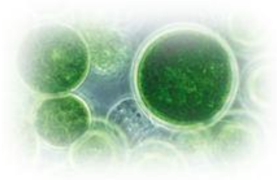   

ProAlgae2013

Industrial production of marine microalgae as an EPA- and DHA-source for use in fish feed

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FHF
The Research Council of Norway

Fish oil price are expected to increase

UN FAO Aquaculture and Fisheries, 2012

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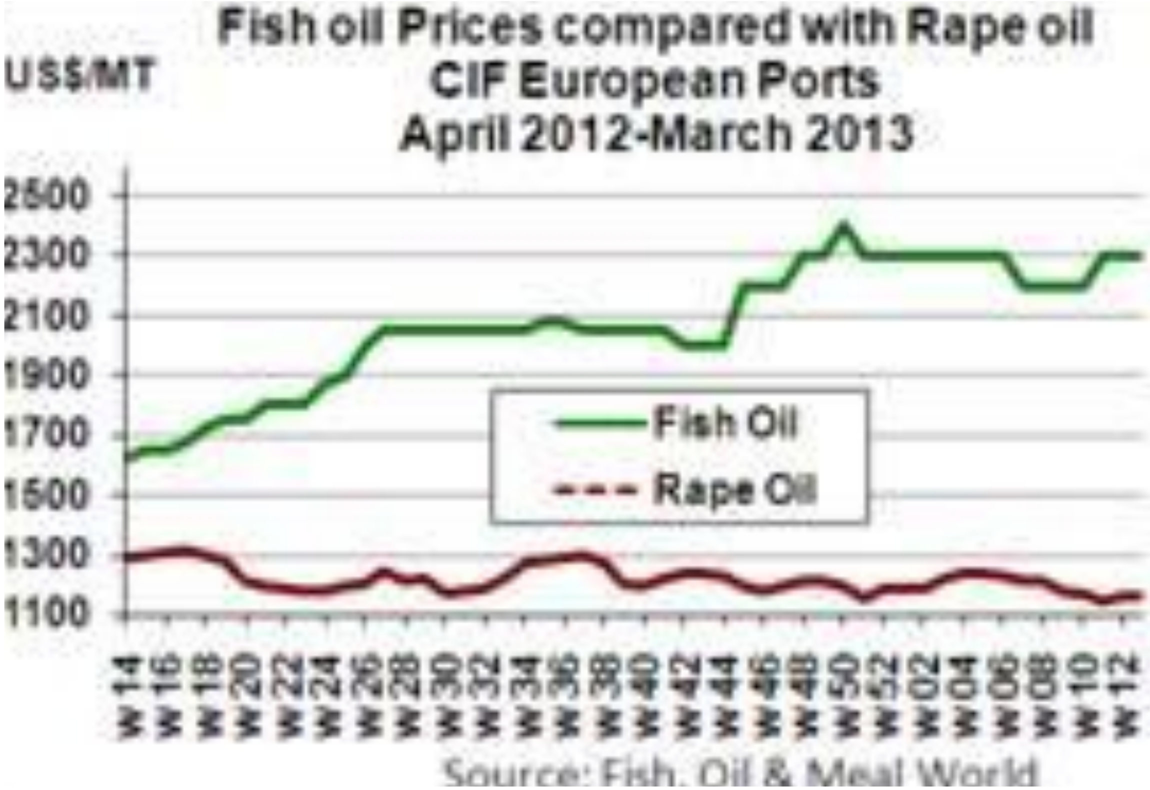
FO price is affected by limited supply



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ProAlgae

Industrial production of marine microalgae as an EPA- and DHA-source for use in fish feed

Aims:

- "State-of-the-art" report of the international status of knowledge on industrial production of marine microalgae.
- Describe the possibilities to produce EPA and DHA in microalgae for use in feed at an economically viable cost.
  - *Investigate scientific knowledge basis, with emphasis on the potential and limitations*
  - *Identify future research needs and possibilities to develop a commercially viable production to support aquafeed production.*

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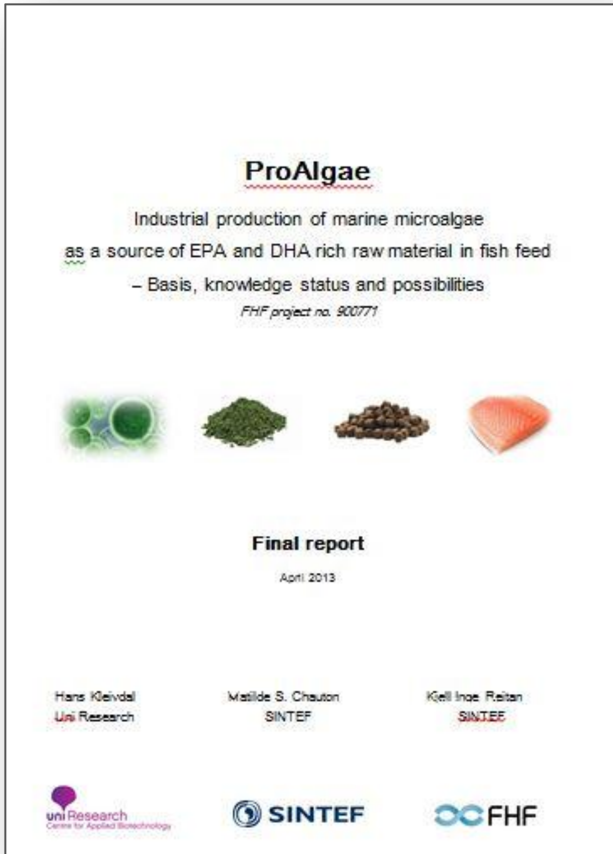
The ProAlgae report


ProAlgae

Industrial production of marine microalgae
as a source of EPA and DHA rich raw material in fish feed
– Basis, knowledge status and possibilities

FHF project no. 900771

Final report

April 2013

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Introduction

1. Background

The knowledge base

2. The biology potential
3. Increasing productivity
4. Production of microalgae
5. Harvesting & processing
6. Feed formulation and application

Industrial status and development

7. Status and potential
8. Techno-economic analysis
9. Risk analysis

Future perspectives

10. Concluding remarks

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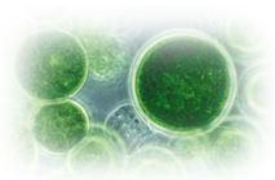
The biology potential

Algae production

Processing and feed development

Application

Algal metabolism → Biodiversity Selection Optimization → Growth conditions Bioengineering → Upscale → Harvest Dewatering Processing → Feed development & formulation → Feeding trials Documentation

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Biology potential

Reported EPA or DHA concentrations and phototrophic productivities. Values are based on cultivation conditions used for each individual study.					
Organism	Cell density [g DW/l]	EPA/DHA			Reference
		[% of DW]	[mg DW/l]	[mg/l·d]	
Nannochloropsis sp.	7-8	5-6			Norsker et al. (2011)
N. oculata	0.4-1	4-5	20-50		Reitan, unpublished
Phaeodactylum tricornutum		2.6-3.1		0.148	Sánchez-Mirón et al. (2003)
Isochrysis galbana	3-10	**6-7**			Fradique (2013) Zhang 2003)
Pavlova lutheri	3-10	15-30*		0.29/0.14	Guedes et al. (2011)

