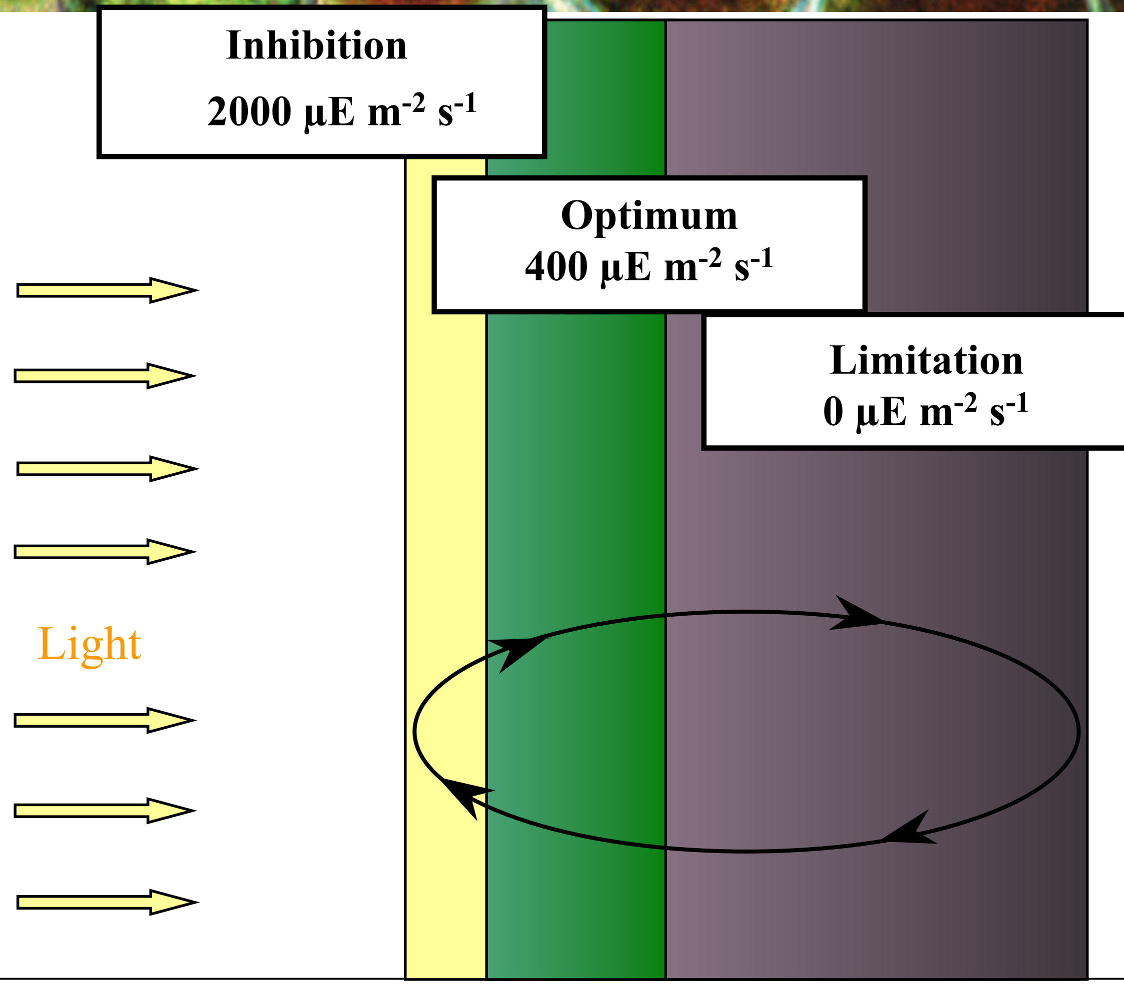
Light supply in dense algae cultures

Problems:

- Inhibition of photosythesis
- Optimal light intensity is 5 to 10-fold lower than the natural light intensity
- Limitation due to dense cultures

Solution:

- Continous transportation of the algal cells through the different zones
- Use of the „flashing light effect“



Reaktorquerschnitt

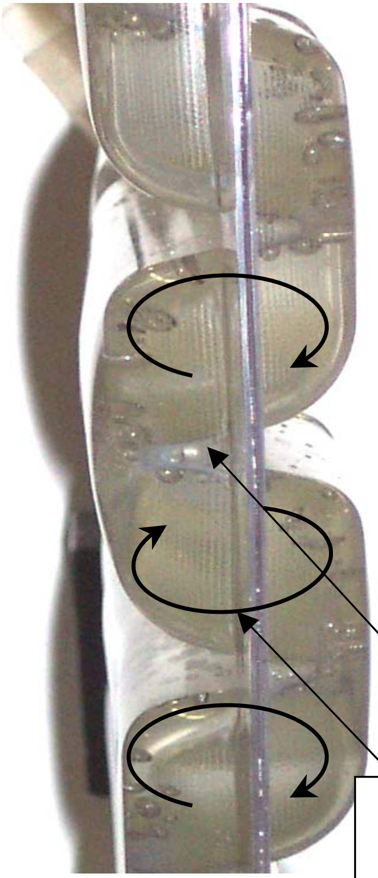
FPA technology

Process engineering

- efficient light supply to all cells
- complete homogenious intermixing
- low mechanical stress to the cells
- simple temperature and pH control
- efficient gas exchange

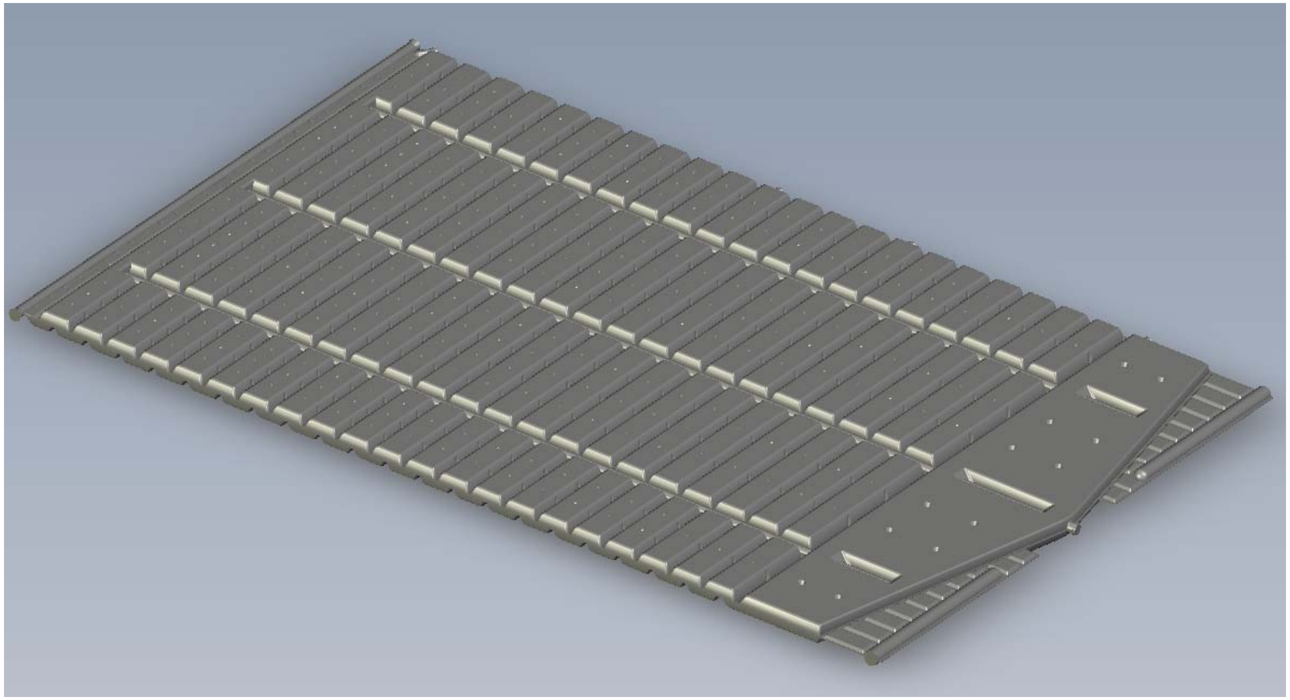
Cost-effectiveness

- high volumetric productivity
- high cell densities
- high reactor volumes
- low capital and operating costs
- high reliability



Halfshells of the FPA made from deep-drawn plastic sheets

FPA-Reactor, 3. Generation (2008)



Technical data:				
	Hights	270 cm	Volume	180 l
	Lengths	175 cm	Material	PVC or
	Thickness	5 cm		PETg

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Advantages of the new FPA - Reactor

- Reduction of production costs of the bioreactor (ca. 1.000 €/m³)
- Could be used over a 5 year period (new materials)
- No problems with leakages (Twin-Sheet technology)
- Reduction of the energy consumption (from 477 W/m³ to 100 - 200 W/m³)

