

PUFAChain:

the value chain from microalgal diversity to PUFAs: technological, environmental and integrated sustainability assessments

Dr Guido Reinhardt (IFEU)

2nd European Workshop
Life Cycle Analysis of Algal based Biofuels and Biomaterials
Brussels, 24 April 2014



Who we are - What we do



IFEU - Institute for Energy and Environmental Research Heidelberg, since 1978

- **Independent scientific research institute**
- **organised as a private non profit company with currently about 70 employees**
- **Research / consulting on environmental aspects of**
 - **Energy (including Renewable Energy)**
 - **Transport**
 - **Waste Management**
 - **Life Cycle Analyses**
 - **Environmental Impact Assessment**
 - **Renewable Resources**
 - **Environmental Education**

20 plus years of experience



F + E-Vorhaben des Umweltbundesamtes
Nr. 104 08 508/02

Endbericht

Energie- und CO₂-Bilanz von
Rapsöl und Rapsölester
im Vergleich
zu Dieselkraftstoff

ifeu – Institut für Energie- und
Umweltforschung Heidelberg
Fachbereich „Verkehr und Umwelt“

Dezember 1991

First full life cycle balance on
biodiesel in Europe

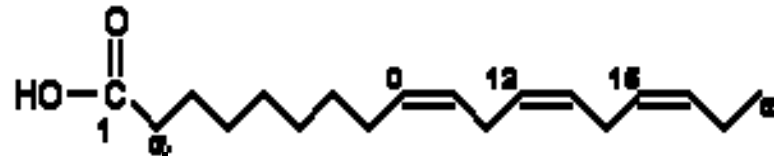
1991



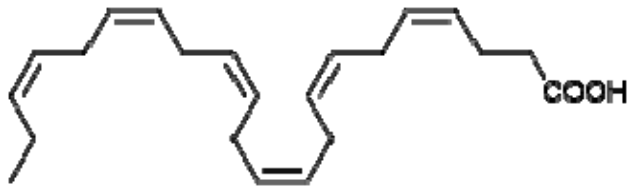
What are PUFAs?

PolyUnsaturated FattyAcids

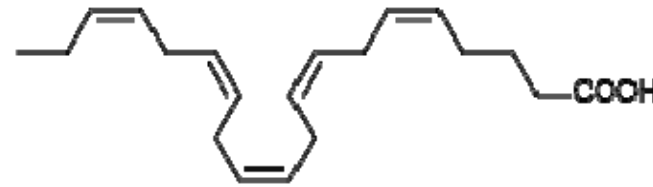
omega-3 types



all-cis-9,12,15-octadecatrienoic acid or 18:3(n-3)



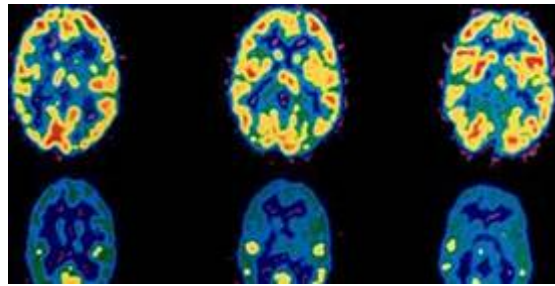
all-cis-
4,7,10,13,16,19-docosahexaenoic acid
(DHA) or 22:6(n-3)



all-cis-
5,8,11,14,17-eicosapentaenoic acid
(EPA) or 20:5(n-3)

What are PUFAs?

- **Increasing significance of omega-3 polyunsaturated fatty acids**
 - maintaining heart health
 - protective properties against cancer and birth defects
 - may offset symptoms of diabetes, arthritis and even neurological diseases



What are PUFAs?

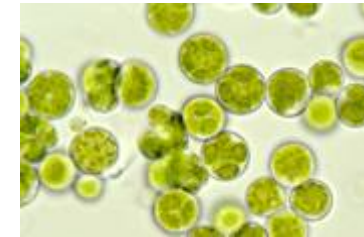
- Omega-3 fatty acids: **essential** fatty acids
 - cannot be synthesized by the human body
 - must be supplied in the diet
- Major health benefits through
 - EPA and DHA
 - mainly obtained from cold water fish
- Concentration of EPA/DHA in fish oil varies considerably, depending on
 - location
 - annual season
 - availability of phytoplankton



Why are algae a promising source for PUFAs?

Microalgae:

- forming feed for other marine life
 - identified as the generic source of VLC fatty acids
 - can be cultivated
- alternative and promising source for EPA and/or DHA
- Other marine oils always deliver a mixture of both acids
 - Some algae strains provide different acids much more selectively
- facilitates further isolation and purification of target products



Designed conditions of cultivation process

- avoiding contaminants like PAH, heavy metals and other unwanted by-products
- these have to be removed from oils obtained from wild and farmed fish



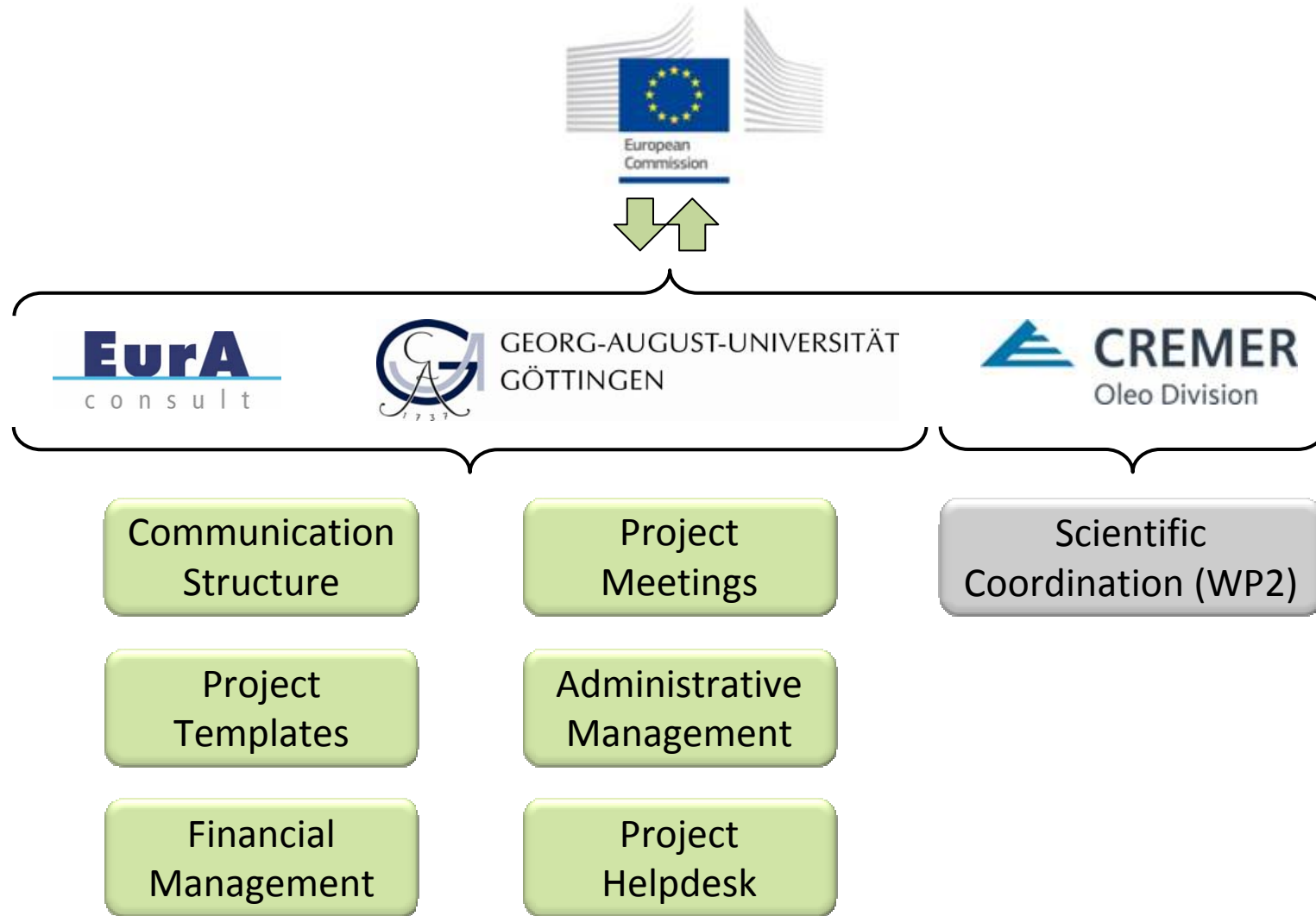
PUFAChain: Project Overview

Call	KBBE.2013.3.2-02: The CO ₂ algae biorefinery
Project title	PUFAChain – The Value Chain from Microalgae to PUFA
Grant Agreement No.	613303
Duration	48 months
Start	1 st November 2013
End	31 th October 2017
No. of participants	9 partners from 4 different countries
Total estimated costs	7,149,939.60 Euro
Total EU contribution	5,124,066.00 Euro