Reported DHA concentrations and heterotrophic productivities.					
Organism	Cell density [g/l]	DHA			Reference
		[% of TFA]	[g/l]	[g/l·d]	
Thraustochytrid strain 12B	21	50-55	5.6	2.8	Perveen et al., 2006
S. limacinum SR21	59	~65	15.5	3.0	Yaguchi et al., 1997
Aurantiochytrium sp.	90-100	35	14	2.2	Jakobsen et al., 2008
Schizochytrium sp.	160-180	**40**	40-45	10-12	US 7732170

Research challenges to improve the biology potential:

- *Screen the biodiversity for productive strains with high EPA and DHA levels.*
- *Establish robust and sustainable strains of the selected algae suitable for in industrial production*

Biological productivity

Biomass and lipid productivity, and denominations		
Productivity factor	Unit	Limitations
Total cell biomass	gram dry weight/liter/day or ton dry weight/hectar/year	- Sunlight and ability to convert into energy - CO_2 and nutrients - Efficient circulation for mass transfer
Total lipid fraction in the cell	gram lipid/liter/day	- Metabolic status
EPA or DHA content in the lipid fraction	gram EPA/liter/day gram DHA/liter/day	- Highly specific enzymes involved in the synthesis of EPA and DHA

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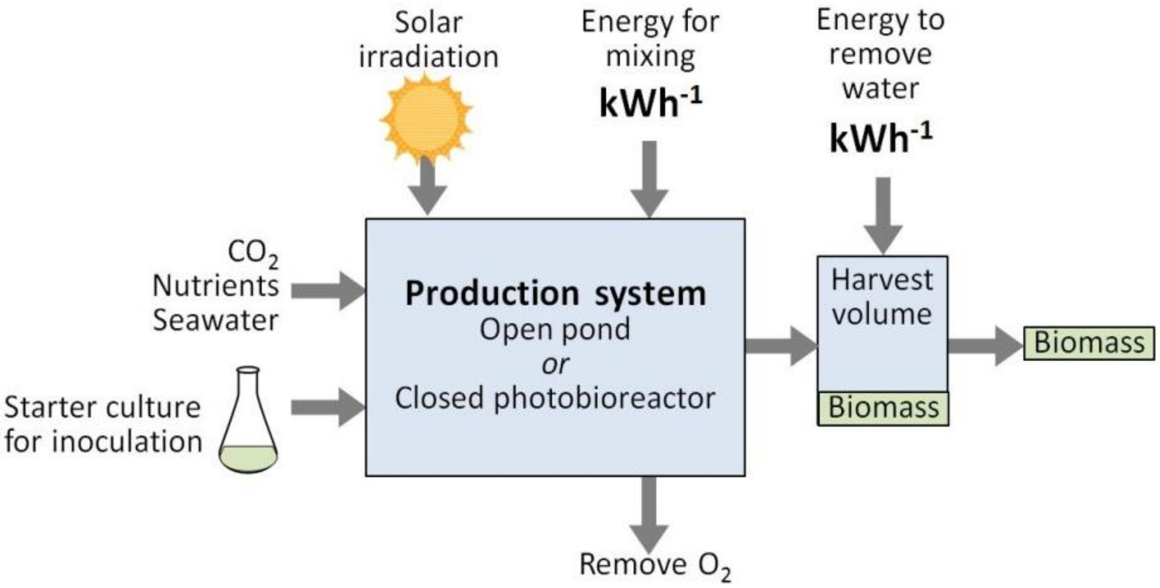
Increasing productivity

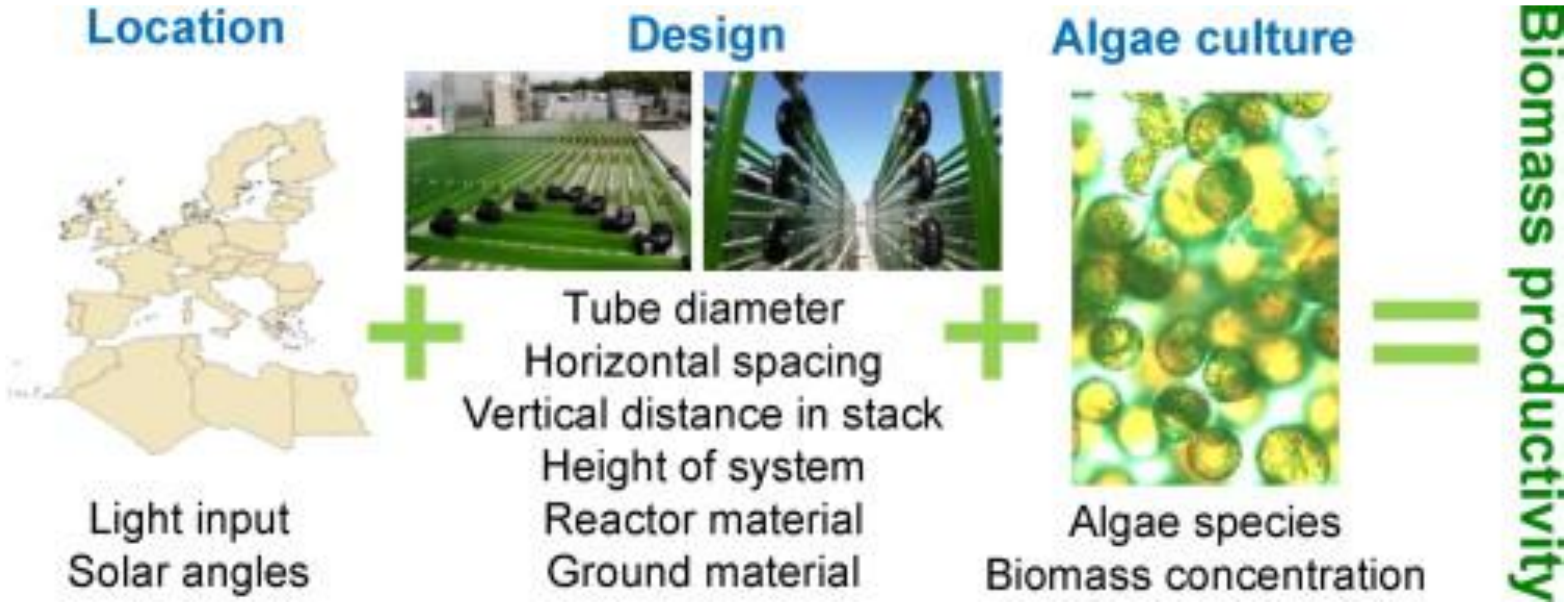
Strategy	Resource	Principle	Potential increase
Exploit the physiological potential	High productivity strain	Metabolic stress by growth conditions	→ Lipid yield: 2-4 fold
Improve strains by selection & breeding	Diverse collection of strains	Selection pressure for phenotype	→ Productivity: 2-4 fold *and/or* → Lipid yield: 2-4 fold
Improve strains by genetic modification	Appropriate strain Molecular tools	Mutagenesis or metabolic engineering	→ Productivity: 2-4 fold *and/or* → Lipid yield: 2-8 fold

Research challenges to improve the biological productivity:

- *Develop model systems and molecular tools to allow genetic modification programs.*
- *Combine optimal traits and channel energy into synthesis of EPA and DHA.*
- *Develop improved strains with 2-4 times higher levels of EPA and DHA.*
- *Develop model systems and molecular tools to allow genetic modification*