Pilot plants

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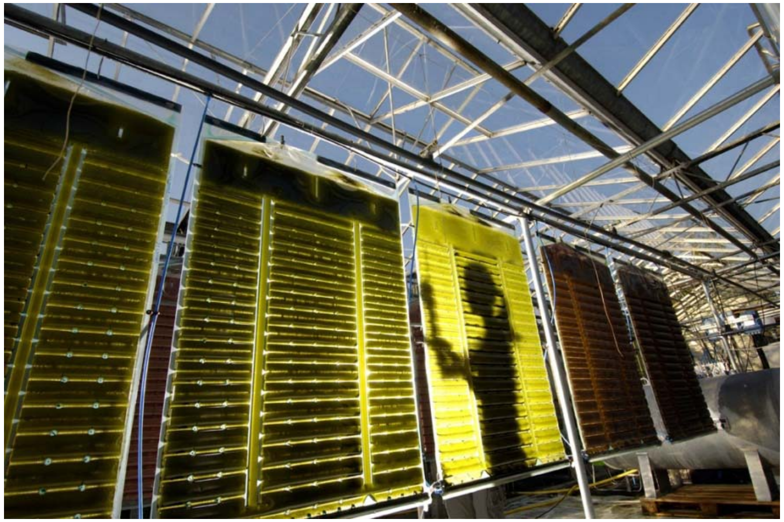

Pilotanlage der Subitec GmbH in Stuttgart-Vaihingen (2005)

Pilot plants

since 2005: Pilot plant in Stuttgart-Vaihingen, based on 33 L-Reactors for the cultivation of Haematococcus and Phaeodactylum

May 2008: Start of the pilot plant in Eutingen-Weitingen
Multipurpose plant, based on 180 L-Reactor,
Total volume: ca. 4 cbm

June 2008: Start of the pilot plant in Hamburg-Reitbrook,
two modules with 4 x 180 L-Reactors

2009: Pilot plant in a greenhouse (4 modules of 6 x 180 L-Reactors),
Production plant with 180 cbm total volume,
ca. 0,5 – 0,7 ha, in Spain

Flow chart – production modul

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Pilot plant in Eutingen-Weitingen (2008)

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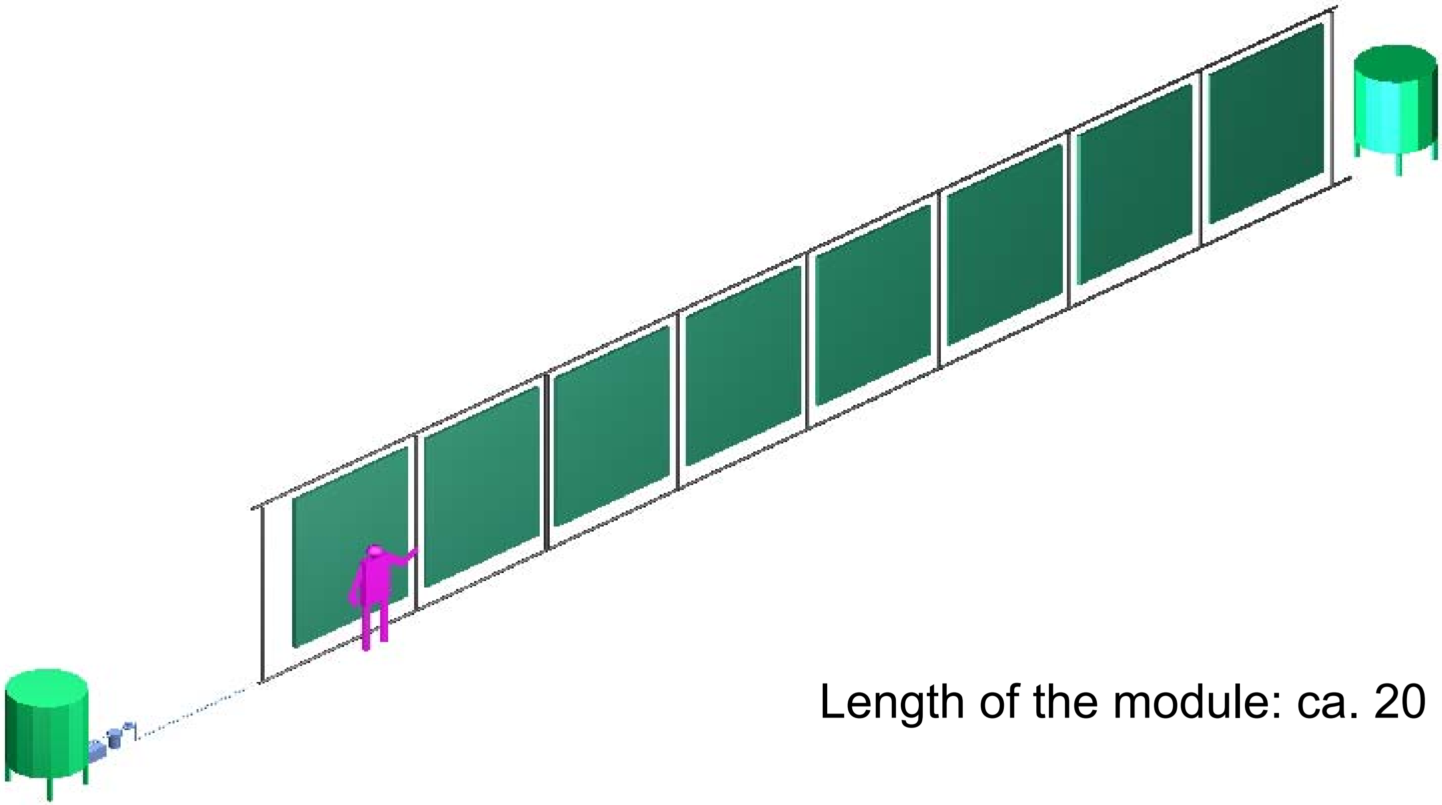
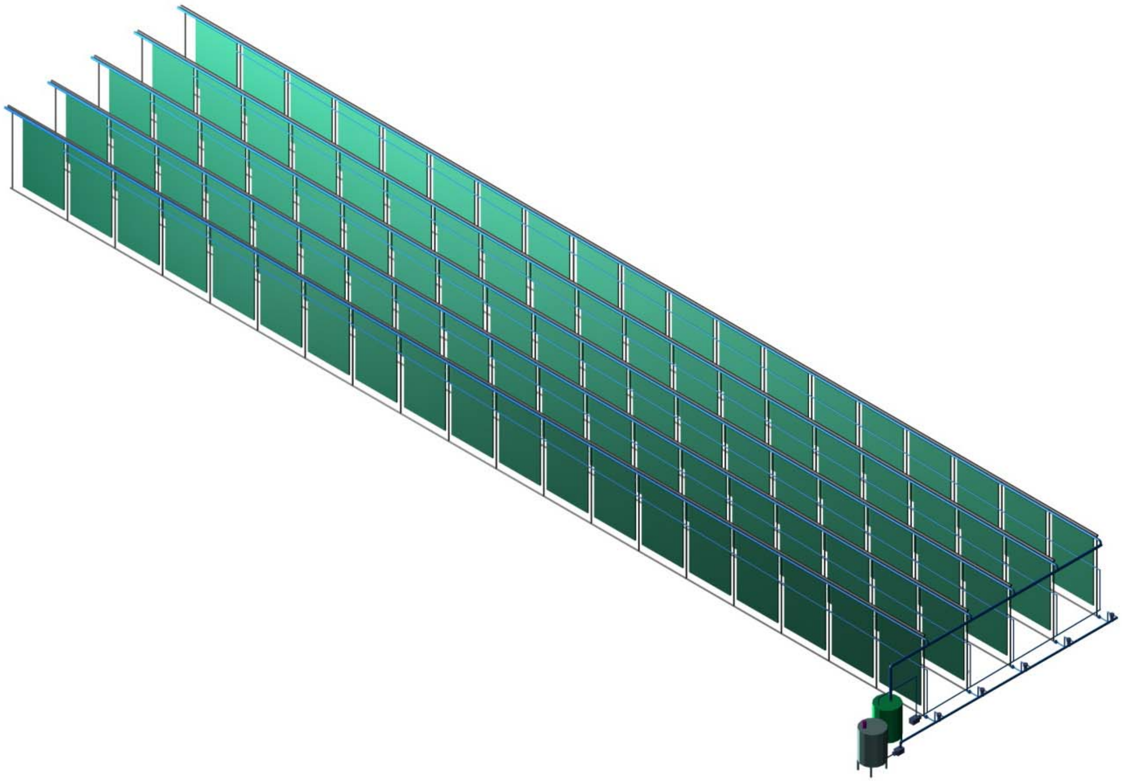
Pilot plant in Hamburg-Reitbrook in cooperation with E.ON Hanse (2008)