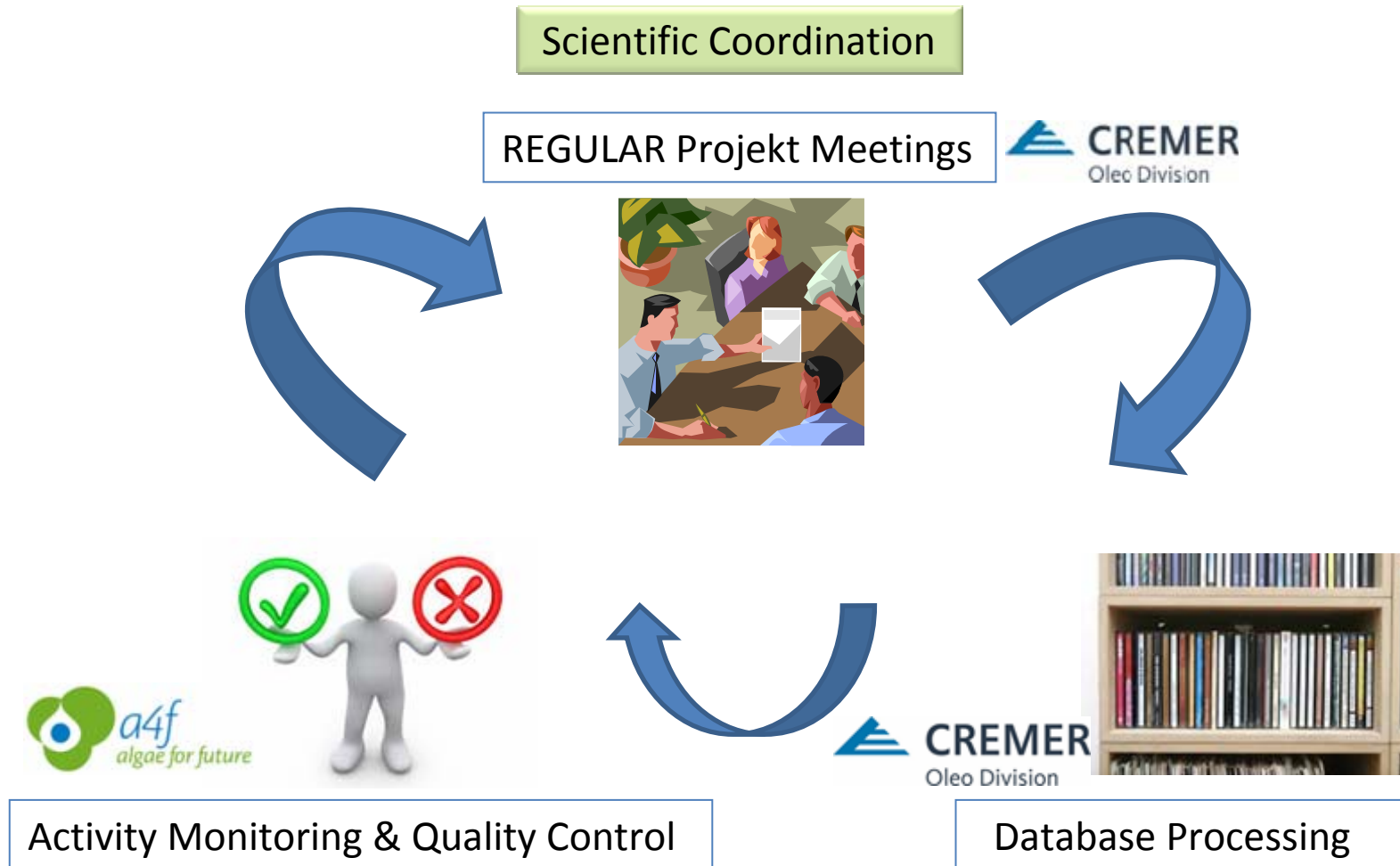
Project partners



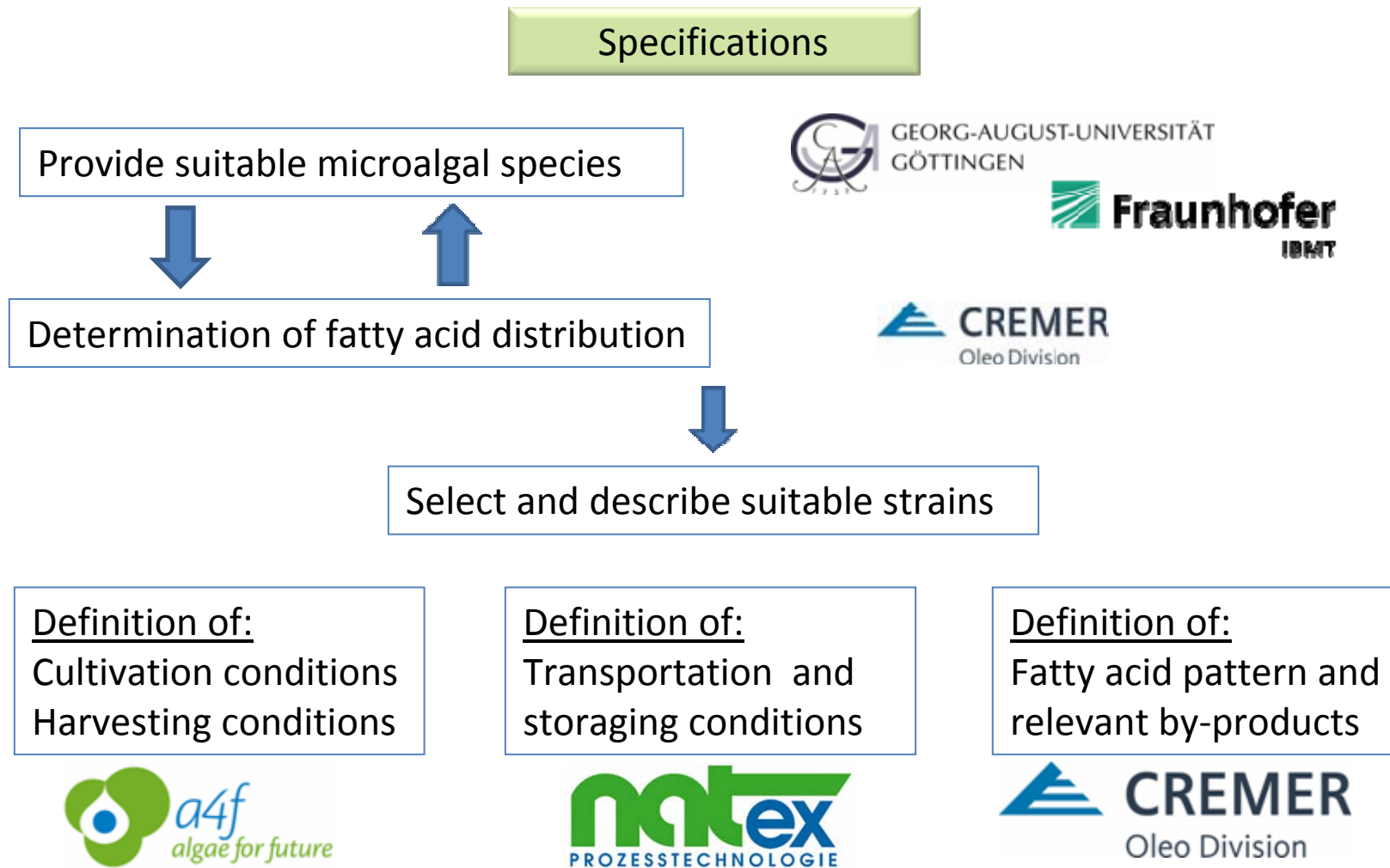
WP 1: Management



WP 2: Specifications and Scientific Coordination



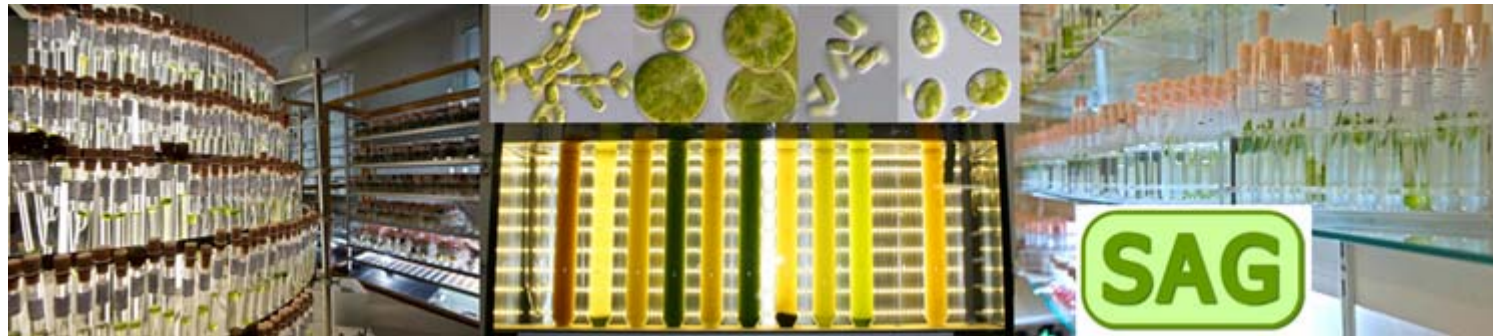
WP 2: Specifications and Scientific Coordination



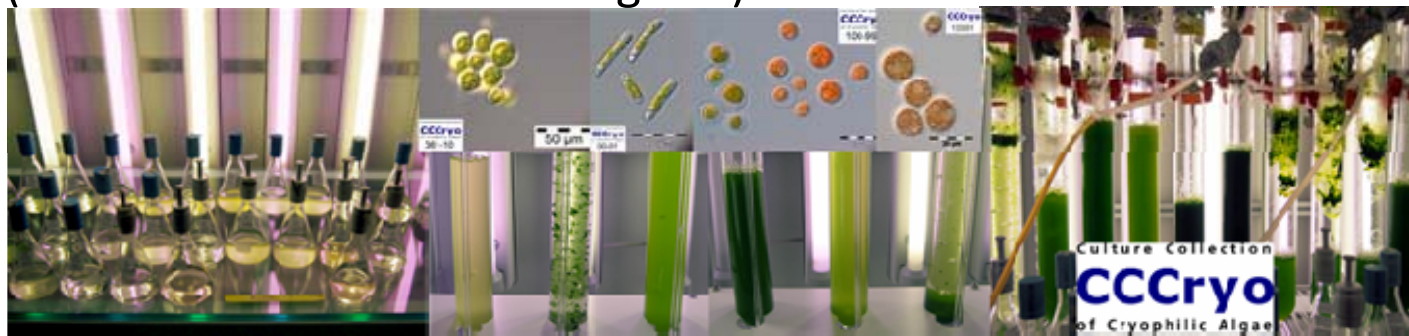
WP 3: Biology

Selecting the appropriate from the microalgal diversity

- **SAG** (University of Goettingen, Germany): Broad diversity of model algal species, important: different isolates with different properties of the same species, novel still unexploited isolates



- **CCCrvo** (Fraunhofer, Potsdam): Selection of cold-adapted algal species (novel isolates from Polar regions)



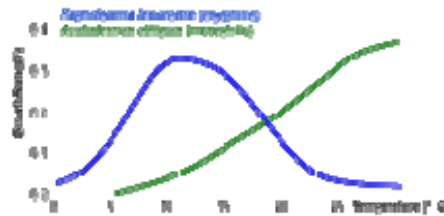
WP 3: Biology

Task 1. Optimization of pre-selected algal strains

- pre-selection: ~ 150 strains with PUFAs EPA and DHA > 5% in lipid profiles (Lang et al. 2011) AND promising to reach high cell densities in photobioreactors
- growth experiments to optimize PUFA yield, high cell densities may compensate if PUFA yield still low

Task 2. Optimization of microalgae from Polar regions (Algal Crop Rotation principle)

Cold-adapted in winter (outdoor), mesophilic or thermophilic in summer (outdoor)



Task 3. Genetic characterization of potential production strains and cryopreservation

- Quality management (strain identification, detection of contamination) using DNA barcodes
- Genetically stable cryopreserved stock of test and production strains

WP4: Bioprocess Engineering

2014 **Biomass optimization at laboratory scale**

- nutritive media, productivity,...