Production concepts

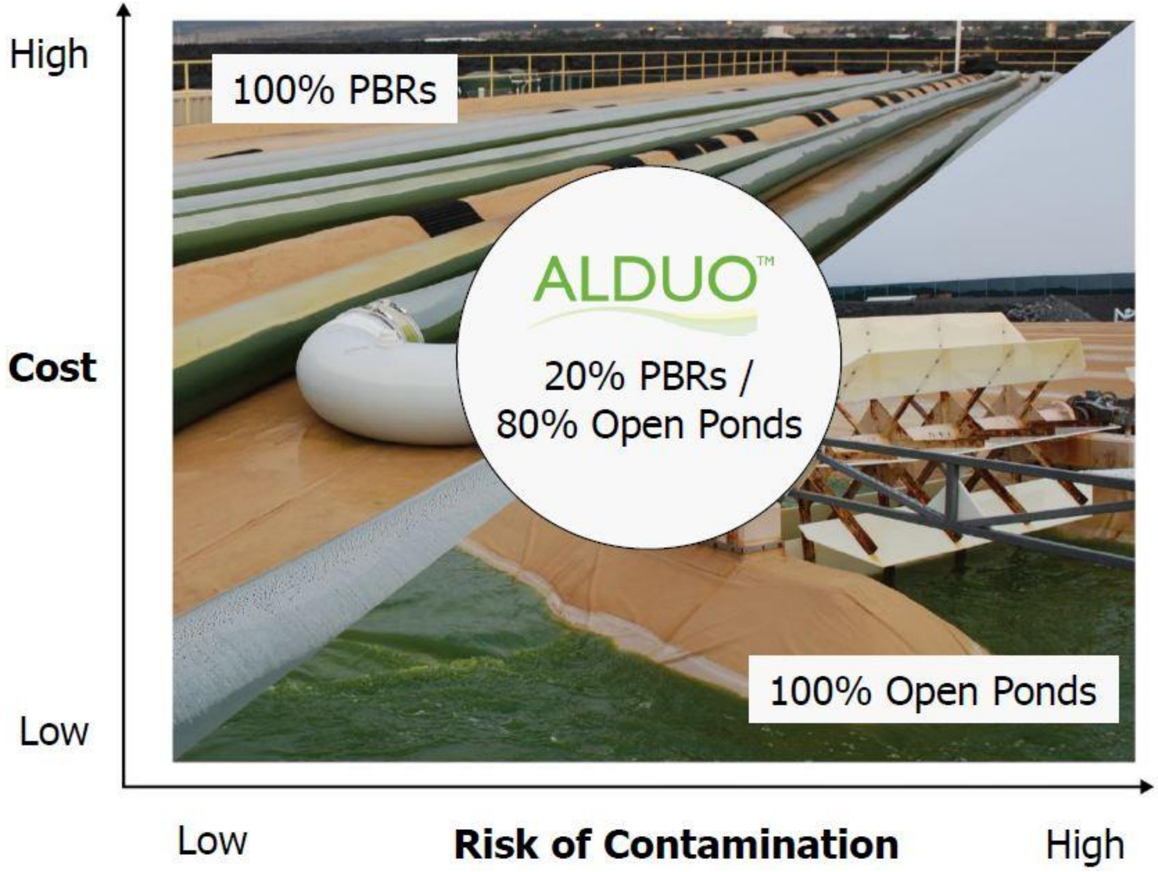




Research challenges to improve production systems and reduce costs:

- *Development of low-energy circulation systems for mass transfer*
- *Establish cultivation systems using low-cost materials*
- *Identify novel strains with optimal production characteristics*
- *Ensure sustainability and improve process design through life cycle analysis*
- *Improve process design through techno-economic analyses*