Modul with 8 x 180 L FPA reactors

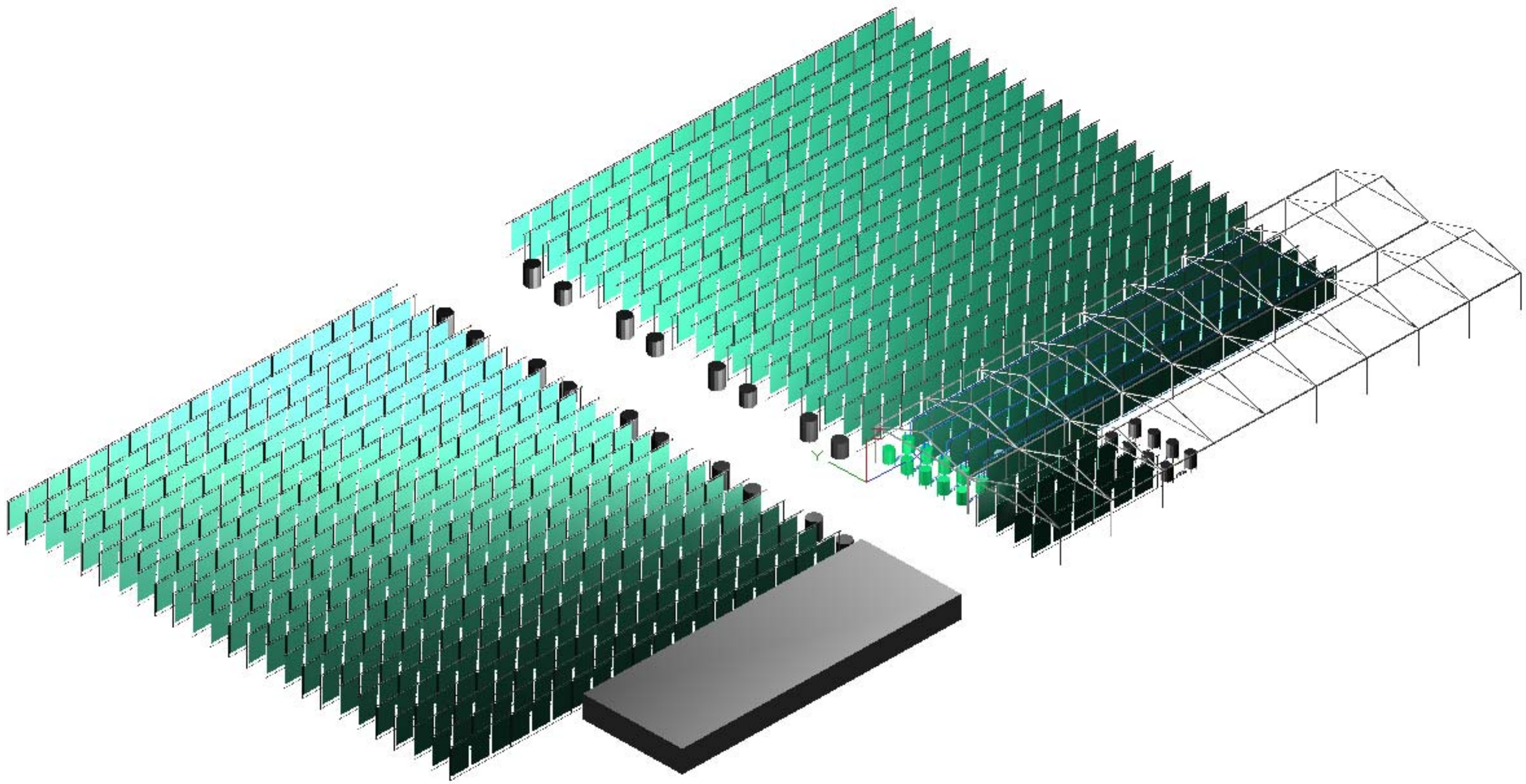


Length of the module: ca. 20 m

Sceme of a 5 x 20 module



Pilot plant in Spain (180 m³)