Inoculum



Laboratory tests set-up



2015 **Scale-up from 10 L to 10000 L**

- Data collection at 2 m³ operation (harvesting using Mahle membranes)
- Expansion project from 2 m³ to 10 m³
- Biomass supply for processing
- Data collection at 10 m³ operation

Scale-up 2 m³



Project



2016

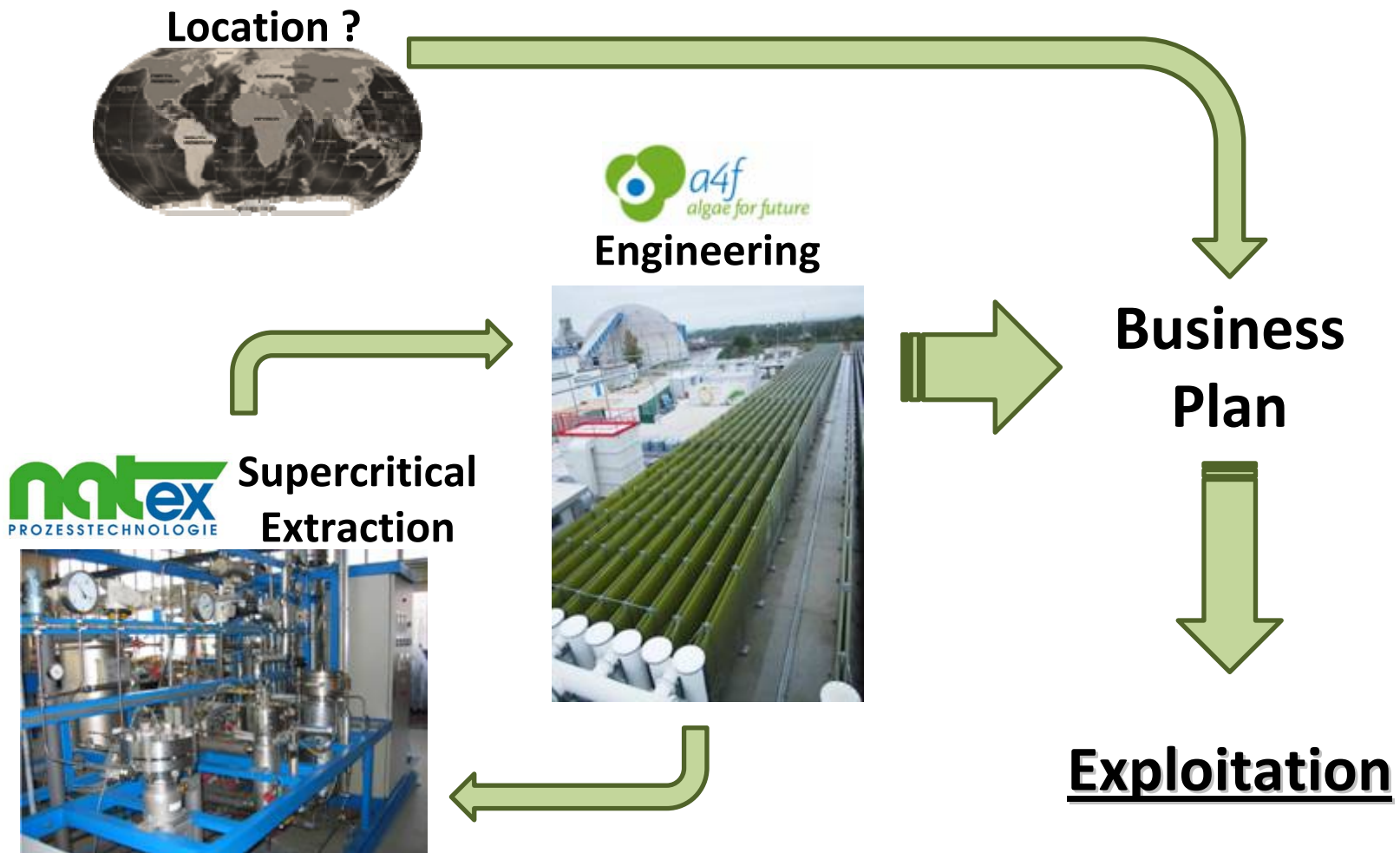
Biomass pre-processing

- Optimizing pre-processing before extraction

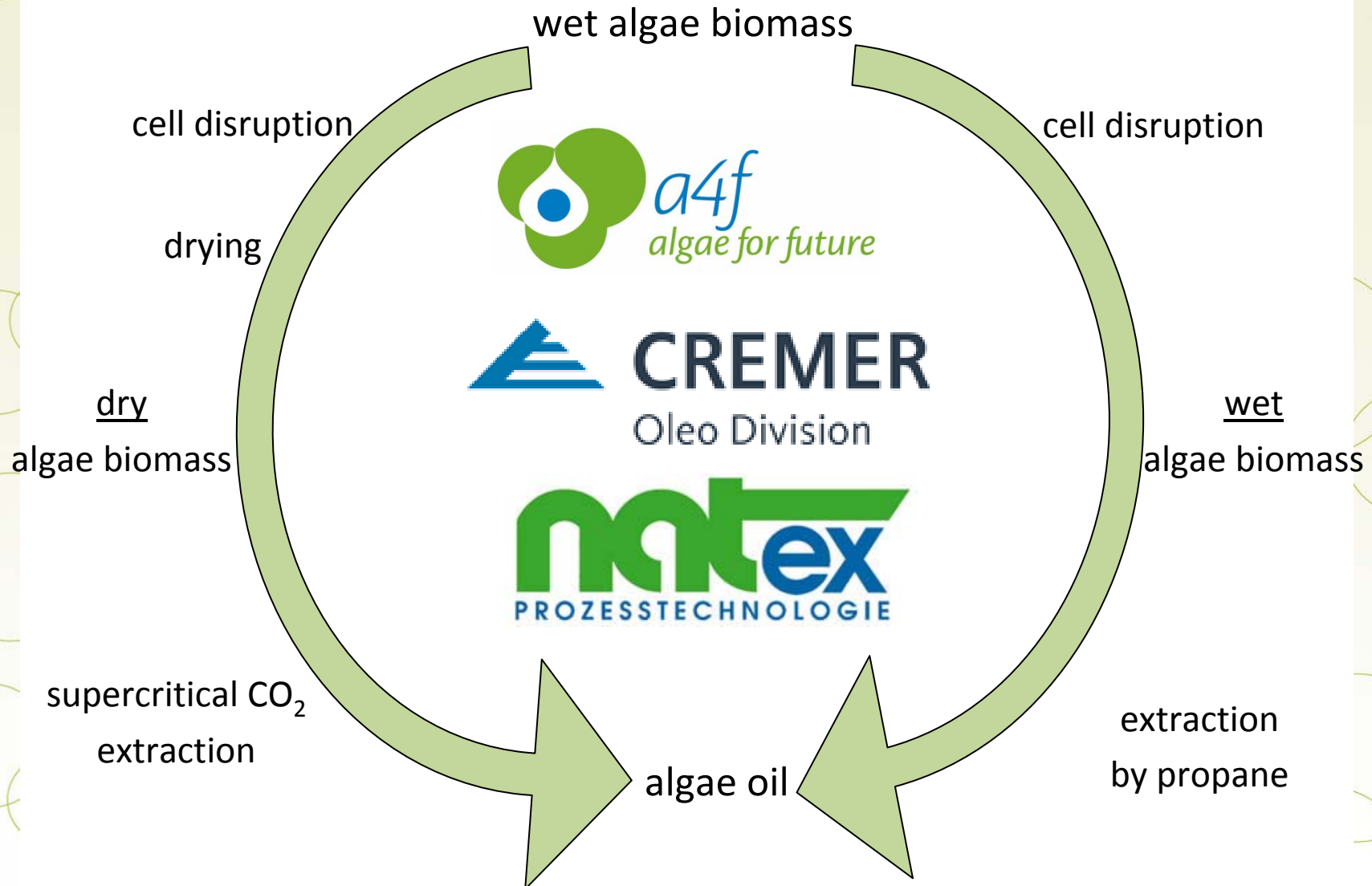
Membrane set-up



WP5: Industrial Production



WP 6: Downstream



WP 7: Production Formulation

Characterization of crude algal oil (e.g. ratio neutral and polar lipids; free fatty acids)

Evaluation of the most promising refining and separation technology

- Chemical or
- Biocatalyzed esterification/hydrolysis



Removal of non-target fatty acids



Preparation of various esters from DHA and EPA



WP 8: Demonstration



Demonstration
Algae cultivation
and processing



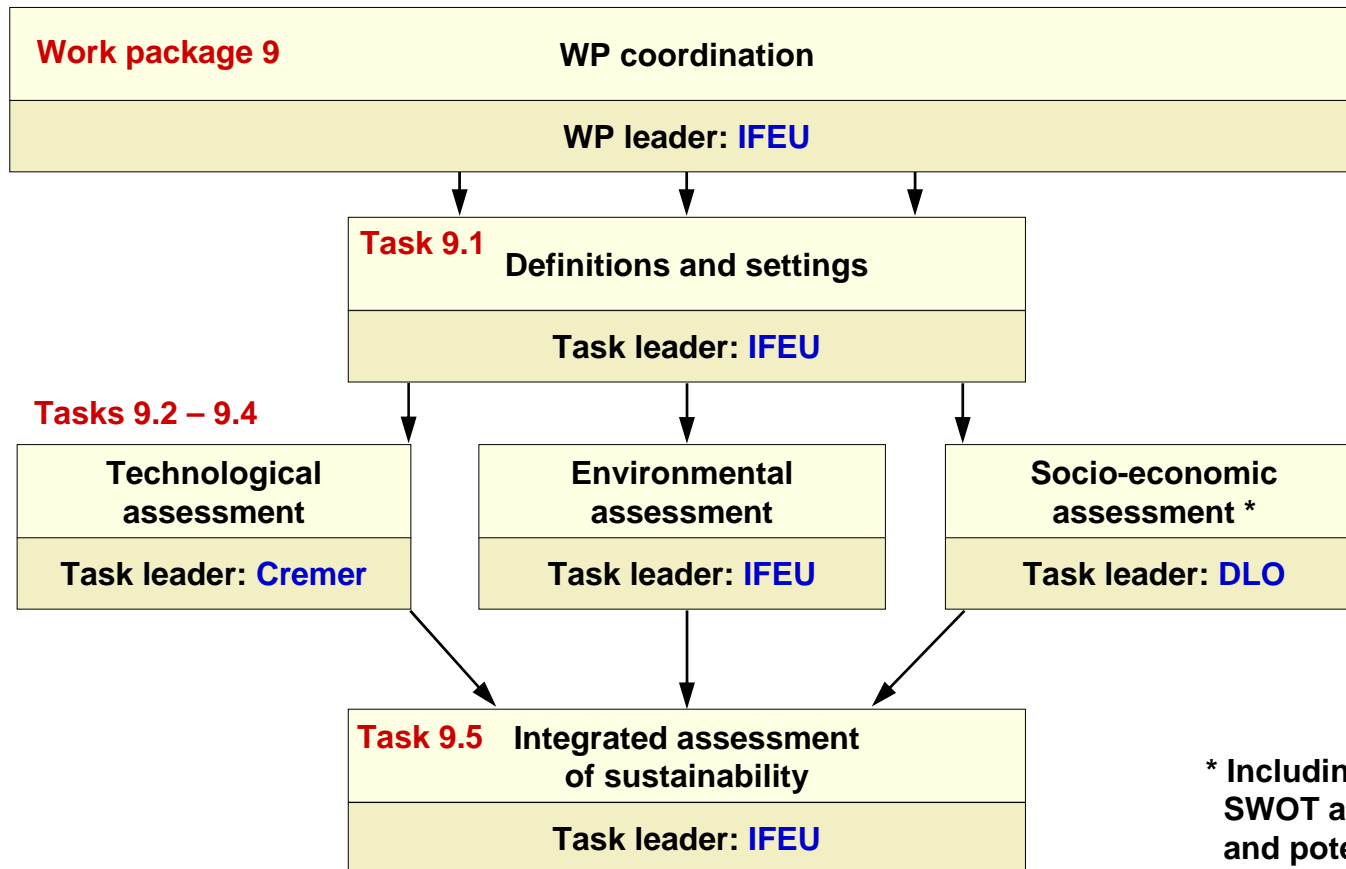
Demonstration
Production of crude
algae oil