Technology development



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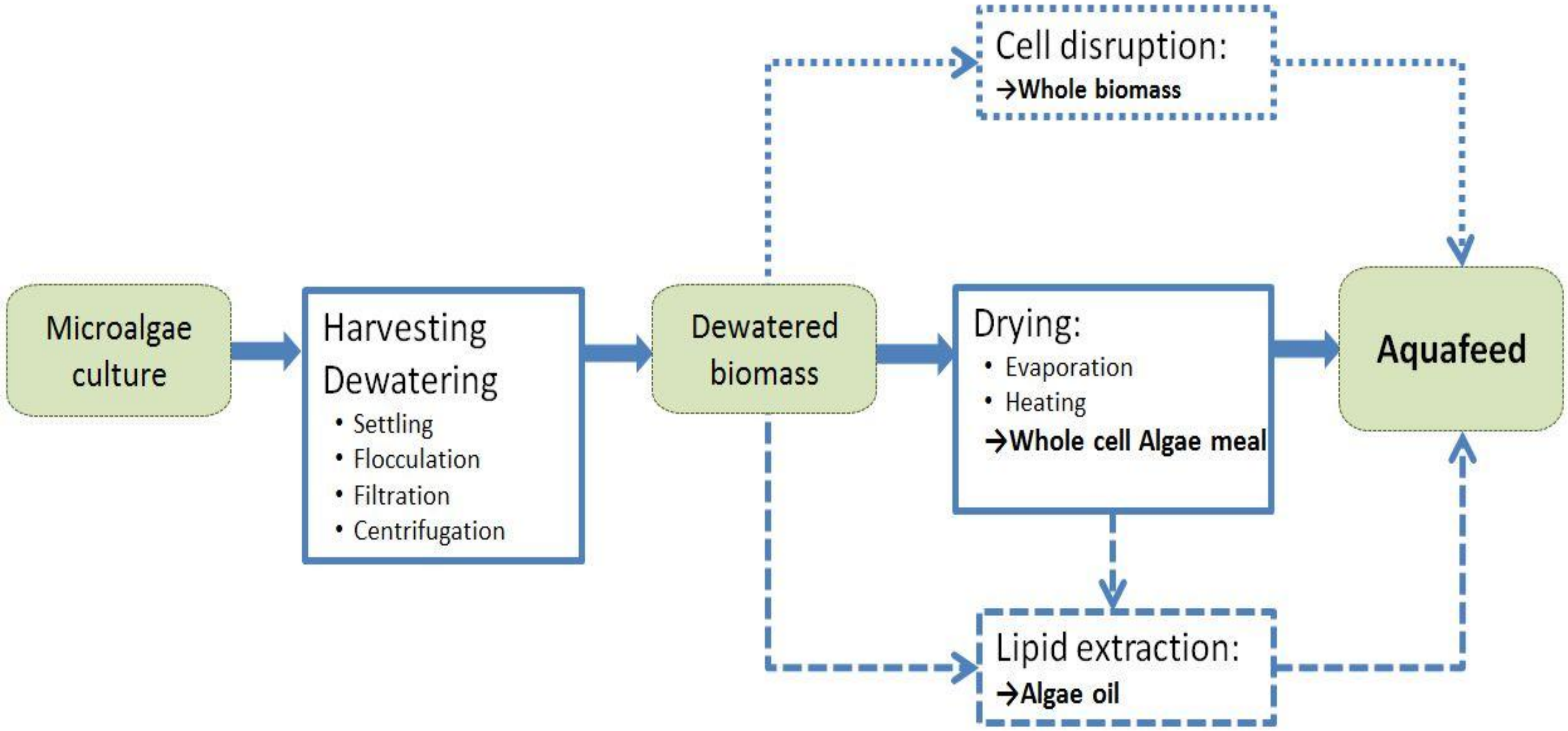
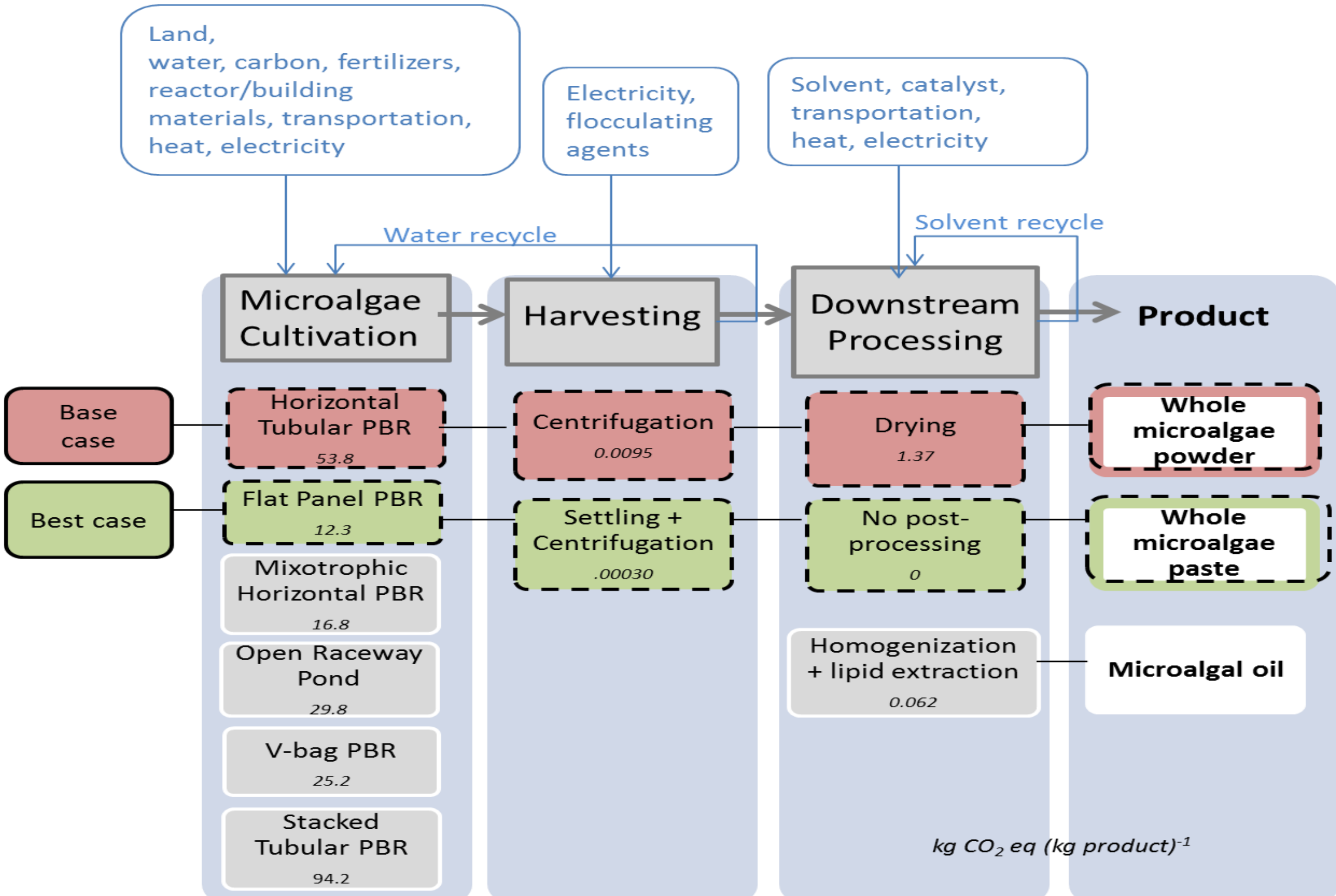
Harvesting and processing

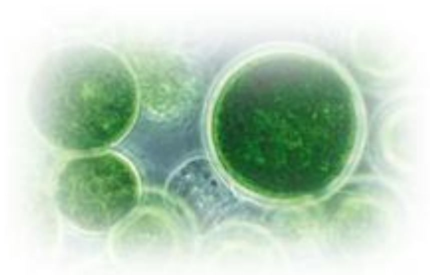




Research challenges to improve harvesting and processing systems:

- *Development of low-cost dewatering of microalgae with high content of EPA and DHA*
- *Development of low-cost drying methods for dewatered microalgae biomass*
- *Develop minimal processing procedure for EPA/DHA-rich microalgae for aquafeed*
- *Identify the need for lipid extraction of microalgae biomass*

Feed development



Research challenges for the development of microalgae as a feed ingredient:

- *Selection of algae strains that have the right nutritional profile and high nutrient digestibility in carnivorous fish*
- *Develop efficient processing method that ensure high digestion of all nutrients in the microalgae*
- *Determine optimum inclusion level of microalgae products into fish feed*
- *Study effects of microalgae on physical quality of extruded fish feed*
- *Define optimum feed production technology with use of microalgae as raw material*
- *LCA analysis for using microalgae as fish feed*

Industrial status and potential

Industrial challenges:

- *Maximize product value*
- *Develop cost-efficient production lines.*
- *Develop novel value chains*

Comparison of the photoautotrophic microalgae production of biofuels and EPA/DHA rich biomass for aquafeed.

Process step	Algae biofuels	EPA/DHA biomass for aquafeed
I. Develop optimal algae strains		
• **Increase productivity (PE)**	Very important	Very important
• **Increase neutral lipid content**	Very important	Not relevant - unless positive for EPA and DHA content
• **Increase EPA/DHA content**	Not relevant	Very Important
• **Optimize for production (tolerance to temp, pH and high cell density, robust)** • **Develop methods to optimize strains**	Important Important	Important Important
II. Production/mass cultivation		
• **Improve photobioreactor design**	Important	Important
• **Reduce cost on CAPEX**	Important	Important
• **Reduce cost on OPEX**	Important	Important
• **Optimize resource usage and integrate industrial side streams**	Important	Important
III. Harvesting and Drying		
• **Reduce cost on CAPEX**	Important	Important
• **Reduce cost on OPEX**	Important	Important
IV. Commercial operations		
• **Successful scale-up**	Important	Important
• **Stable, continuous production**	Important	Important

Opportunities

Short term

- Opportunities for heterotrophic DHA
- Integrated research approach in pilot scale
- Develop value chains for phototrophic EPA/DHA

Medium & Long term

- Develop sustainable production chains for phototrophic EPA/DHA

Phototrophic microalgal EPA/DHA production

A Techno-economic analysis

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Kjell Inge Reitan, SiNTEF
Ragnar Tvetarås, University of Stavanger
Steffen Boga, BTO
Niels-Henrik Norsker, bioTOPIC

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Assumptions, tubular PBR, NL