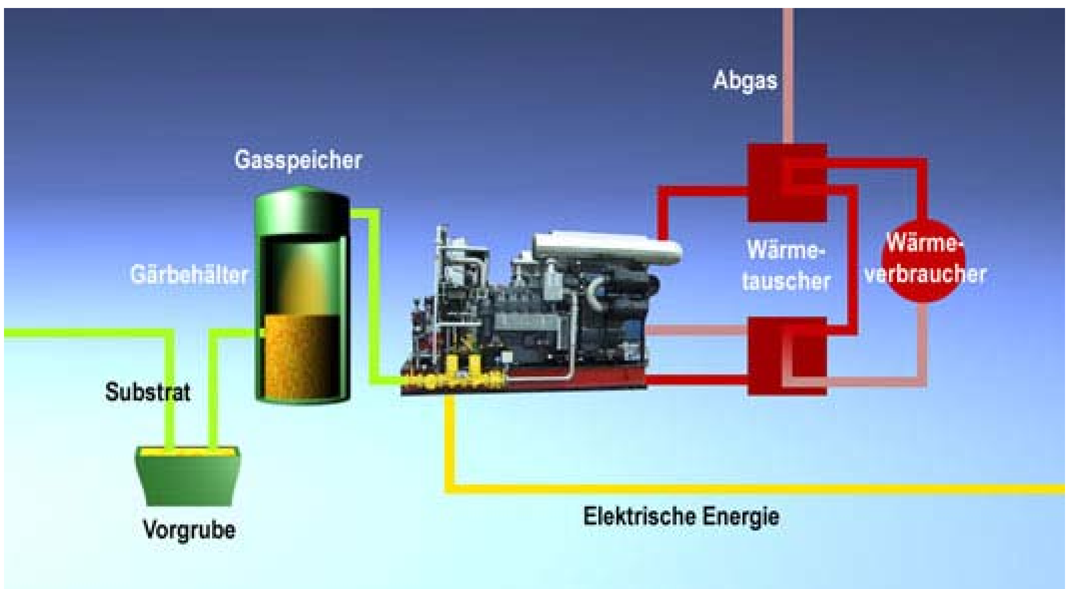


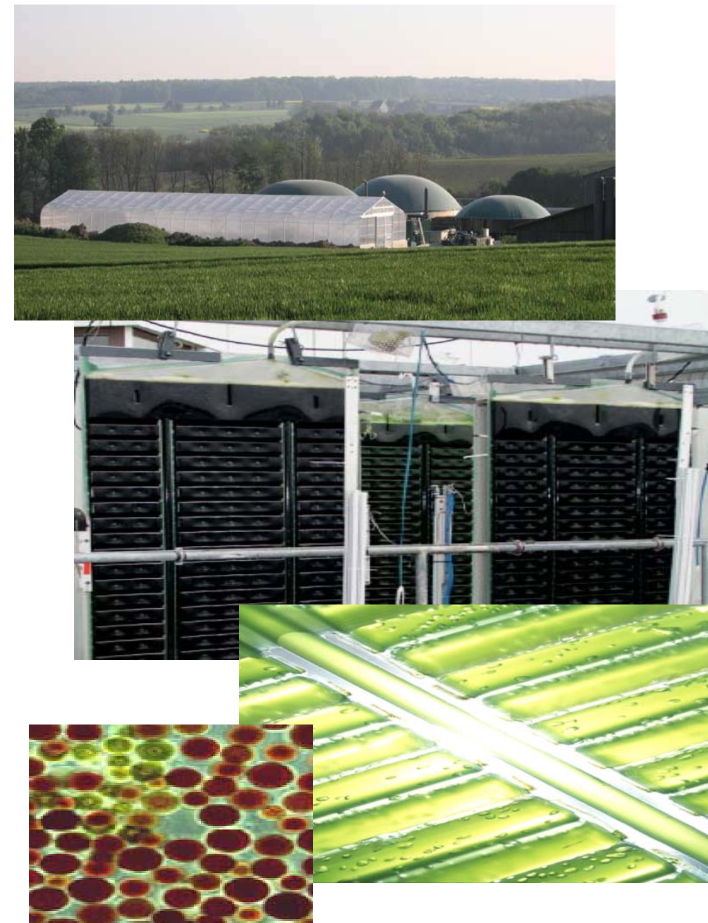
Basic process of the pilot plants

CHPs

•in Hamburg: natural gas
•In Eutingen-Weitingen: biogas

Cultivation of microalgae





Integrated production process including biorefinery

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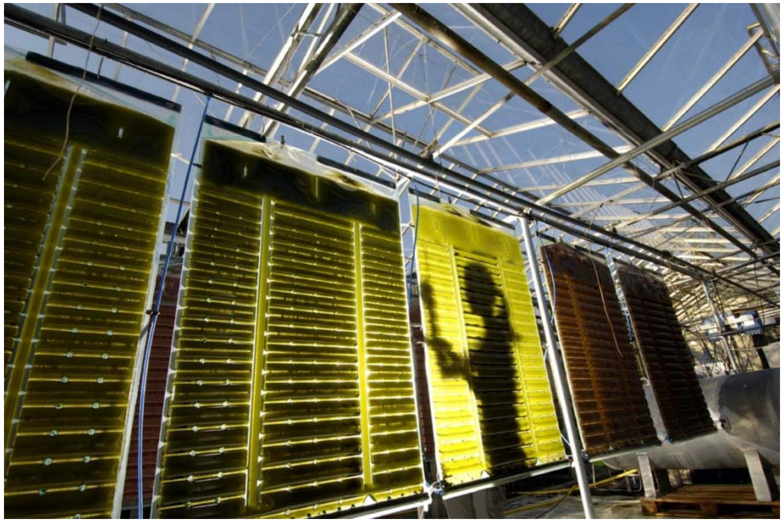
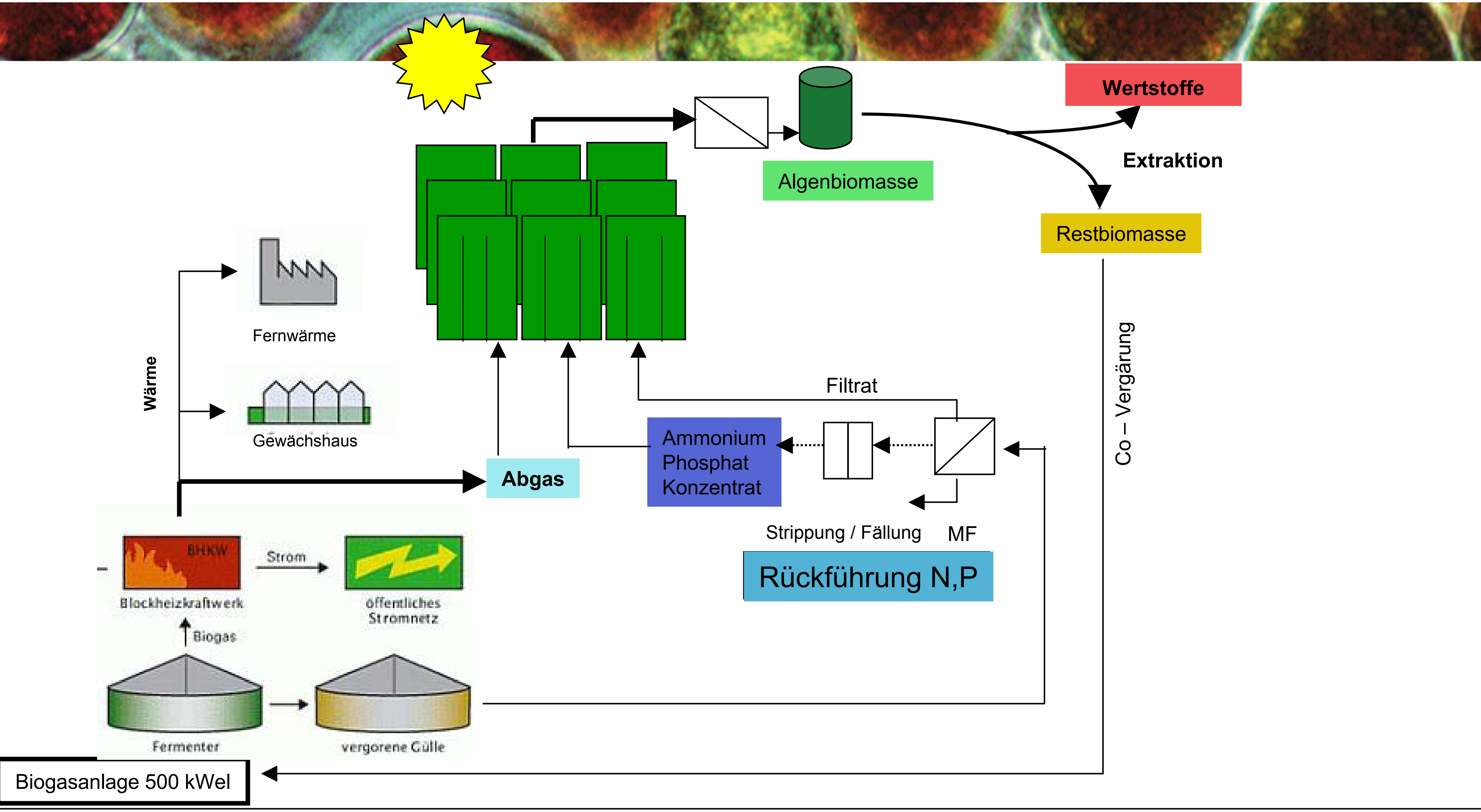
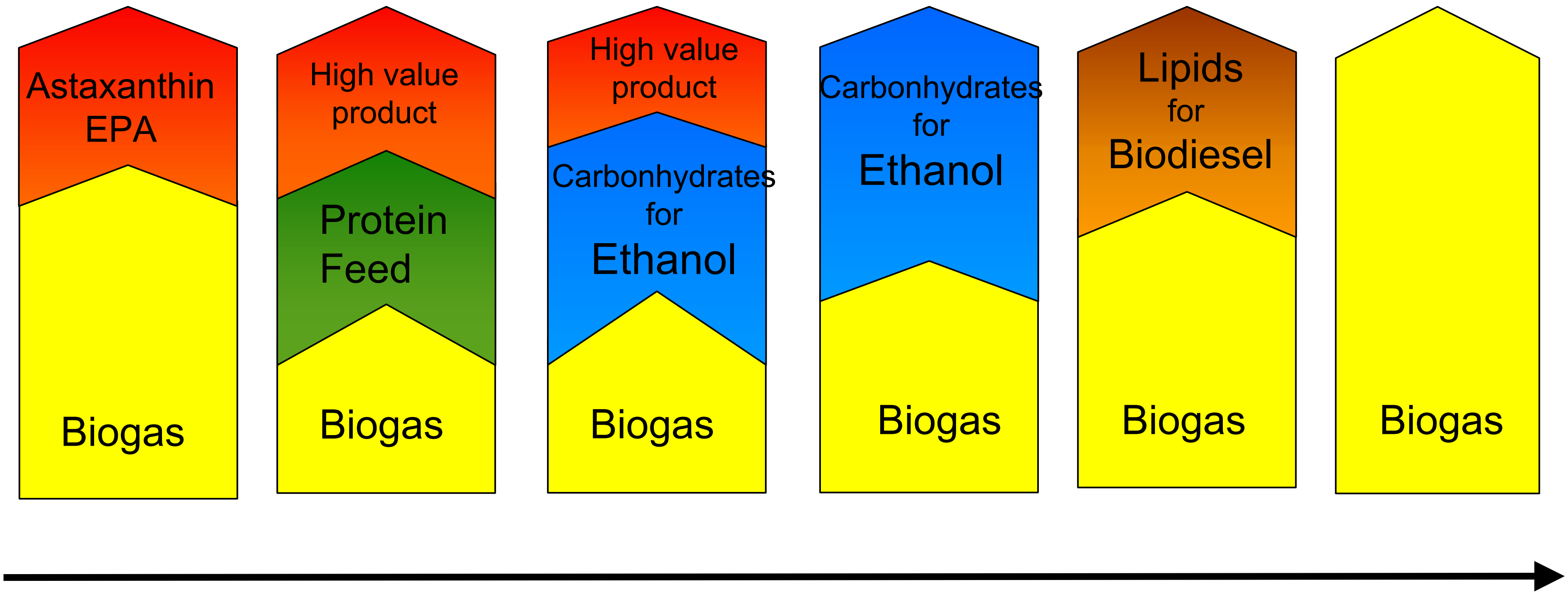


Pilotanlage der Subitec GmbH in Stuttgart-Vaihingen (2005)