Demonstration
Isolation, purification
and further modification
of PUFAs

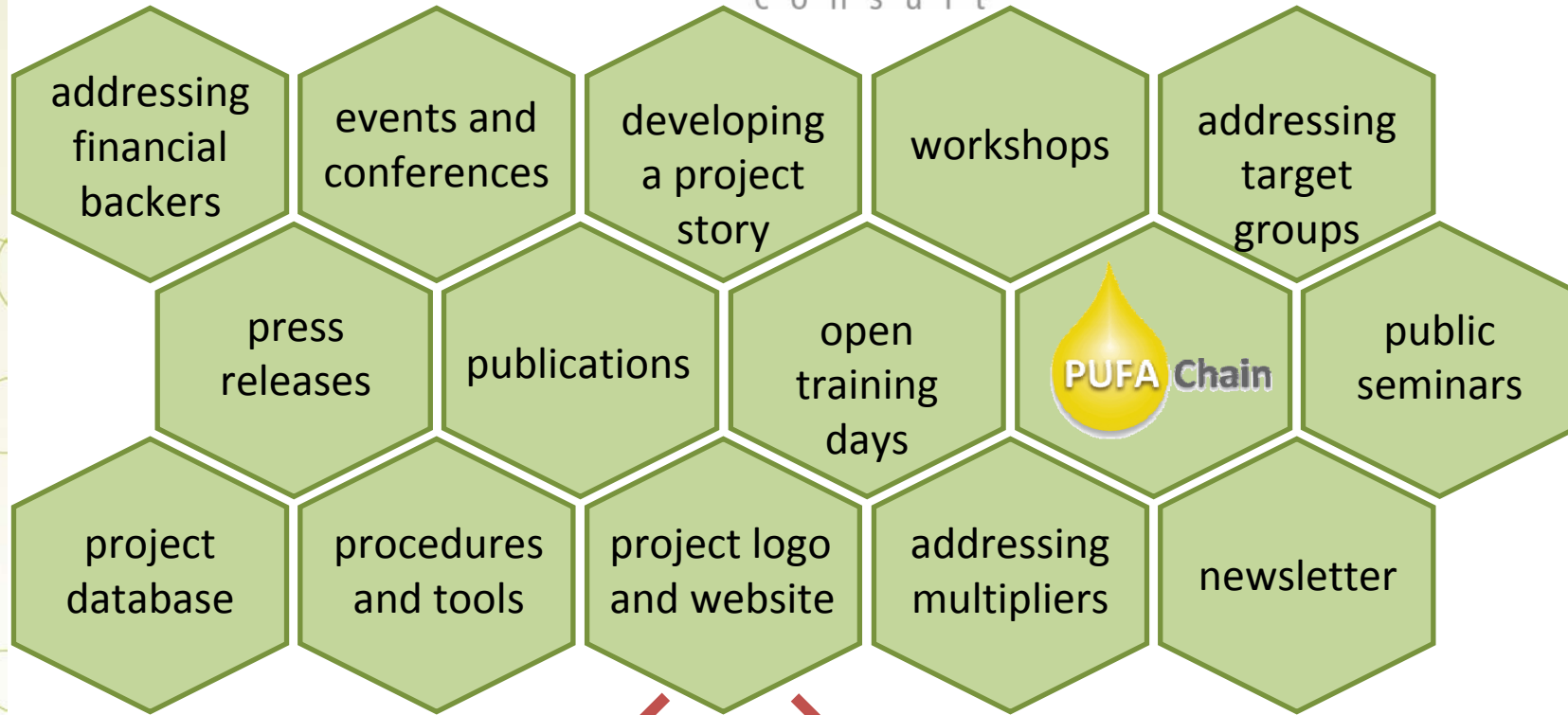


WP9: Sustainability



* Including SWOT analysis and potential analyses

WP 10: Dissemination



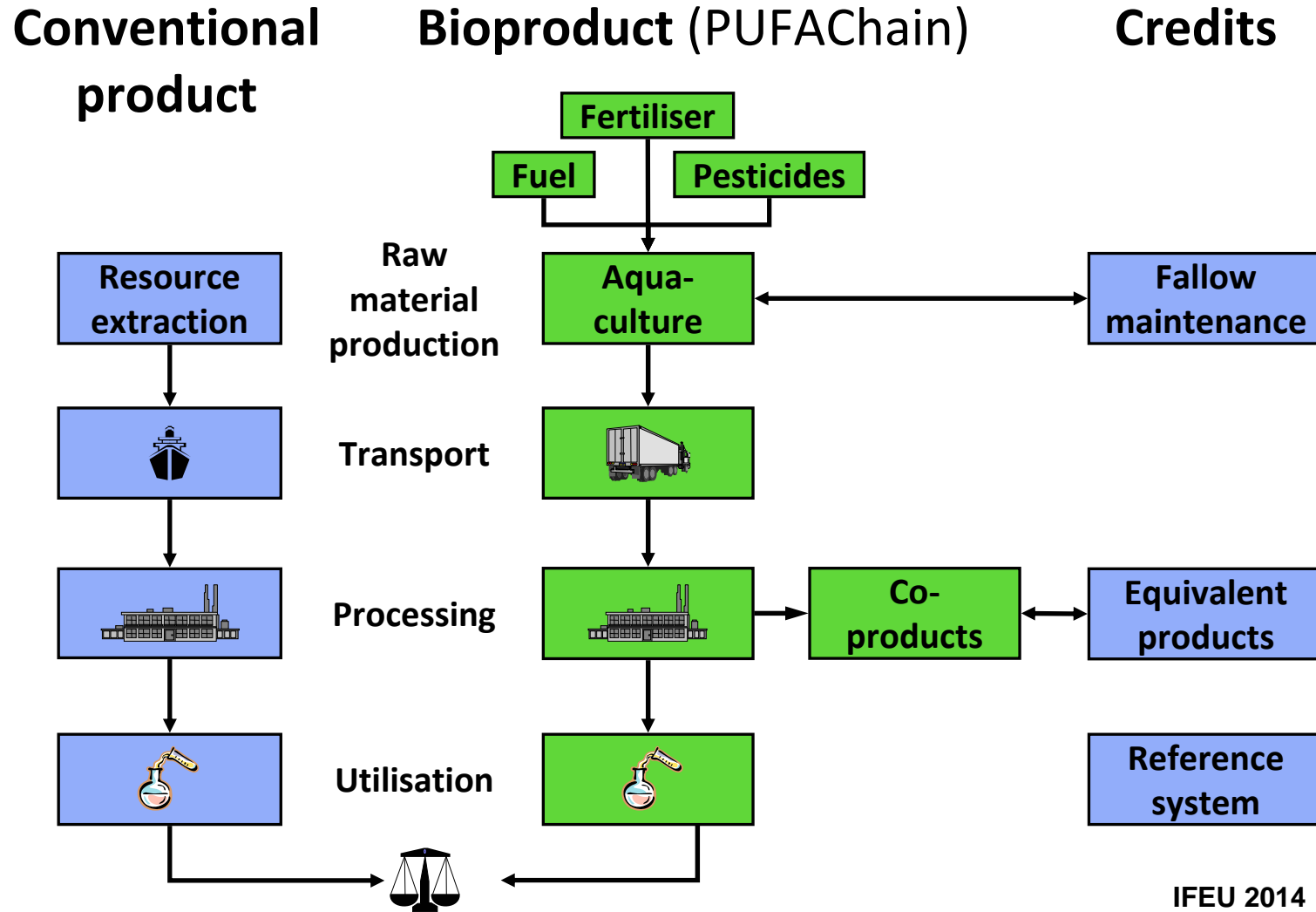
www.pufachain.eu




Agenda

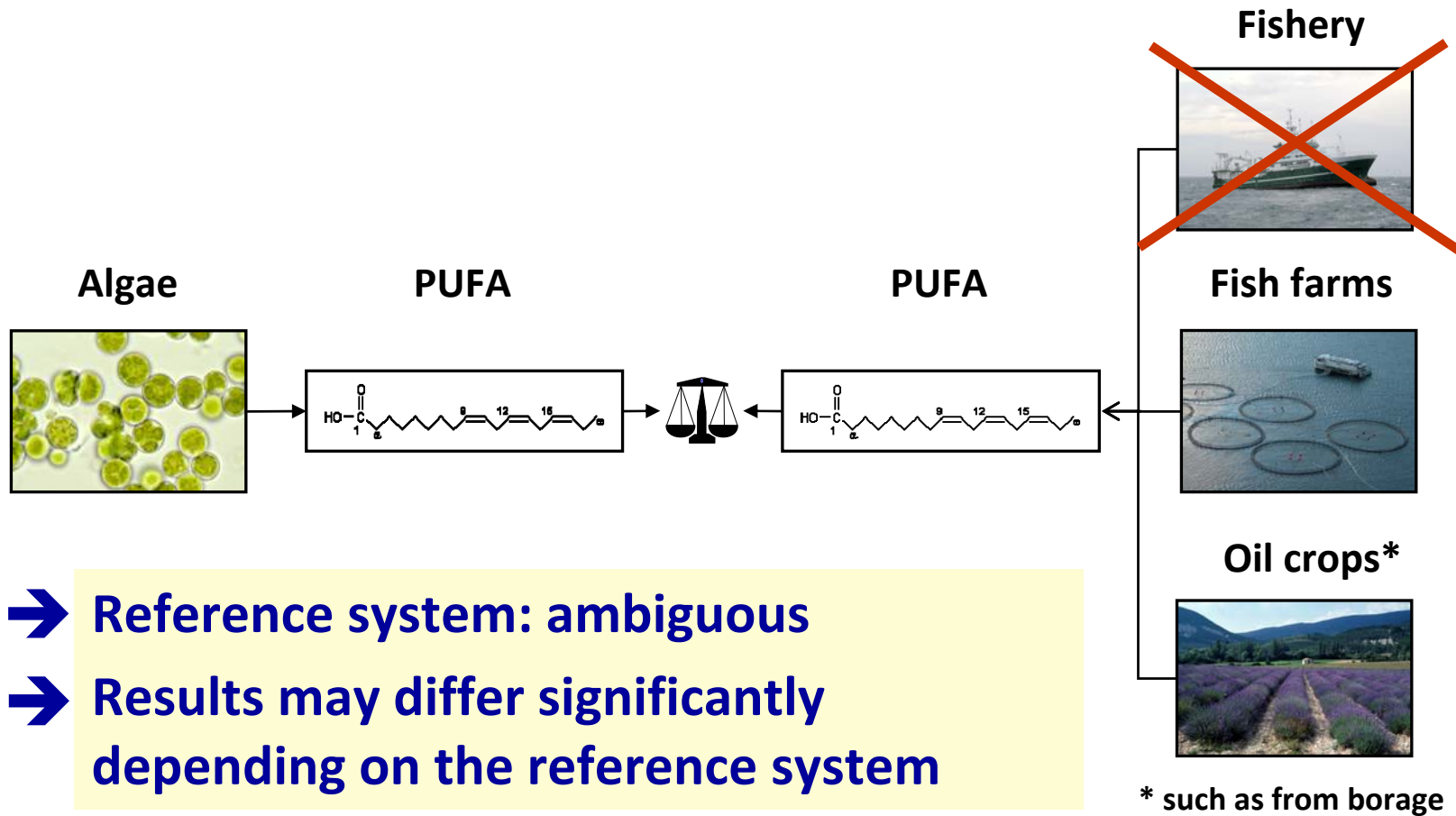
- PUFAChain: an overview
- ➔ LCA: PUFAChain specific highlights
- LCA and LC-EIA in PUFAChain
- Quo vadis: sustainability assessment
- Conclusions and recommendations