Photosynthetic efficiency	3	%
Annual production per ha per year	14.61	
Annual production per ha per year	43.83	ton/ha ground/yr
Total production per year	4383	ton/yr
CO2 fixation (ton CO2 / ton Biomass)	1.8	
Share of EPA/DHA	0.06	
EPA/DHA production total per year	350.64	ton/yr
Interest rate	5	%
Depreciation	10	%
Production area	100	ha
Total land area	1.3	ha
Land price (rent per m2 per year)	2	EUR/m2
Power cost	0.05	€ / kWh
Power consumption	47,869,326	kWh
Labor, technicians	6	person
Labor, engineers	1	person
Wage, technicians	35000	EUR/year
Wage, engineers	50000	EUR/year
Payroll charges	25	% of wage
Maintenance	0.04	Cost per EUR of capital equipment

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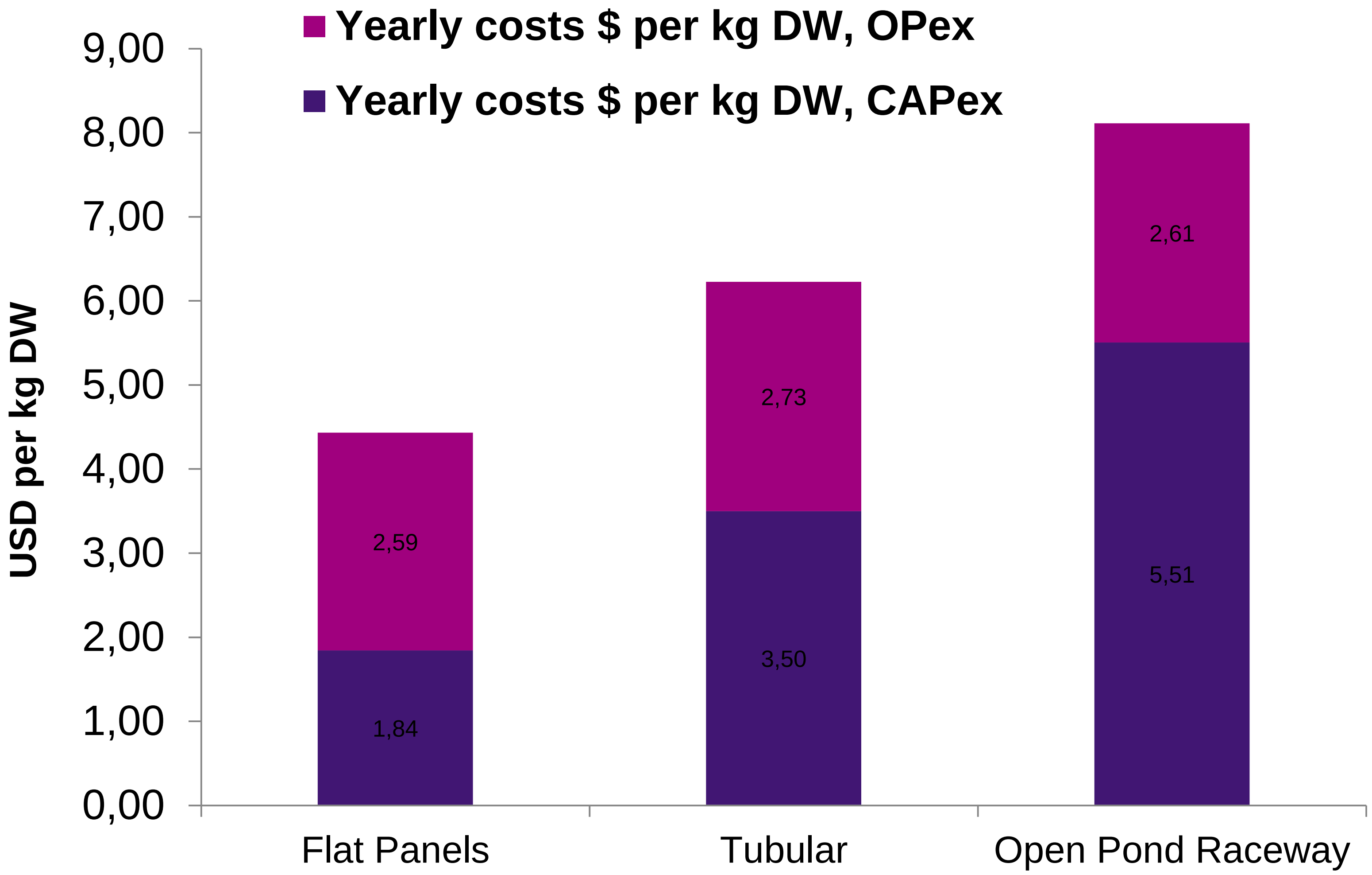
Base case, break down of costs (per kg DW) (Netherlands)



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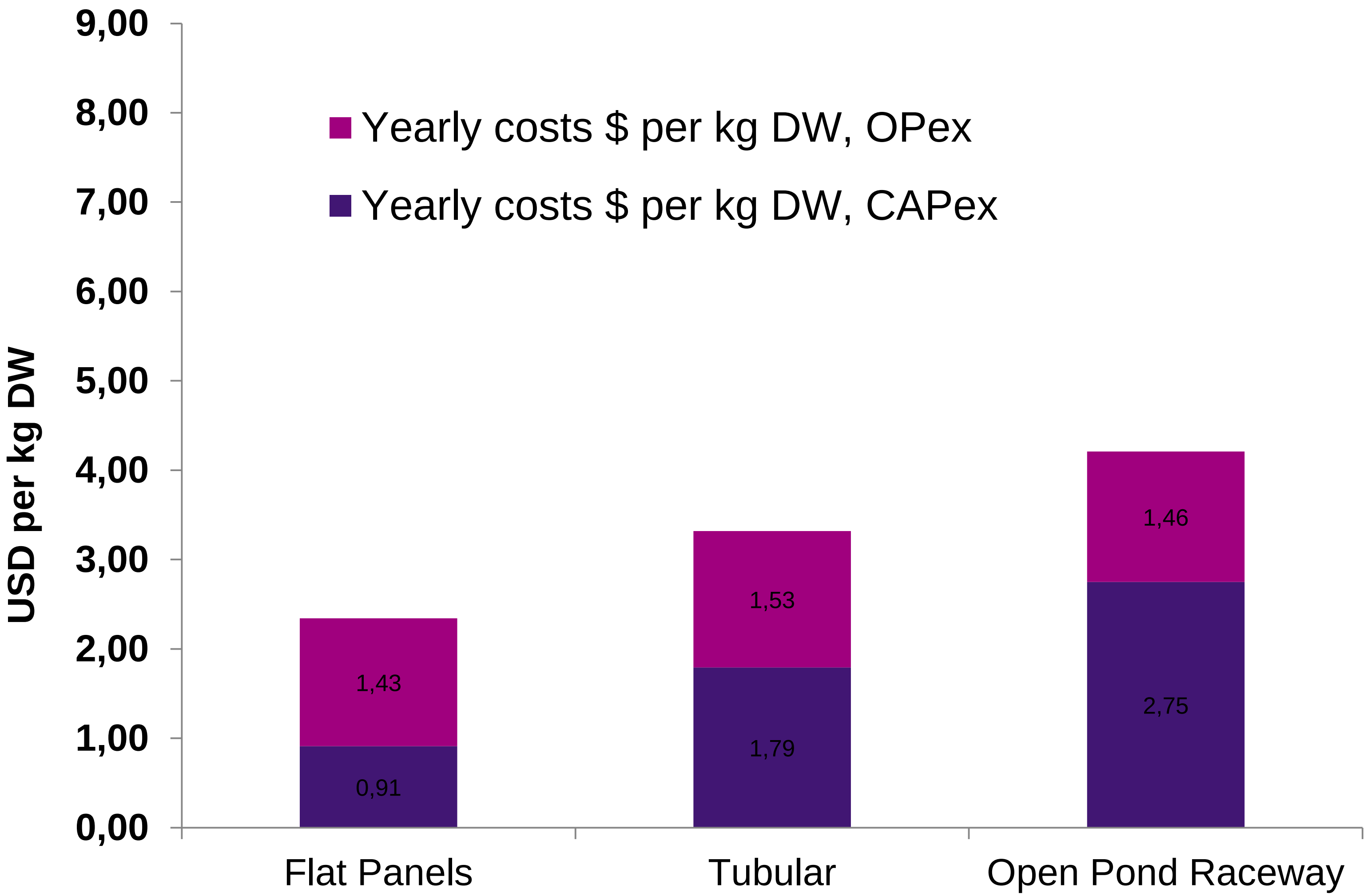
Base case, break down of costs (per kg DW) (Spain)