Integrated production process for microalgae biomass

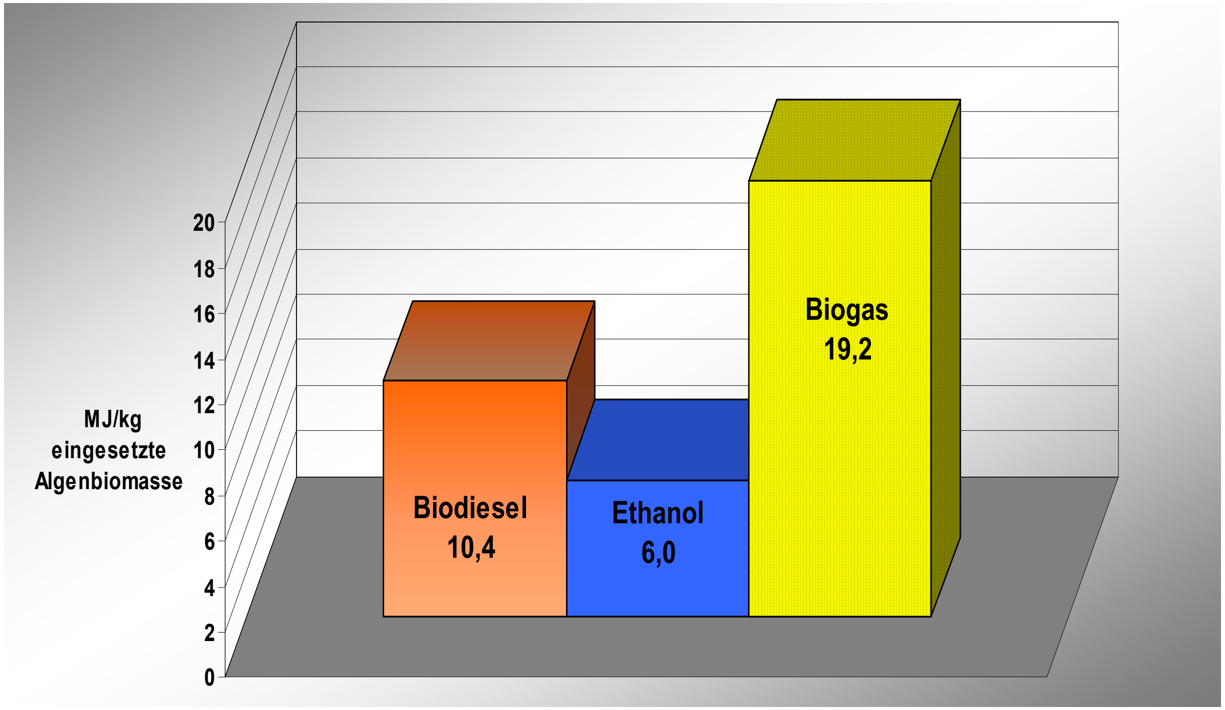


Biorefinery concepts for algae biomass



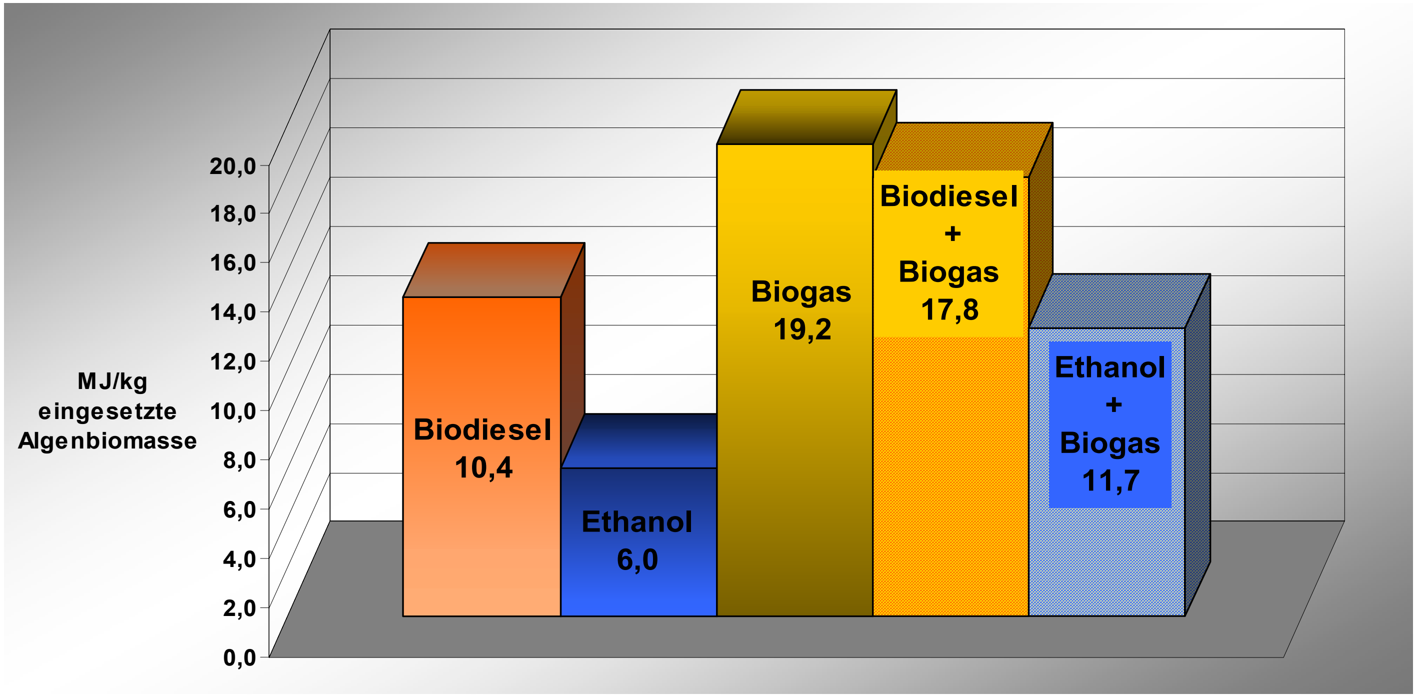
increasing energetical usage

Total energy content of products derived from 1 kg algae biomass



- 35 % of lipids to produce 0,35 kg FME
- 50 % of carbonhydrates to produce 0,225 kg of ethanol
- 0,8 m³ of biogas derived from 1 kg dry algae biomass

Total energy content of product derived from 1 kg algae biomass



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Comparison of different production systems

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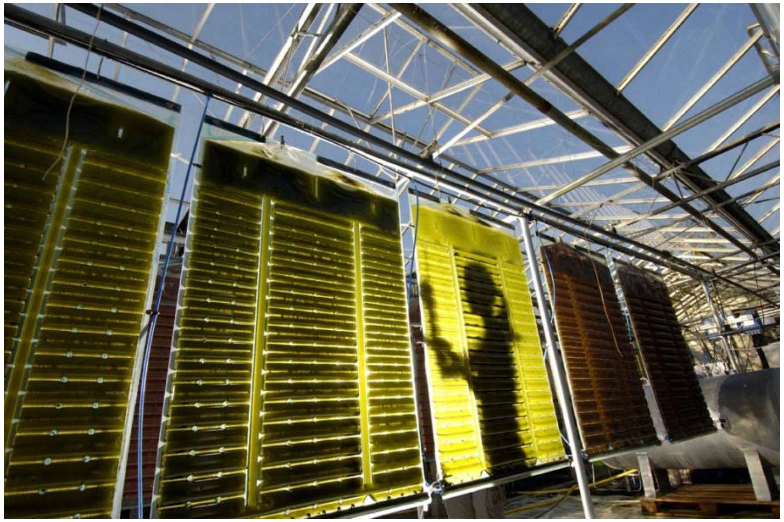

Pilotanlage der Subitec GmbH in Stuttgart-Vaihingen (2005)

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Is net energy production achievable?

Energy content of algae biomass

- energy input for cultivation

Net energy production ???

Comparison of different culture systems

	Open ponds	Tubular	Flat-Panel-Airlift-Reaktor (FPA)
Risk of contamination	high	low	low
Volumetric productivity	low	medium/high	high
Cell density	very low	medium/high	high
Energy input	low	high	low
Capital costs	low	high	medium