Life cycle comparison

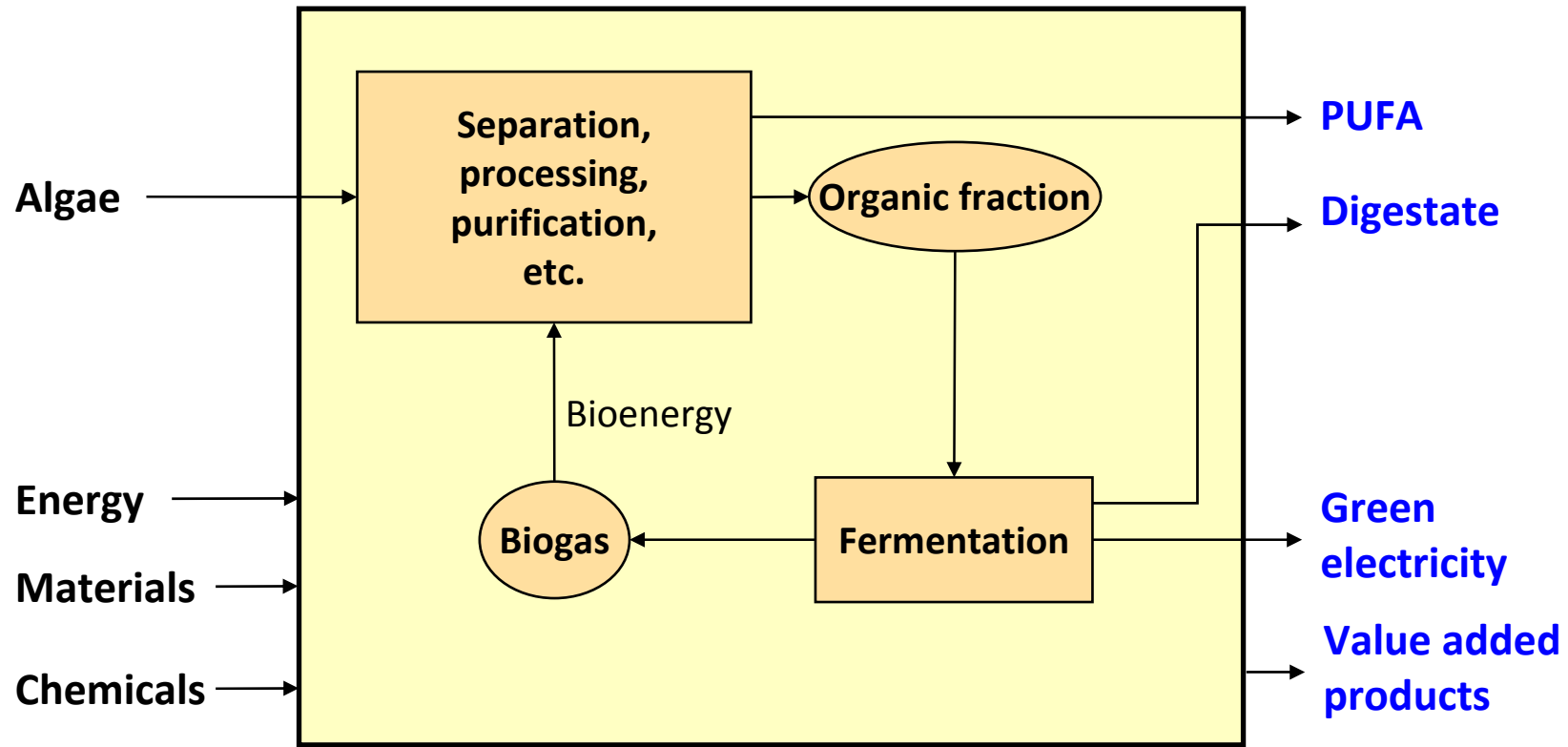


PUFA: life cycle comparisons

Algae pathways →  ← Conventional pathways

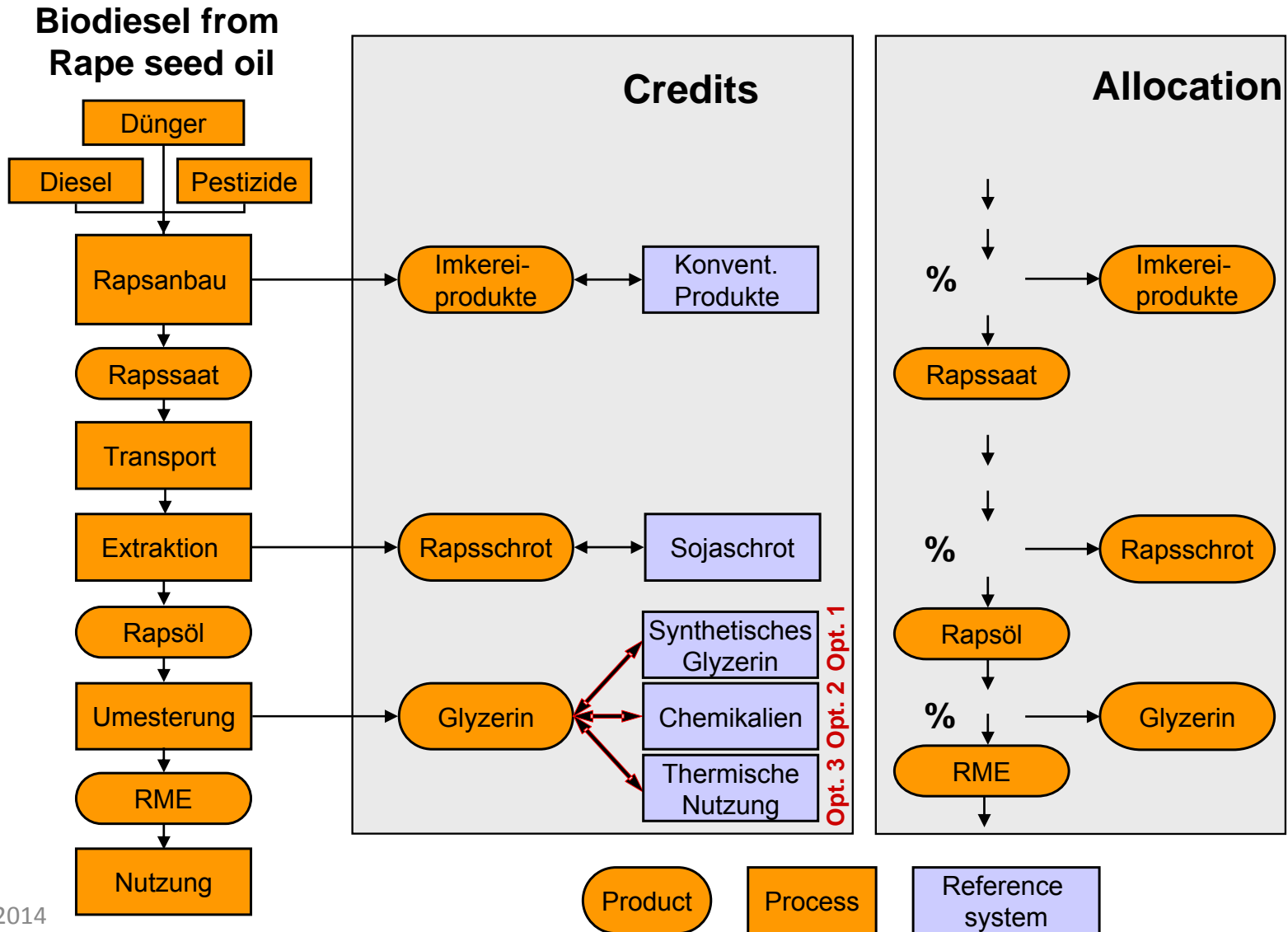


Details: process chain



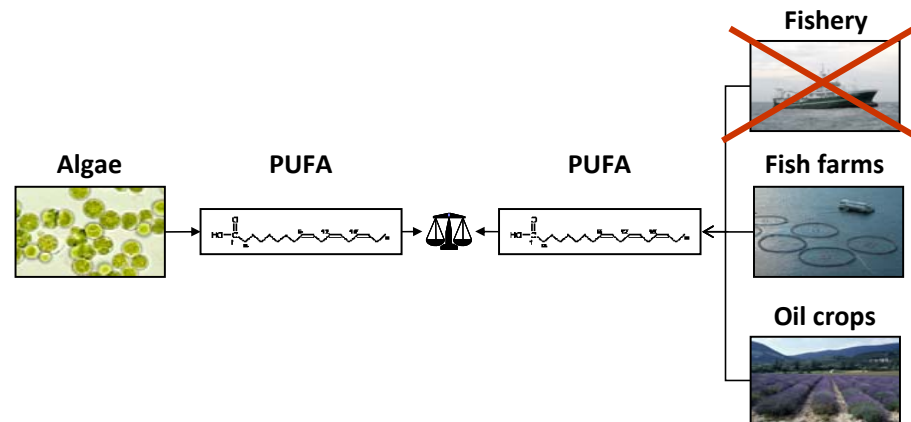
➔ **Results may differ significantly depending on co-product use**

Co-product handling in LCA

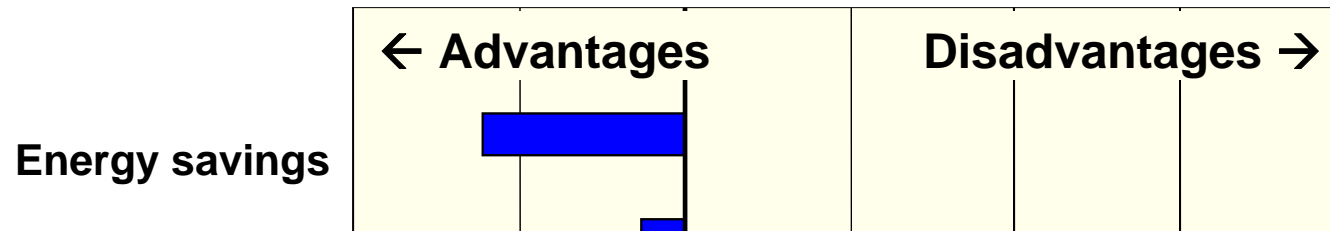


Conclusion I

- ➔ For the sustainability assessment of algae based products, the complete life cycle comparisons should be investigated by consideration of the full basket of commodities (“system expansion” instead of “allocation”).