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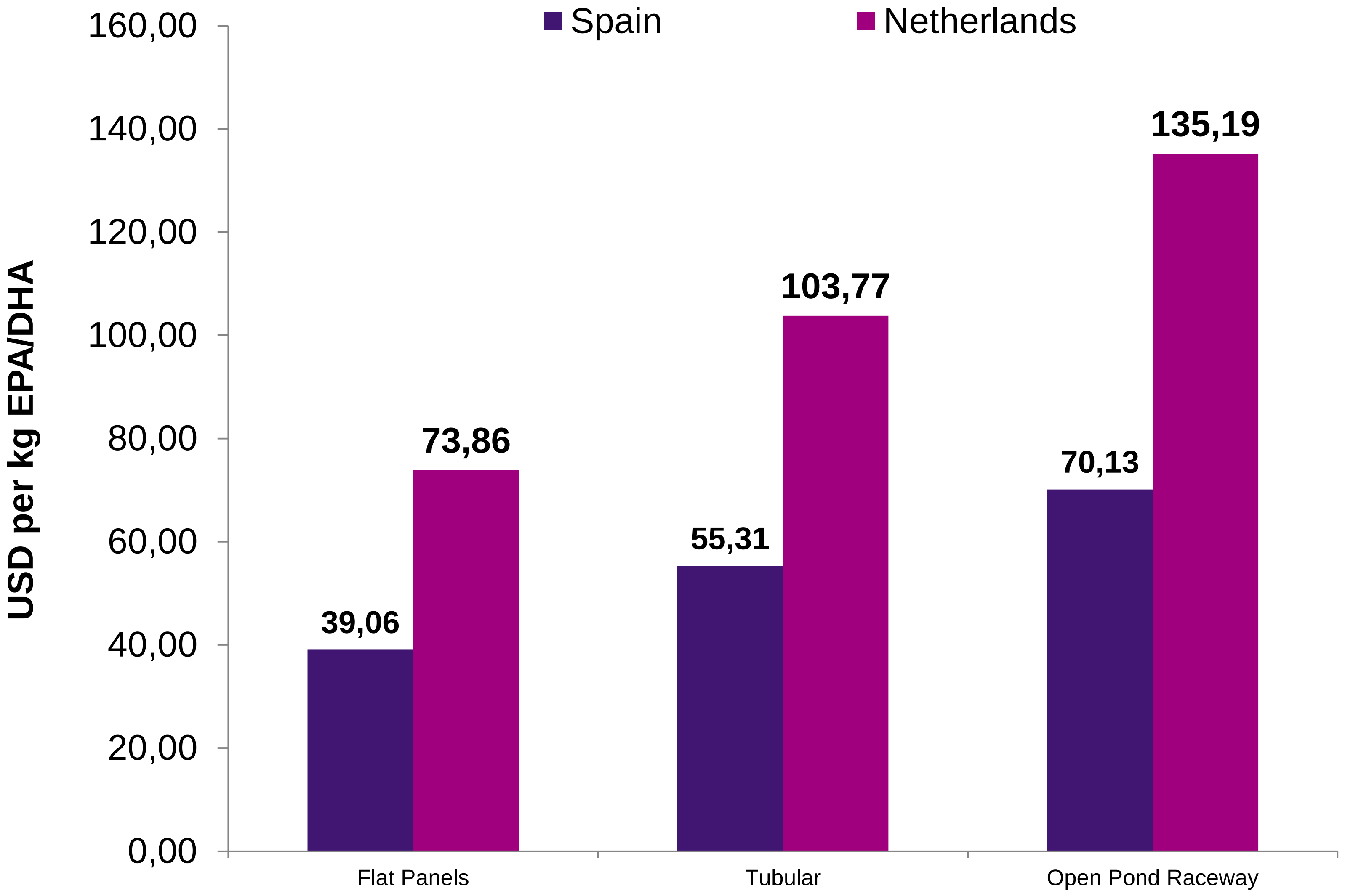
Base case cost omega-3 (USD/kg)



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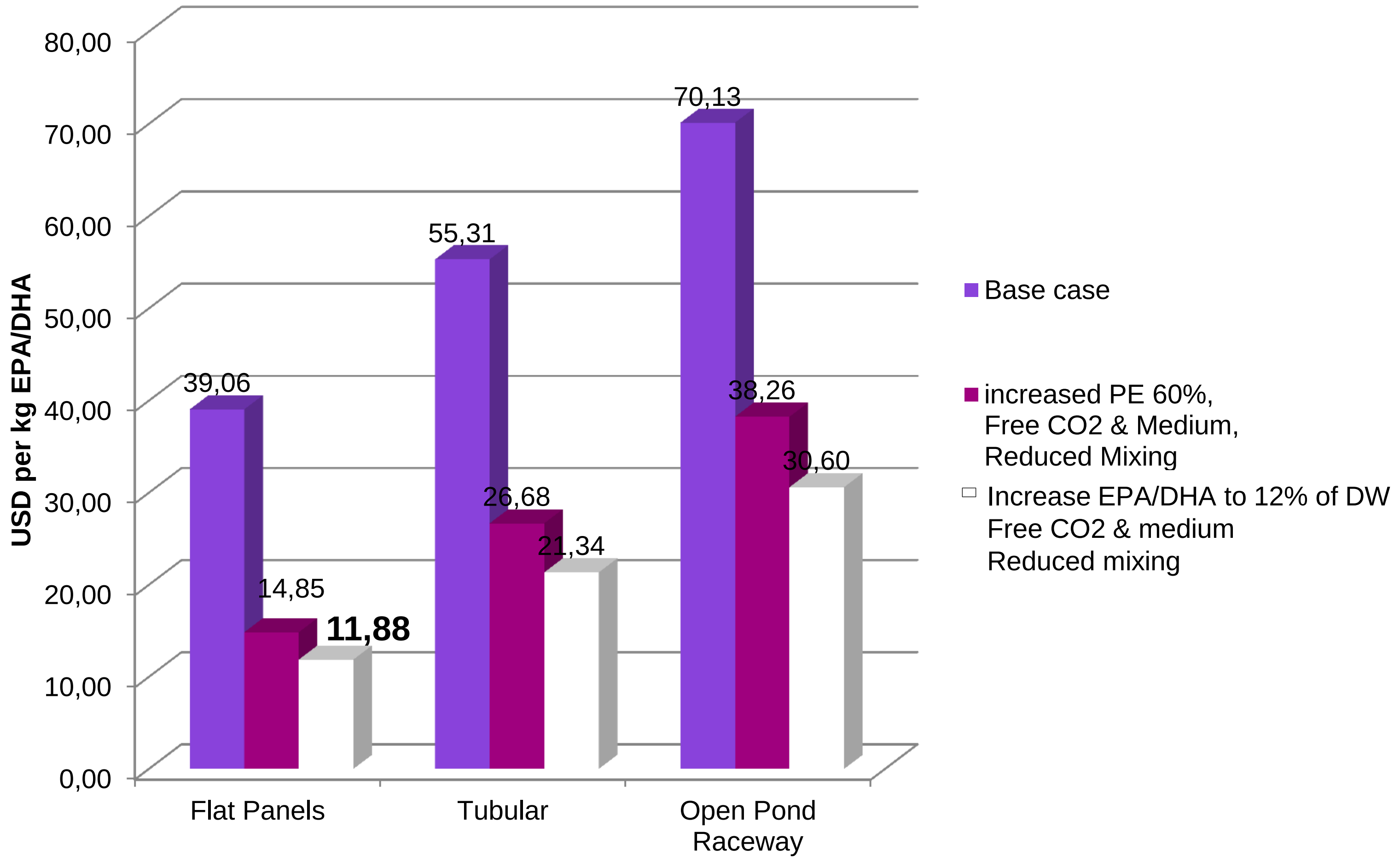
Best case EPA/DHA costs, combined factors (per kg DW)