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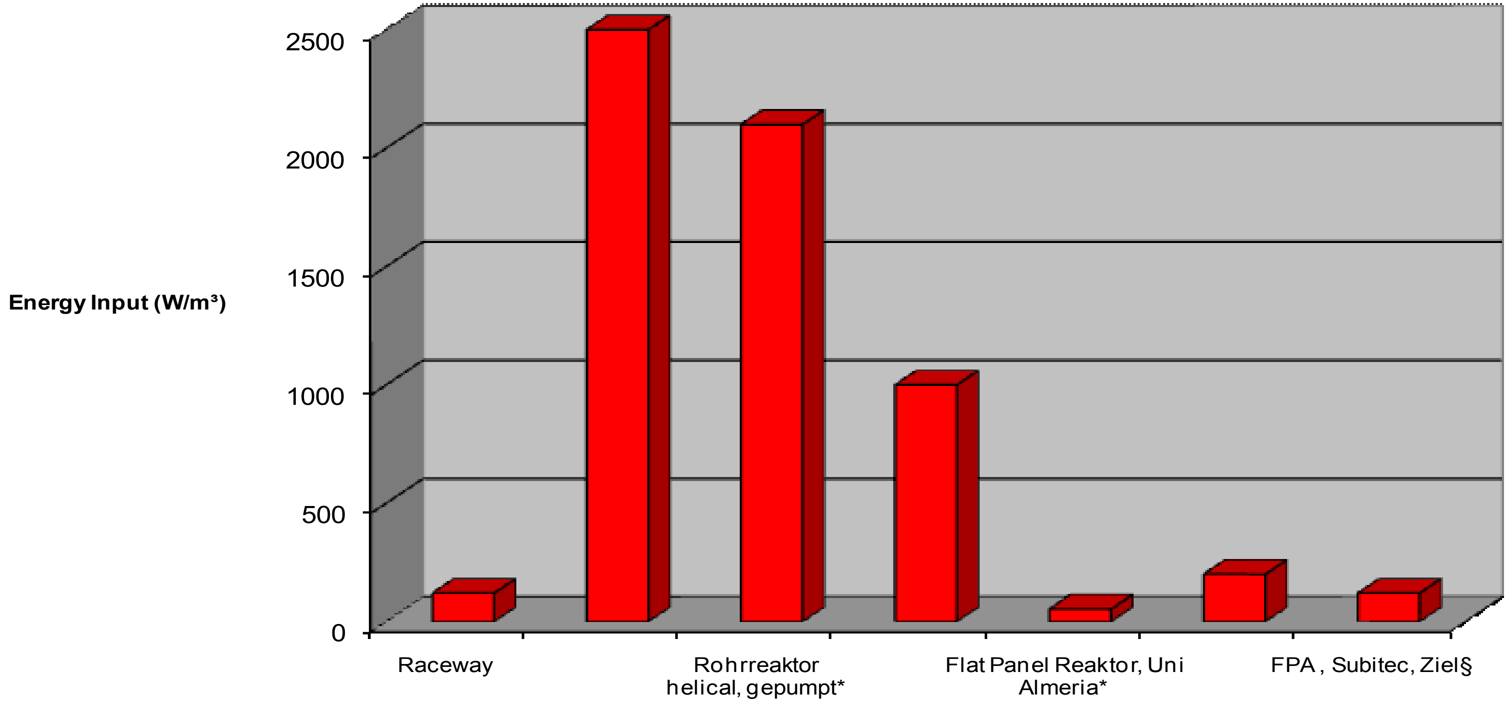
Comparison of the energy input of different production systems

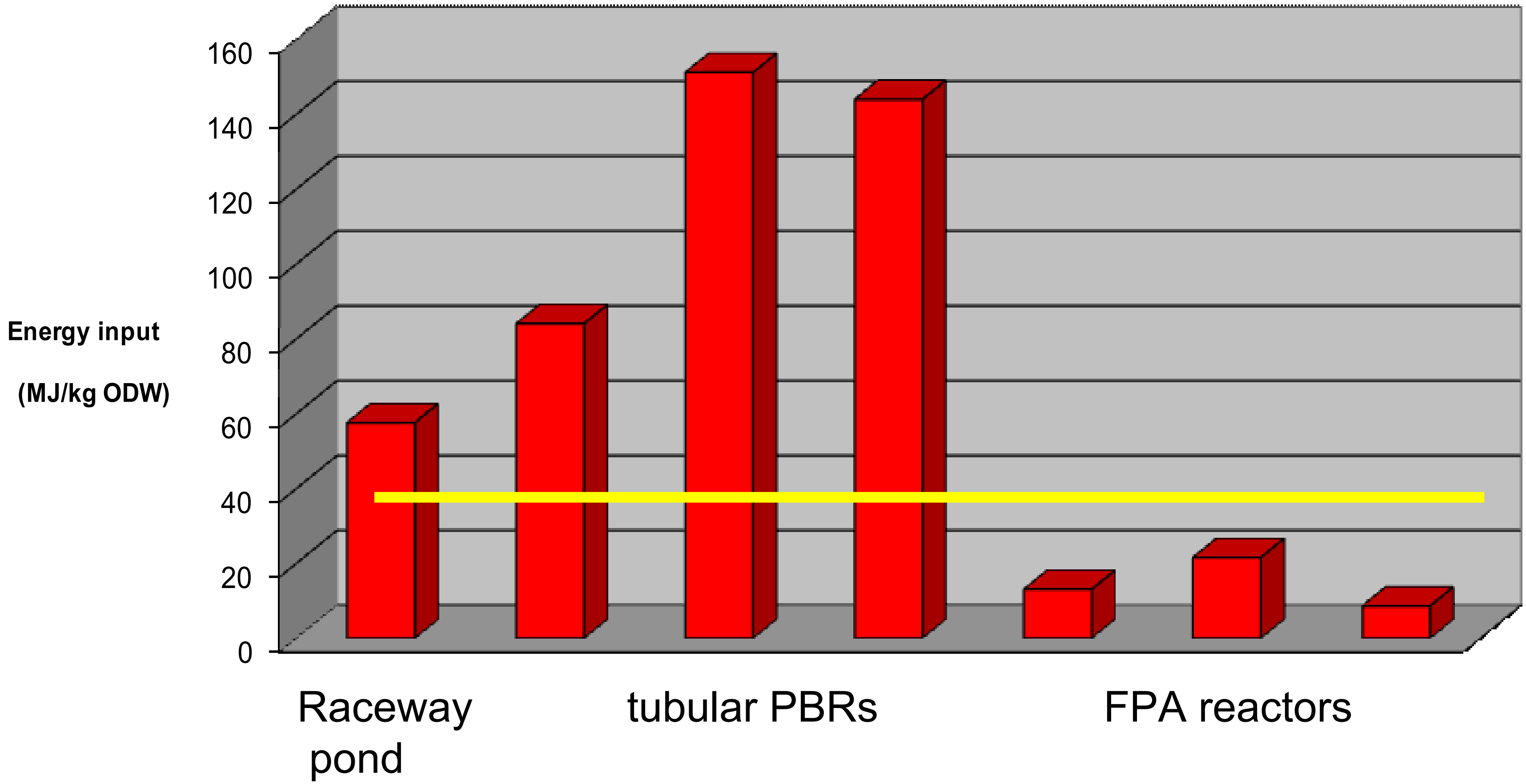


* Daten aus Sierra et al. 2007

** abgeschätzt nach Angaben Pumpenleistung, IGV

§ Angaben für 165 L-FPA

Comparison of the energy input per kg DW of different production systems



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Net energy production is achievable!

It can be proven
that a net energy production is only achievable with
a Flat Panel Airlift-Bioreactor system.

Pressure losses for the FPA-System

Total working pressure = Sum of partial pressure losses

Compressor → Tubing → Sterile filtration → Membrane → Water pressure → Exhaust gas

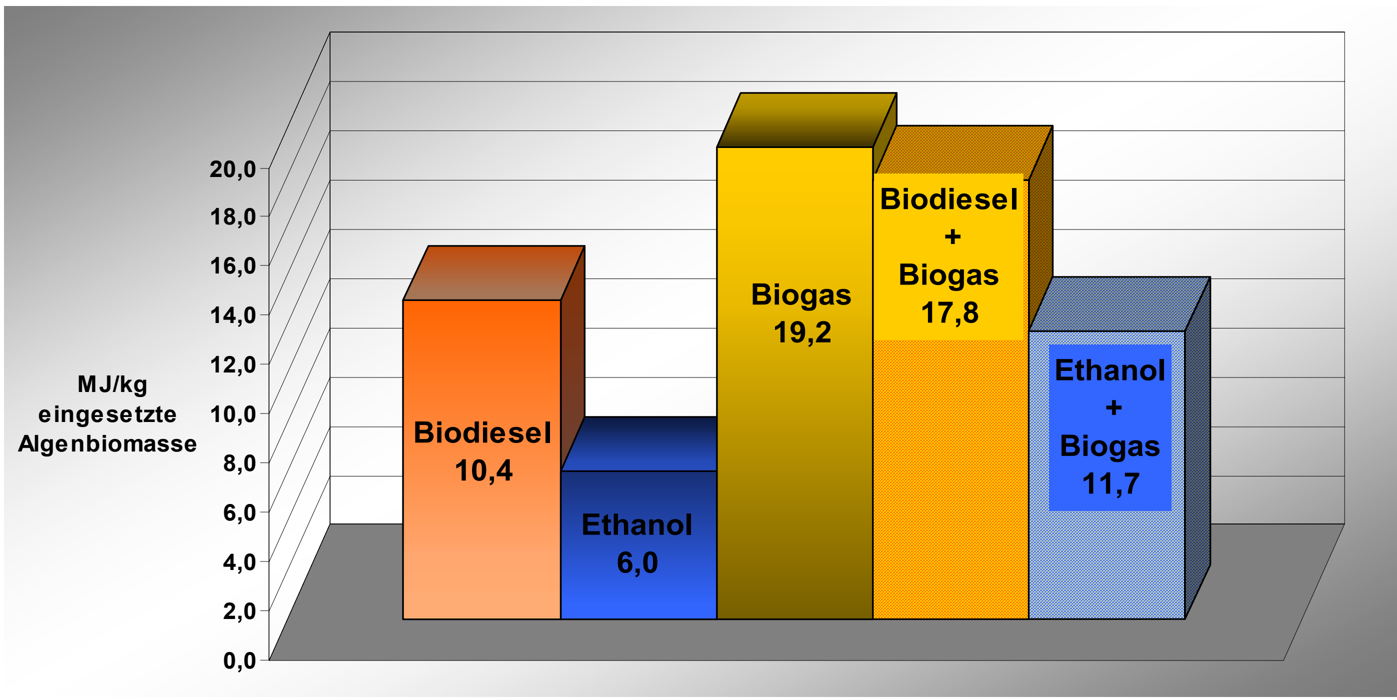
Tubing	Sterile filtration	Membrane	Water pressure	Exhaust gas
< 50mbar	ca. 150 mbar	250 mbar	262 mbar	100 mbar