LCA results: bio-products

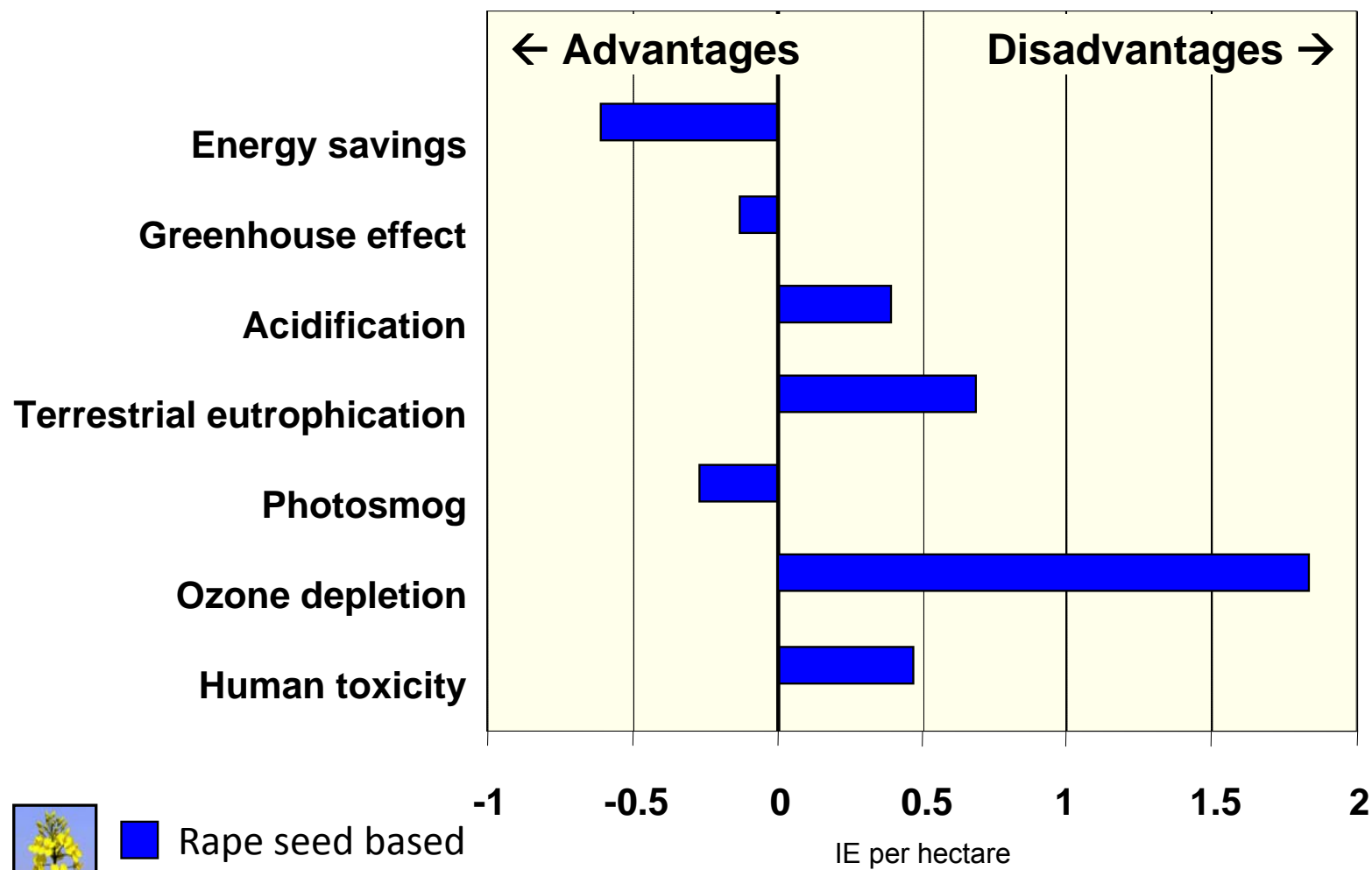


Algae based bio-product's scenario I:

- **Low production rate**
- **Low processing efficiency / high energy input**
- **Low amount of high value added products**
- **High amount of low value added products**

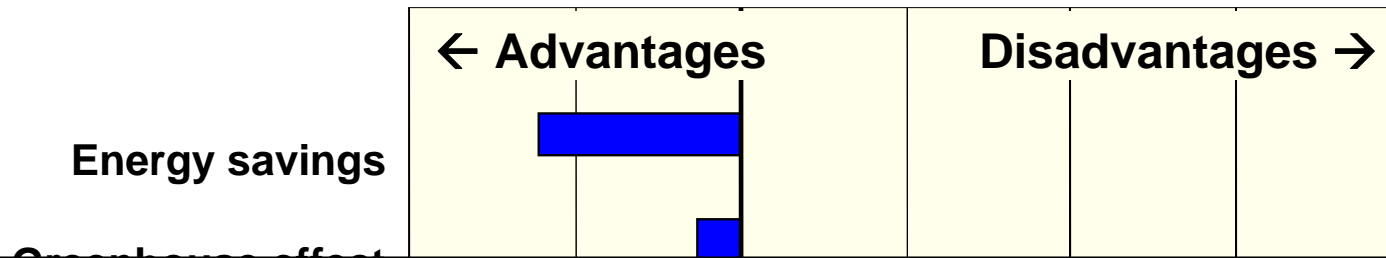
Source: IFEU 2014

LCA results: bio-products



Source: IFEU 2014

LCA results: bio-products

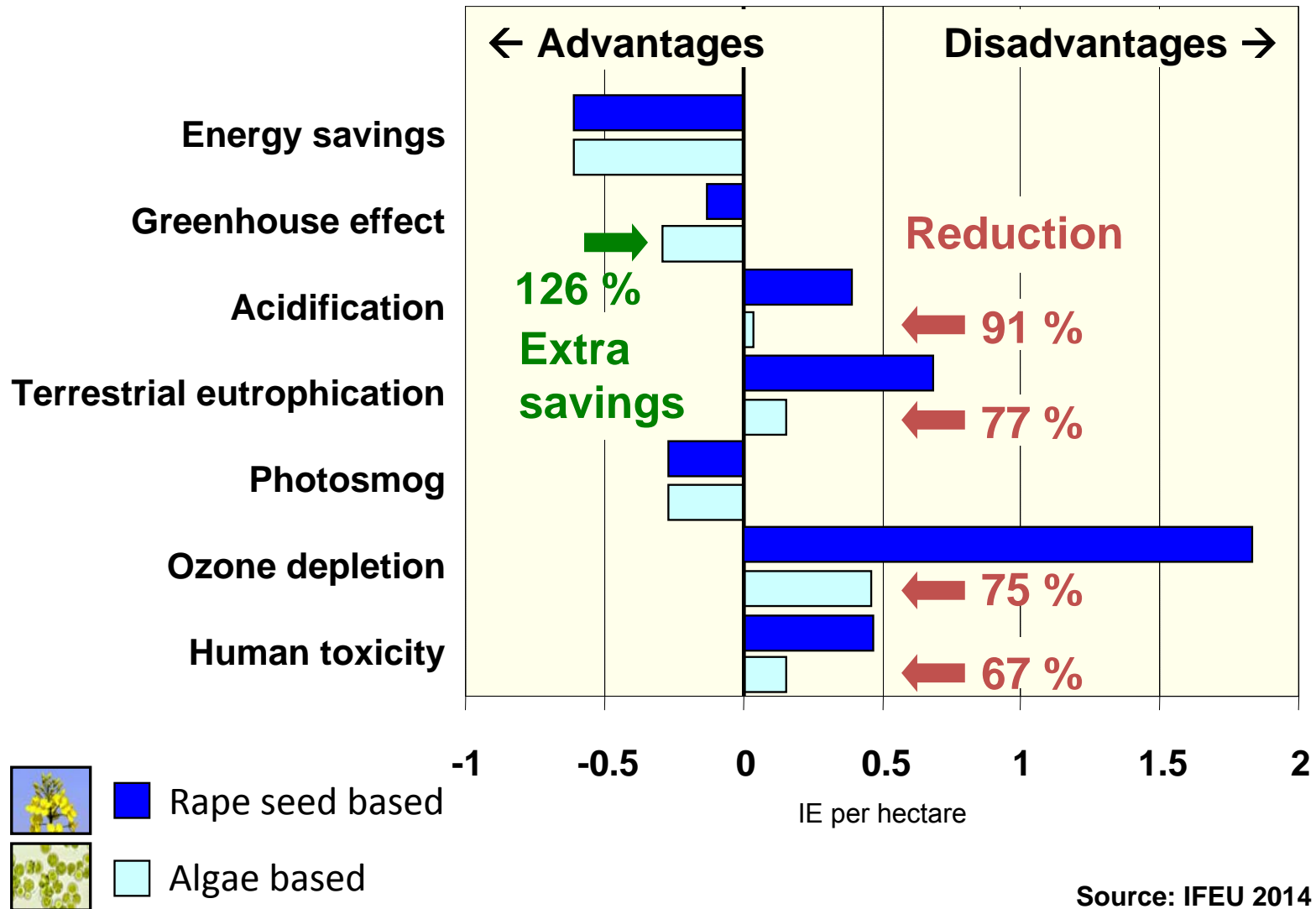


Algae based bio-product's scenario II:

- Closed production units
- Typical processing efficiency

Source: IFEU 2014

LCA results: bio-products



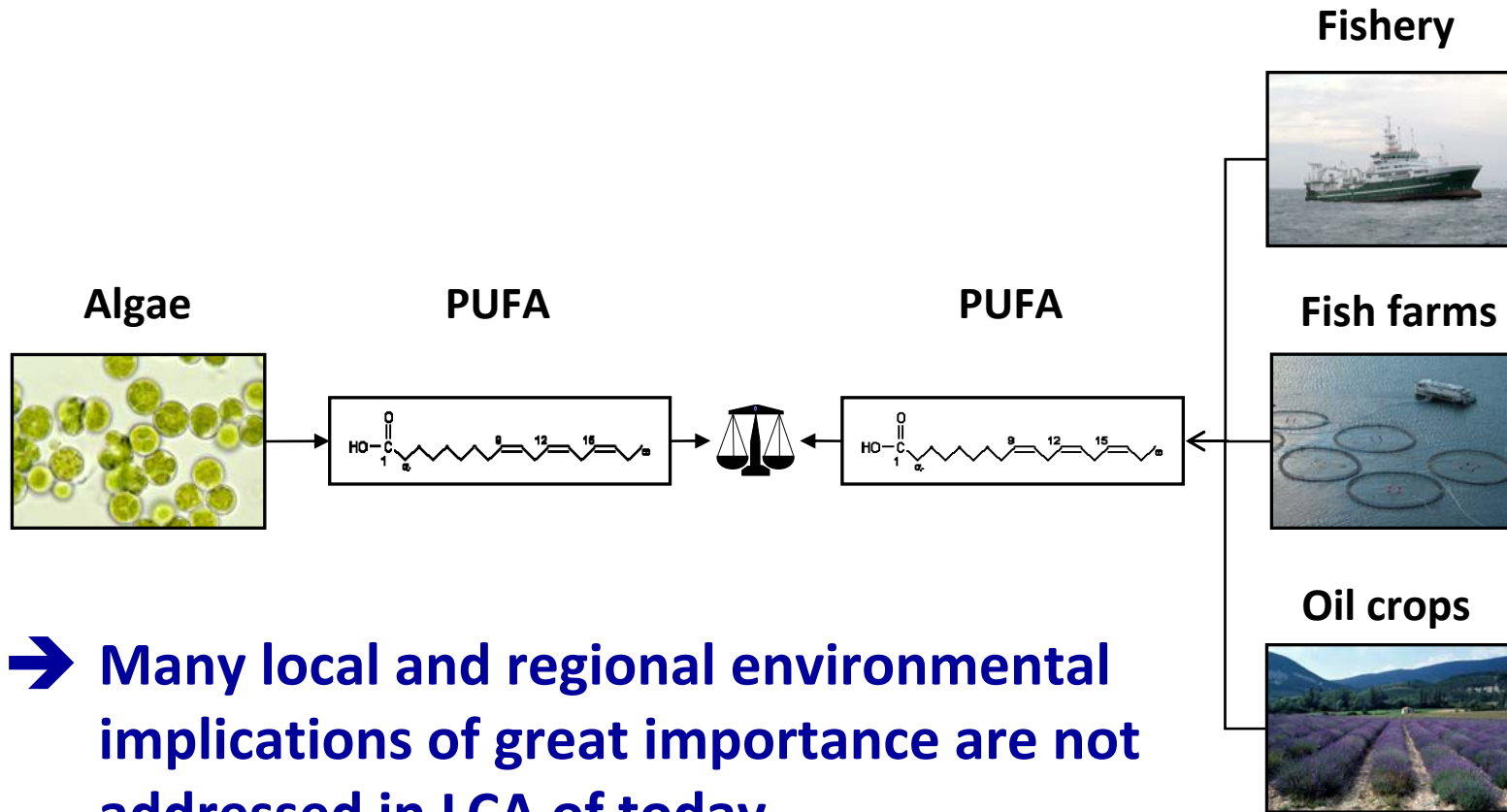
Conclusion II and III

- ➔ **Not all bio-products from algae such as bio-energy, bio-chemicals or bio-nutrients are associated with environmental benefits – just because they are “bio”.**
- ➔ **There is a high potential – far above average – for algae based products being environmental friendly.**

Agenda

- PUFAChain: an overview
- LCA: PUFAChain specific highlights
- ➔ LCA and LC-EIA in PUFAChain
- Quo vadis: sustainability assessment
- Conclusions and recommendations

PUFA: life cycle comparisons



- ➔ Many local and regional environmental implications of great importance are not addressed in LCA of today
- ➔ Need to supplement LCA methodology by a respective assessment tool

Environmental assessment

Methodologies

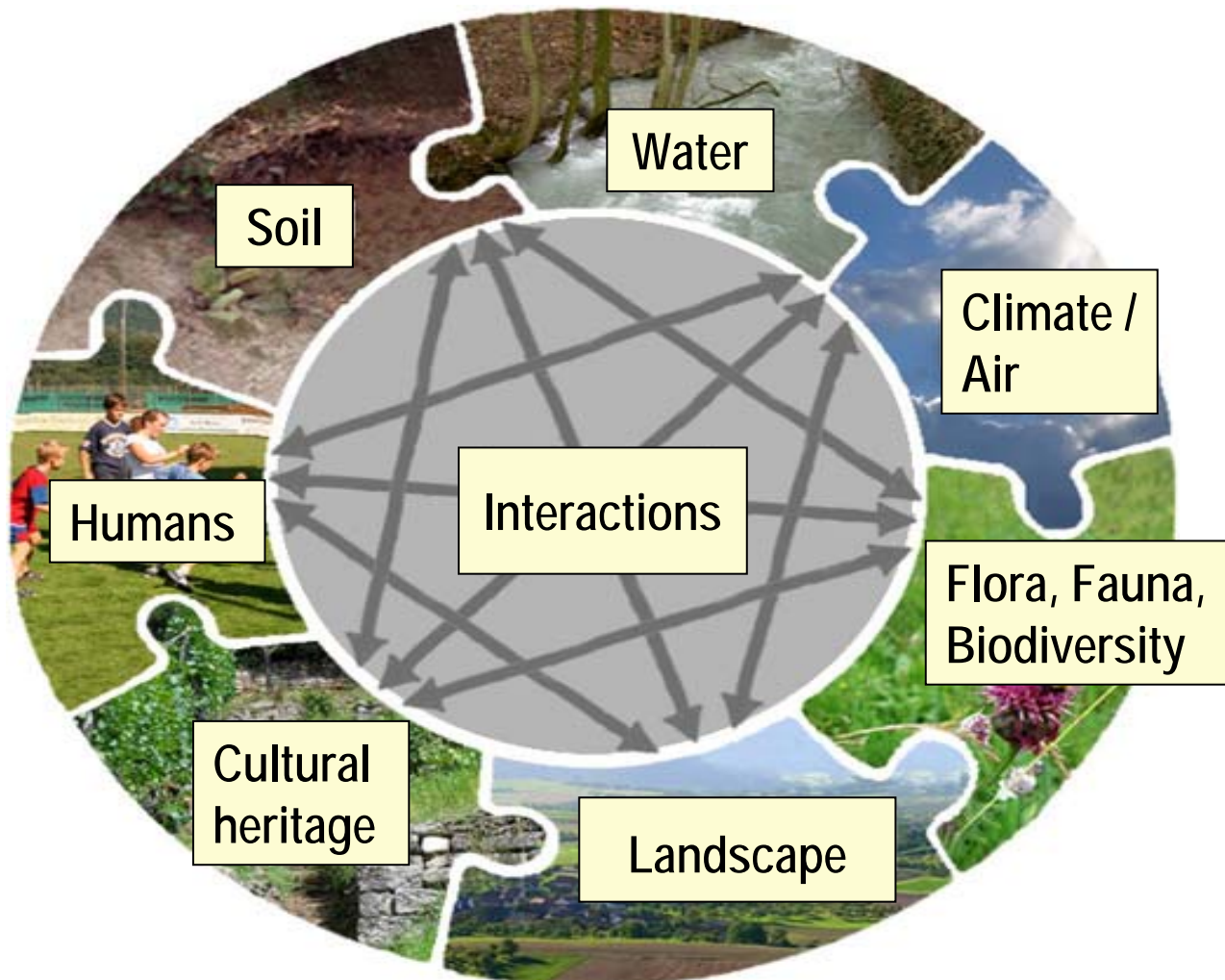
- Life cycle assessment (LCA)
- Life cycle environmental impact assessment (LC-EIA)

LCA	LC-EIA
→ Global impacts	→ Site-specific impacts



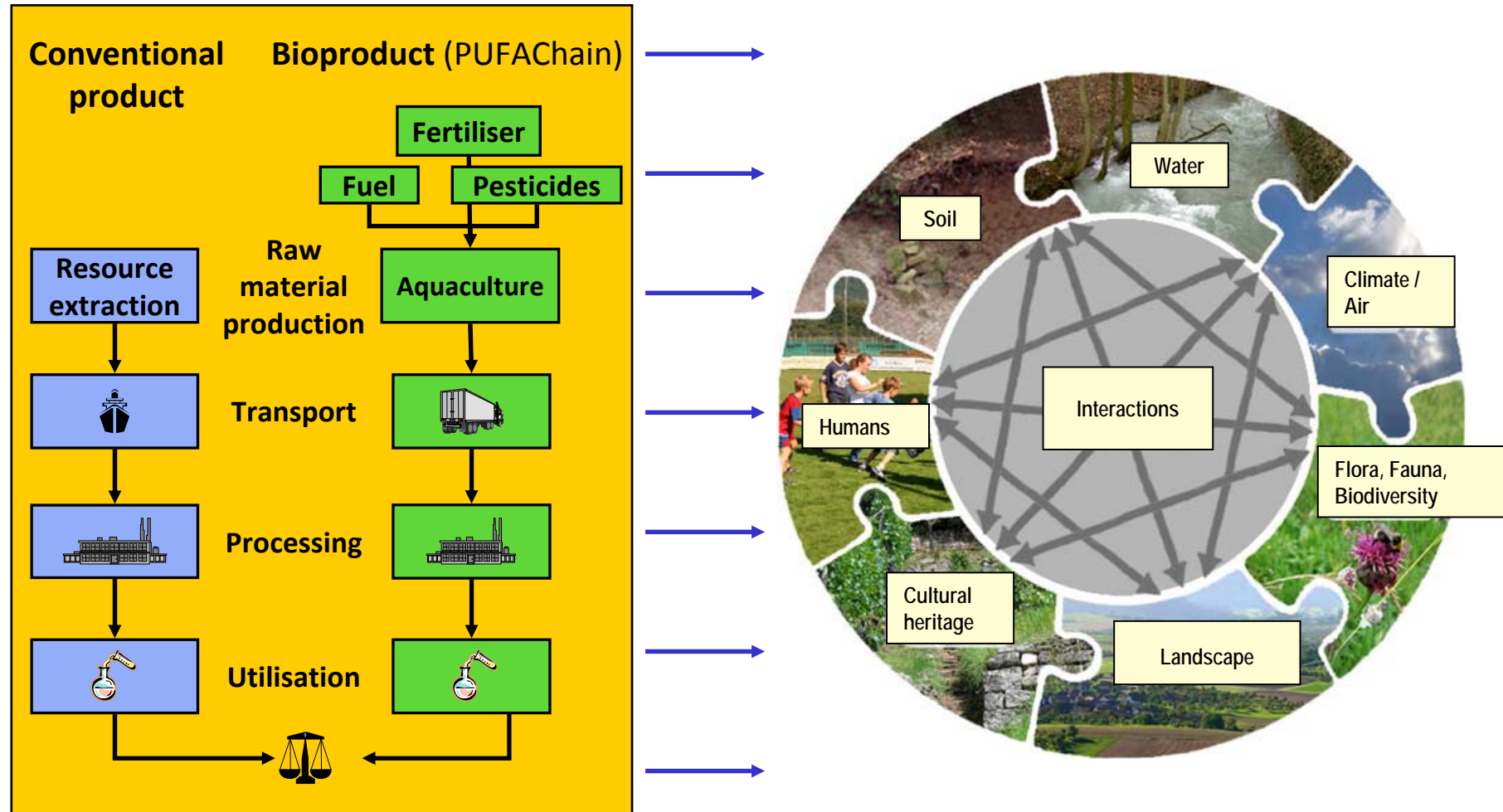
Environmental assessment

Compartments of the environment



Environmental assessment

LC-EIA: Life cycle environmental impact assessment



Results of an LC-EIA (example: comparisons)