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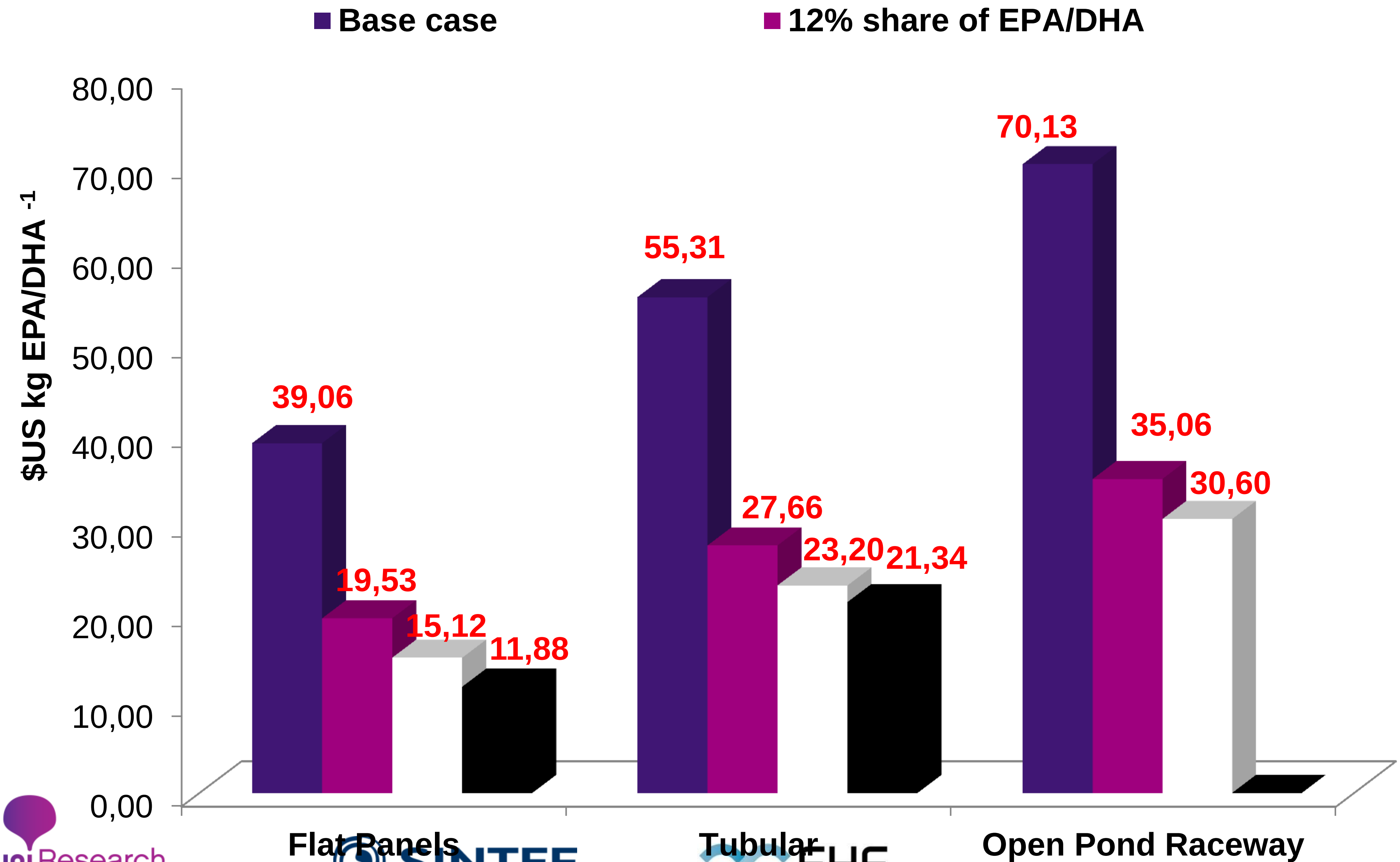
Best case – combined factors (Spain)



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Price levels and volumes of different fish oil products.

Modified table from Wahren & Mehlin (2011). The table has been modified by converting NOK/kg into USD/kg- and by estimating the cost per EPA&DHA unit cost.

Fish oil product	EPA and DHA content	Estimated cost USD/kg fish oil product	Estimated cost USD/kg EPA & DHA equivalent
Refined oil	30 %	5-10	15-30
Concentrated oil	40-70 %	9-33	27-99
Concentrated oil	70-90 %	20-98	28-137
Concentrated oil	≥ 90 %	98-445	108-490

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Comparison of production costs per unit EPA and DHA based on phototrophic and heterotrophic production

Production cost estimates based on techno-economic analysis and cost projections (chapter 8).