Energy Input: 100 – 200 W / m³

Possible optimisations:

1. Membrane
2. robust algae cultures / mixed cultures
3. Use of industrial processes, which deliver CO_2 under pressure
4. Airflow adapted to light intensity/actual productivity

Total energy content of product derived from 1 kg algae biomass



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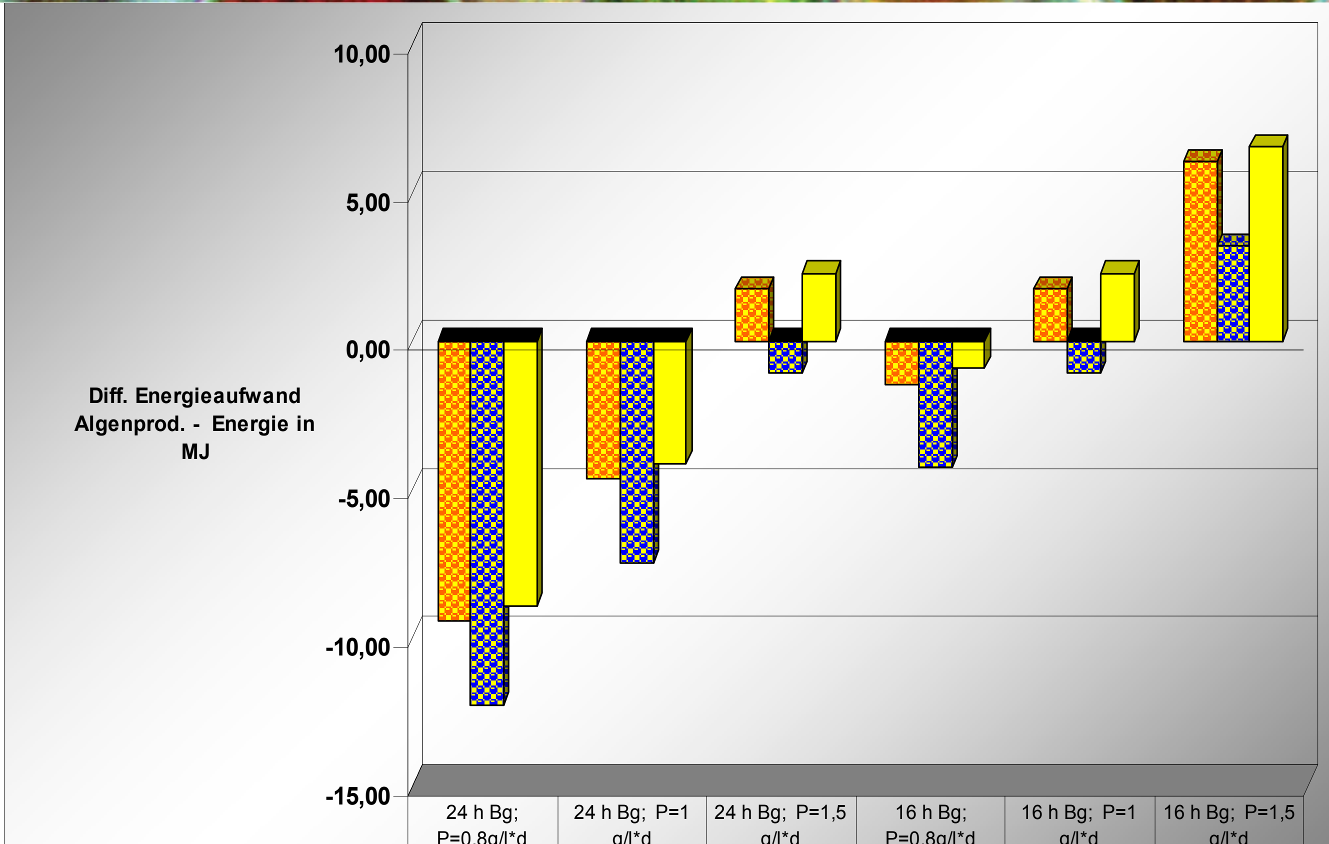
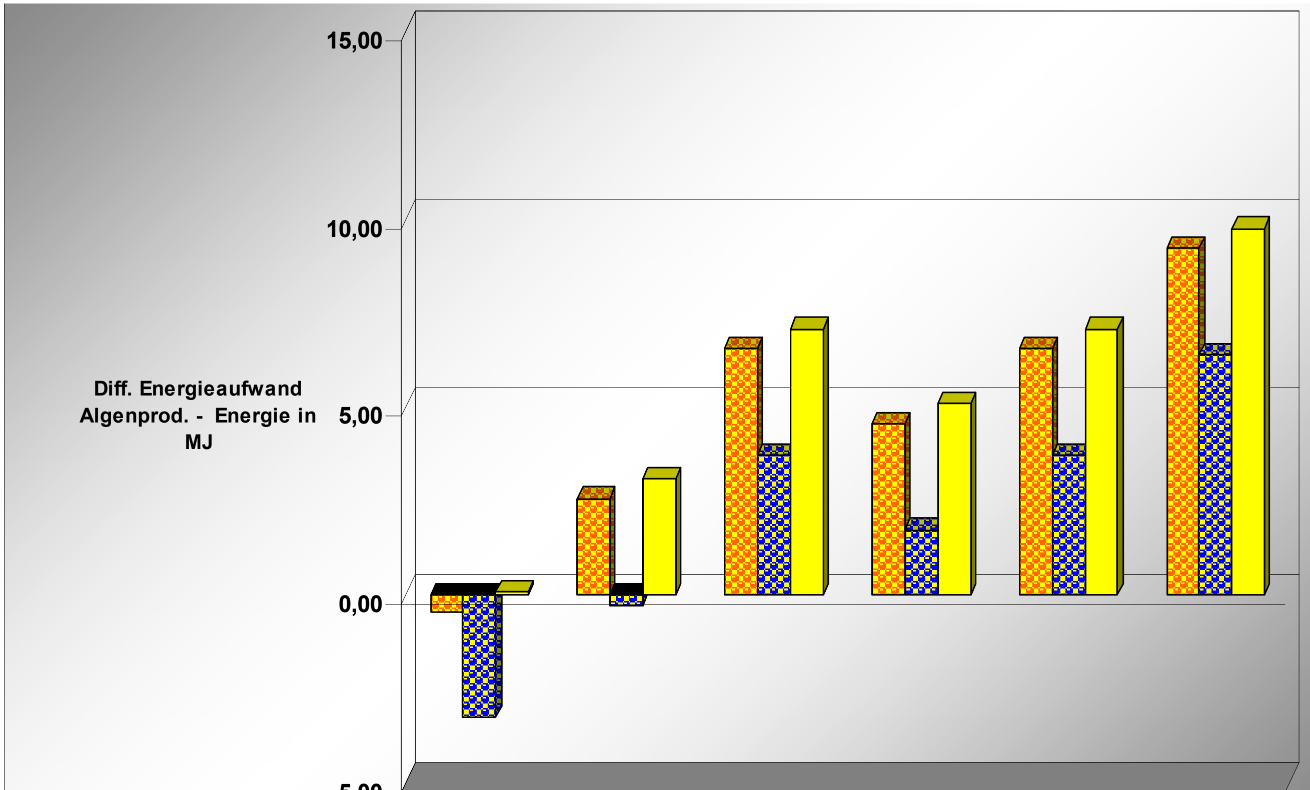
Net energy gain with FPA at 0,8 bar working pressure



	24 h Bg; P=0,8g/l*d	24 h Bg; P=1 g/l*d	24 h Bg; P=1,5 g/l*d	16 h Bg; P=0,8g/l*d	16 h Bg; P=1 g/l*d	16 h Bg; P=1,5 g/l*d
Nettoenergieprod. Algen-Biodiesel-Biogas	-9,43	-4,63	1,77	-1,43	1,77	6,04
Nettoenergieprod. Algen-EtOH-Biogas	-12,26	-7,47	-1,07	-4,27	-1,07	3,20
Biogas	-8,90	-4,10	2,30	-0,90	2,30	6,57

Net energy gain with FPA at 0,5 bar working pressure



	24 h Bg; P=0,8g/l*d	24 h Bg; P=1 g/l*d	24 h Bg; P=1,5 g/l*d	16 h Bg; P=0,8g/l*d	16 h Bg; P=1 g/l*d	16 h Bg; P=1,5 g/l*d
Nettoenergieprod. Algen-Biodiesel-Biogas	-0,43	2,57	6,57	4,57	6,57	9,24
Nettoenergieprod. Algen-EtOH-Biogas	-3,26	-0,27	3,73	1,73	3,73	6,40
Biogas	0,10	3,10	7,10	5,10	7,10	9,77

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Economics of biomass production in industrial scale

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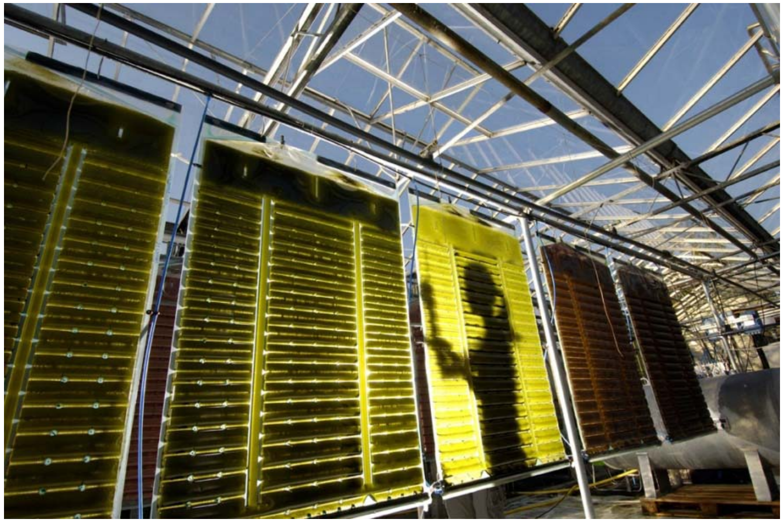
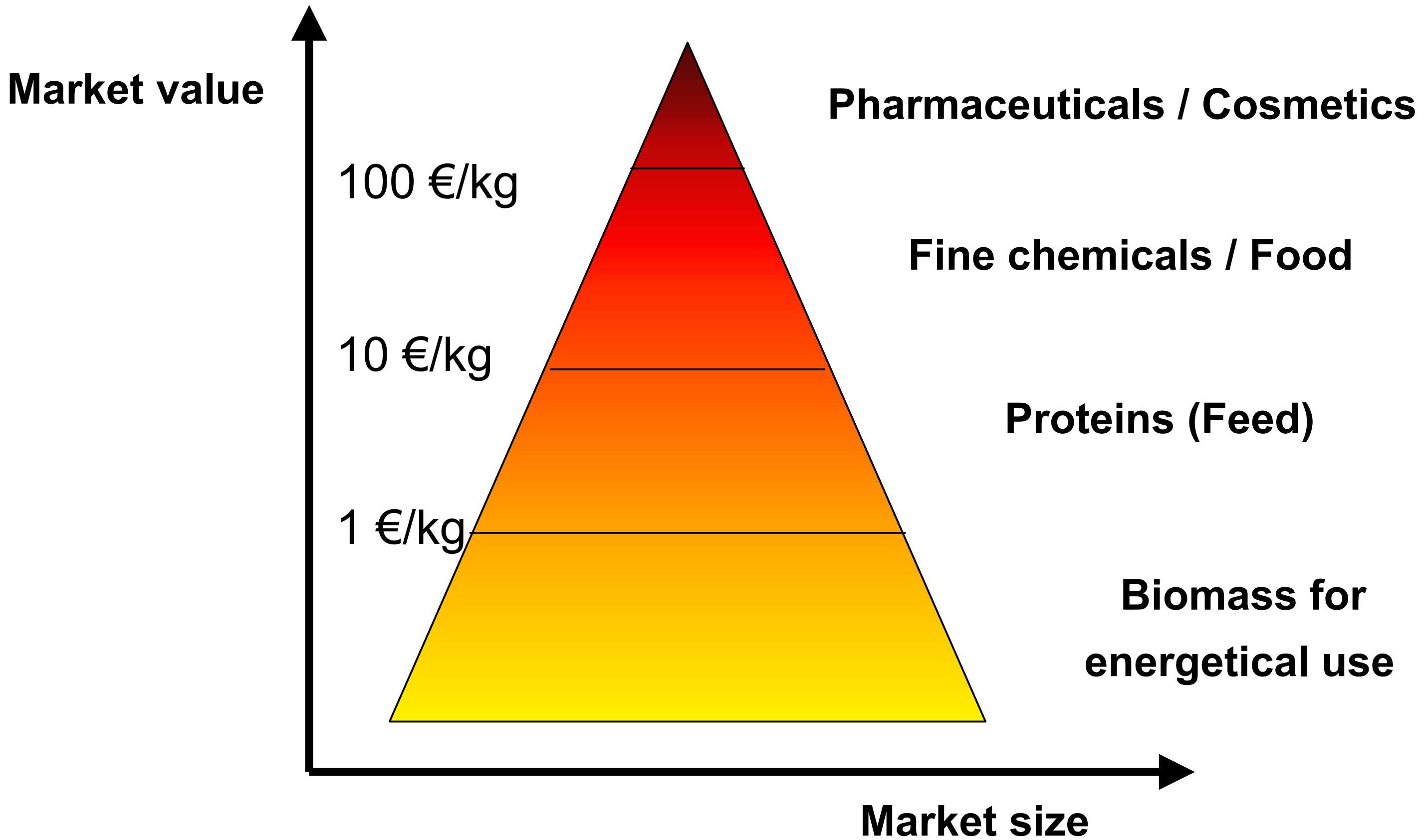


Pilotanlage der Subitec GmbH in Stuttgart-Vaihingen (2005)

Value and market size for algae biomass in different market segments



Annual productivity in different climates

		Productivity per ha and year (t DW / ha*a)	
climatic zone	**productive days per year**	**with ø 1g DW/l*d**	**with ø 0,8 g DW/l*d**
tropical	365	137	110
Mediteranee	300	113	90
central europe	240	90	72
Stuttgart	200	75	60

Calculated for the 180 L-FPA and 2,50 m distance between the modules

productivity > 100 t TS / ha * year

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Production and capital costs

For a 1 ha plant:

- capital costs 1‘500‘000 € (25% for FPA-photobioreactors)
- productivity 120 t / year

- production costs:

Depreciation	2.000	€ / t ODW
Electricity	200	€ / t ODW
Nutrients	1.500	€ / t ODW
Personnel costs	500	€ / t ODW
Total (incl. dep.)	4200	€ / t ODW

For a 100 ha plant: ????

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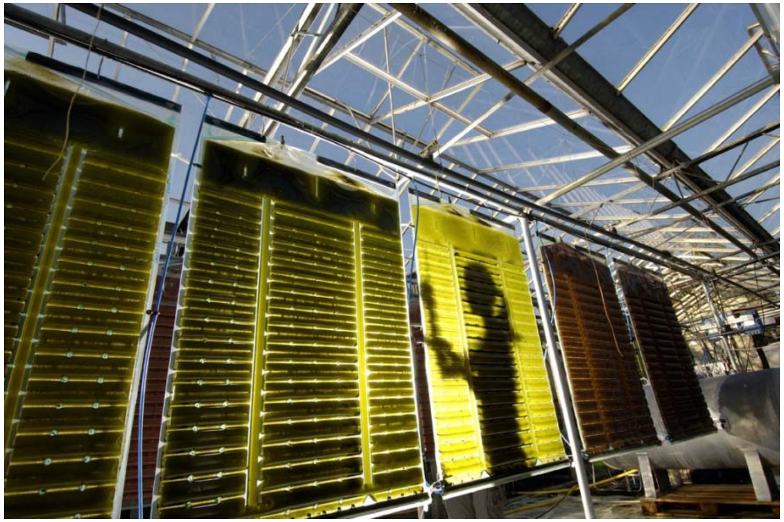

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Summary

- Third generation FPA-Reactors is available since 2008
- 2 pilot plants started operation in 2008
- At least 4 pilot plants are planned for 2009
- Capital costs and running costs for production plants could be diminished radically
- Net energy gain is possible
- Production of fine chemicals in large scale is possible today
- Production of algae biomass for feed, lipid production and for energetical use is achievable in 3 – 5 years

Thanks for your kind attention!