Production principle	Estimated production cost (USD per kg)		
	EPA+DHA	EPA	DHA
Phototrophic production			
Current production cost	39.1	48.8*	156.2*
Production cost after optimization	11.9	15.8*	47.52*
Heterotrophic production			
Current production cost	19.0	-	19.0
Production cost after optimization	11.5	-	11.5

**Assuming an EPA:DHA ratio of 3:1*

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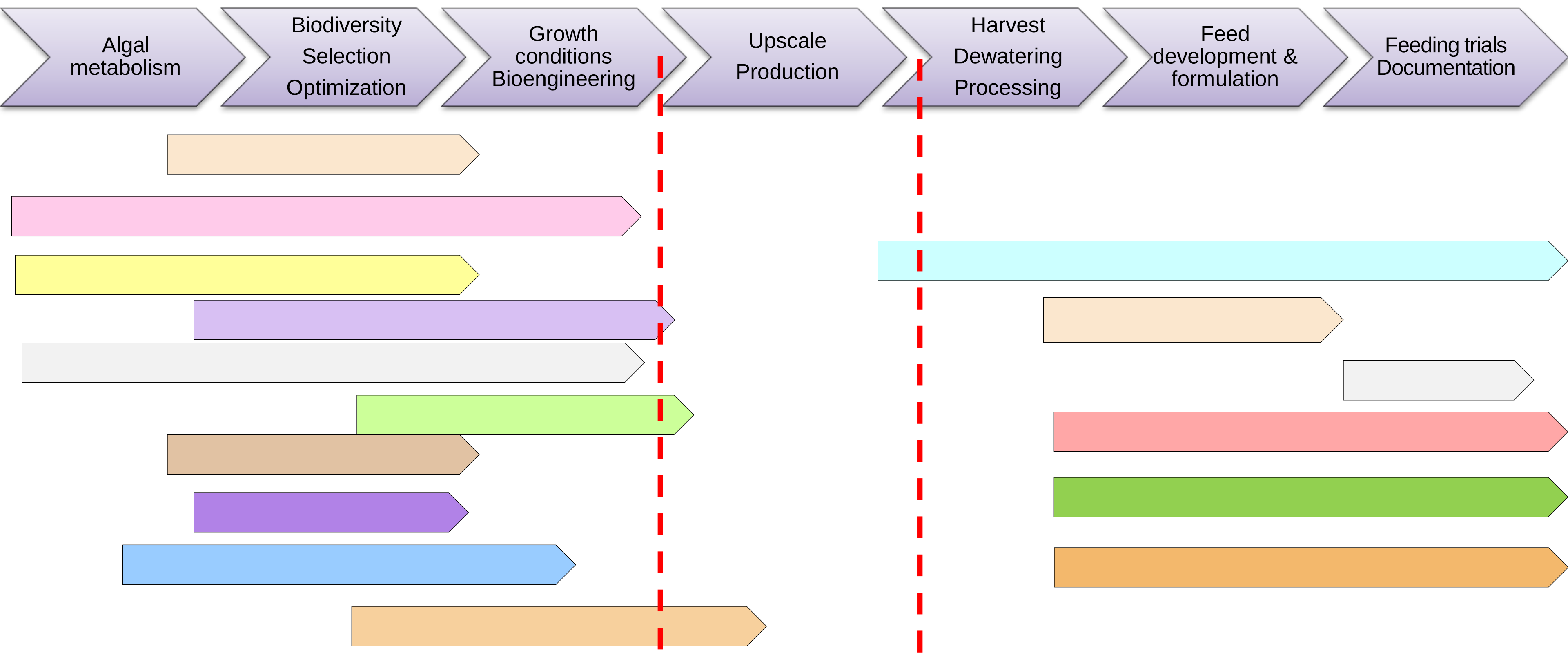
Concluding remarks

1. Microalgae production of EPA and DHA has the potential to develop into a sustainable alternative to fish oil for use in aquafeed.
2. This potential can be realized by establishing a *fit-for-purpose* research and development pipeline with integrated research along the value chain coupled to international centers of expertise in various fields.
3. This should be integrated with ongoing development of industrial microalgae production efforts, to maximize any synergy effects.

ProAlgae2012 Workshop

Microalgae for aquafeed

1. Integrated development of new value-chain (1-2y)



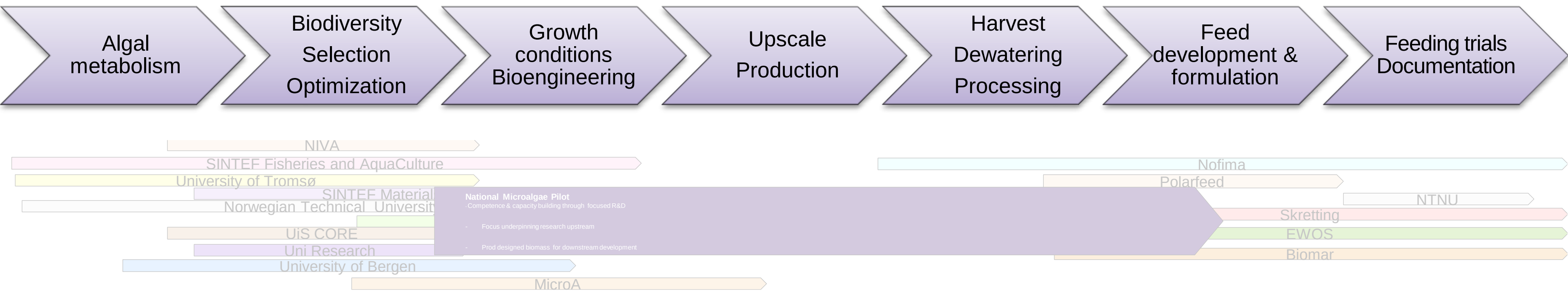
Pilot capacity

- Competence & capacity building through focused R&D
- Focus underpinning research upstream
- Prod designed biomass for downstream development

Development strategy

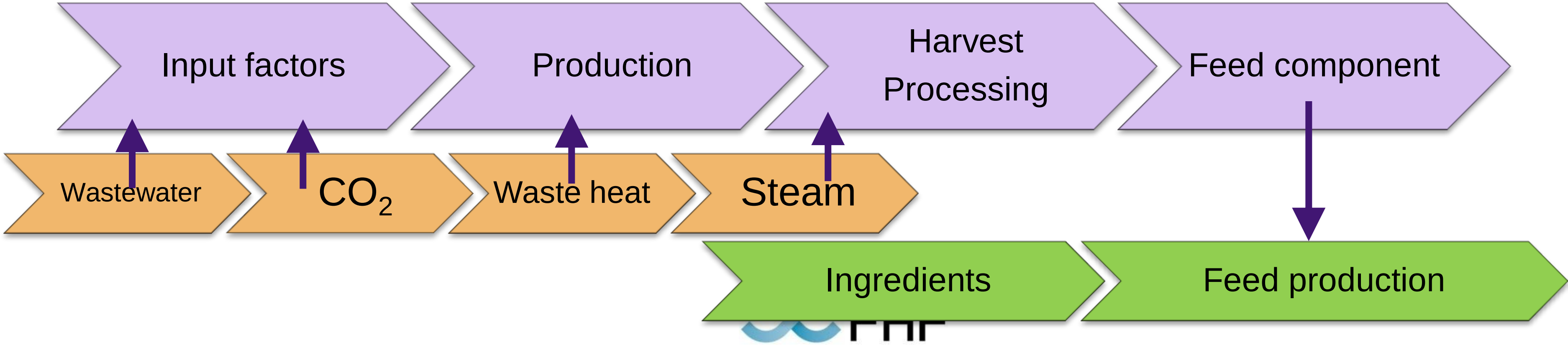
Microalgae for aquafeed

1. Integrated development of new value-chain (1-2y)



2. Operationalize and adopt techno- and biological developments (2-5y)

3. Upscale research pilot to develop industrial value chain (5-8y)



Thanks to all contributors to ProAlgae

An integrated approach to develop novel value chains