		Perennial crops		Annual crops			Residues	
Feedstock		Arundo donax	Sugar cane	Rapeseed	Sorghum	Sugar beet	Cereal	Cereal straw
Type of risk	Reference scenario	non rsl	cerr.	rsl	rsl	rsl	rsl	conv. use
	Soil erosion		B	C	C	C	E	C
Soil compaction		A	D	C	C	E	C	C
Soil organic matter		B	E	D	D	E	D	D
Soil chemistry / fertiliser		C	D	D	D	E	D	D
Nutrient leaching, Eutrophication		B	D	D	D	D	D	D
Water demand		D	D	C	D	E	C	C
Weed control / pesticides		B	E	E	E	E	E	E
Loss of habitat / species diversity		C	E	C	D	D	D	D
Loss of landscape elements		C	C	c	C	C	C	C

Impact category: A = minimum impact; E = maximum impact

non rsl: non-rotational fallow set-aside land, no cropping; **cer.:** cerrado (topical savannah);

rsl: rotational set-aside fallow land, no cropping; **conv. use:** conventional use

Source: IUS 2013

Results of an LC-EIA (example: scenarios)

	BIOLYFE scenarios				Alternatives to BIOLYFE					
	Arundo	Fibre sorghum	Wheat straw	Marginal land (Arundo)	BTL (Arundo)	Wheat ethanol	Beet ethanol	Cane ethanol (Brazil)	Rape seed biodiesel	Maize bio-methane
Environment										
Water	---	-	0	-	---	0	-	-	-	-
Soil	0	-	0	---	0	-	---	0	---	---
Fauna	0	-	0	---	0	-	-	-	-	-
Flora	-	-	0	---	-	-	---	-	-	---
Landscape	0	0	0	0	0	0	0	-	0	0



Ranking by 5 categories: ++ + 0 - --

Results of an LC-EIA (example: scenarios)

→ Quod erat demonstrandum:

LC-EIA (Life cycle environmental impact assessment) ...

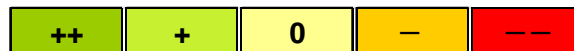
... exists

... works well

... is applicable

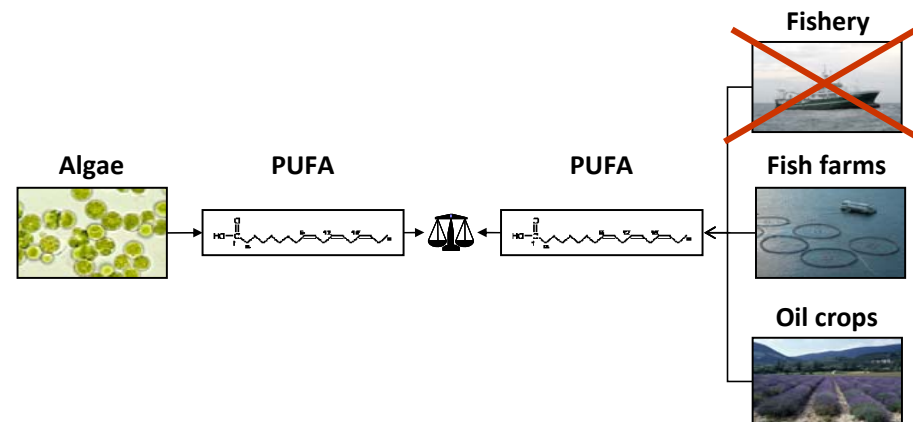
... can supplement LCA

Ranking by 5 categories:



Conclusion IV

➔ For a conclusive environmental assessment for algae based biorefineries a combination is necessary: LCA plus LC-EIA



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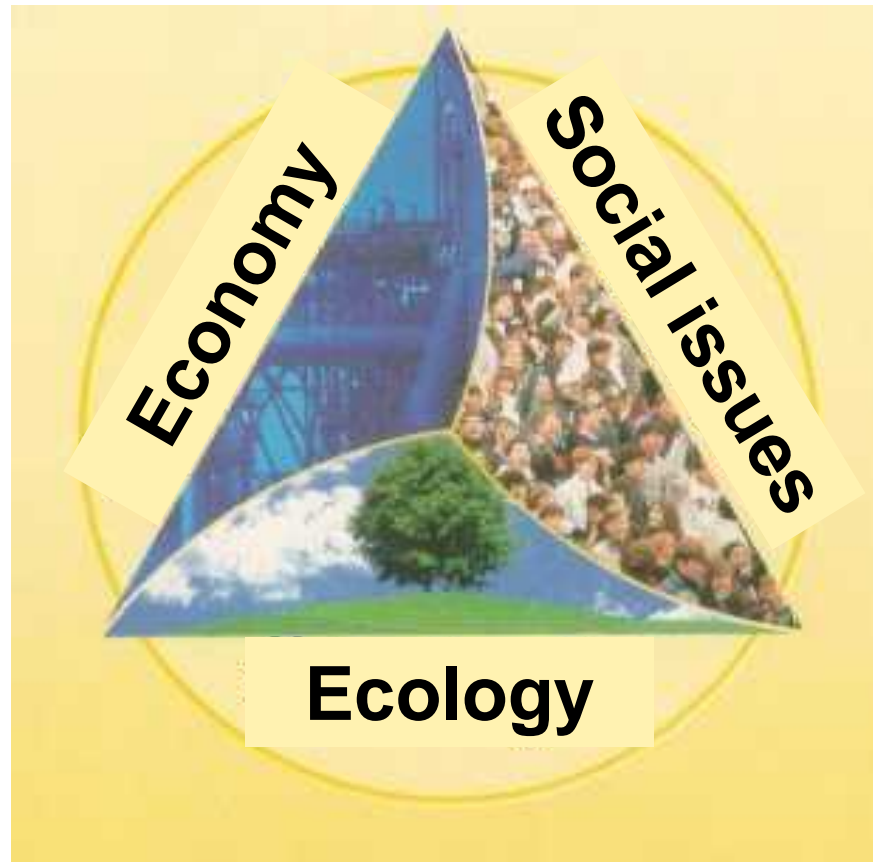
Sustainability

Definition

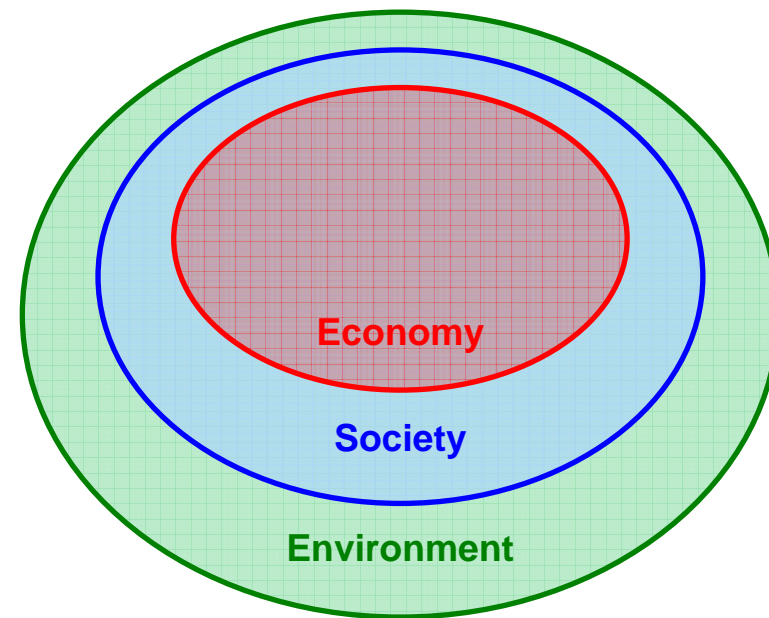
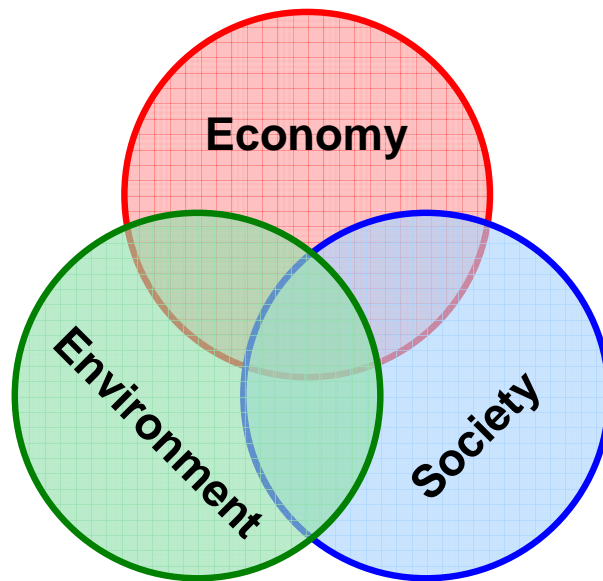
"Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

Brundtland Commission 1987

The principle of sustainability



Sustainability



24th April 2014

Guido
Reinhardt



The research leading to these results has received funding from the European Commission's Seventh Framework Programme (FP7-KBBE-2013-7-single-stage) under the grant agreements n° 613303



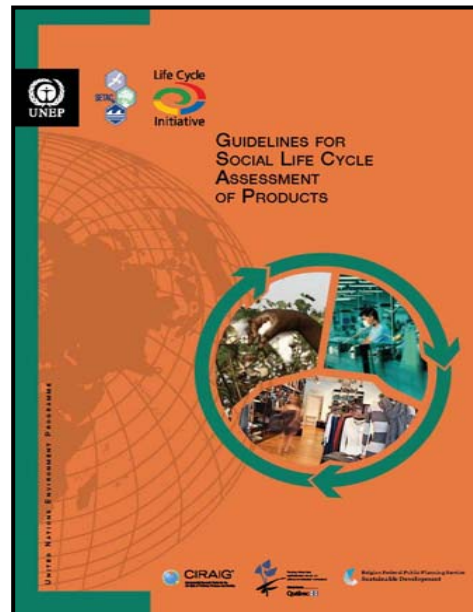
Sustainability

➔ Not sufficient: e.g. technological, legal and political issues are not addressed sufficiently.

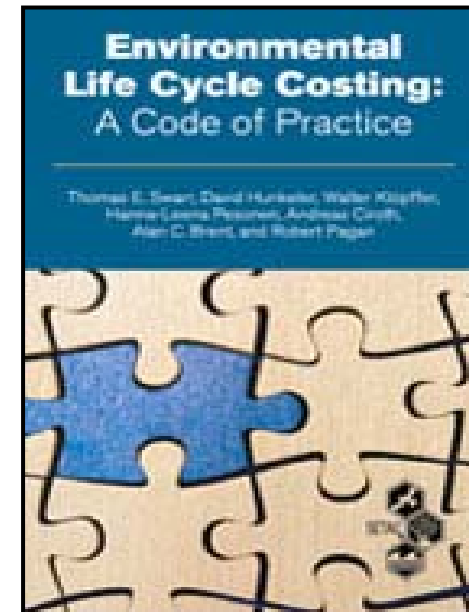
Life Cycle Assessment (LCA)



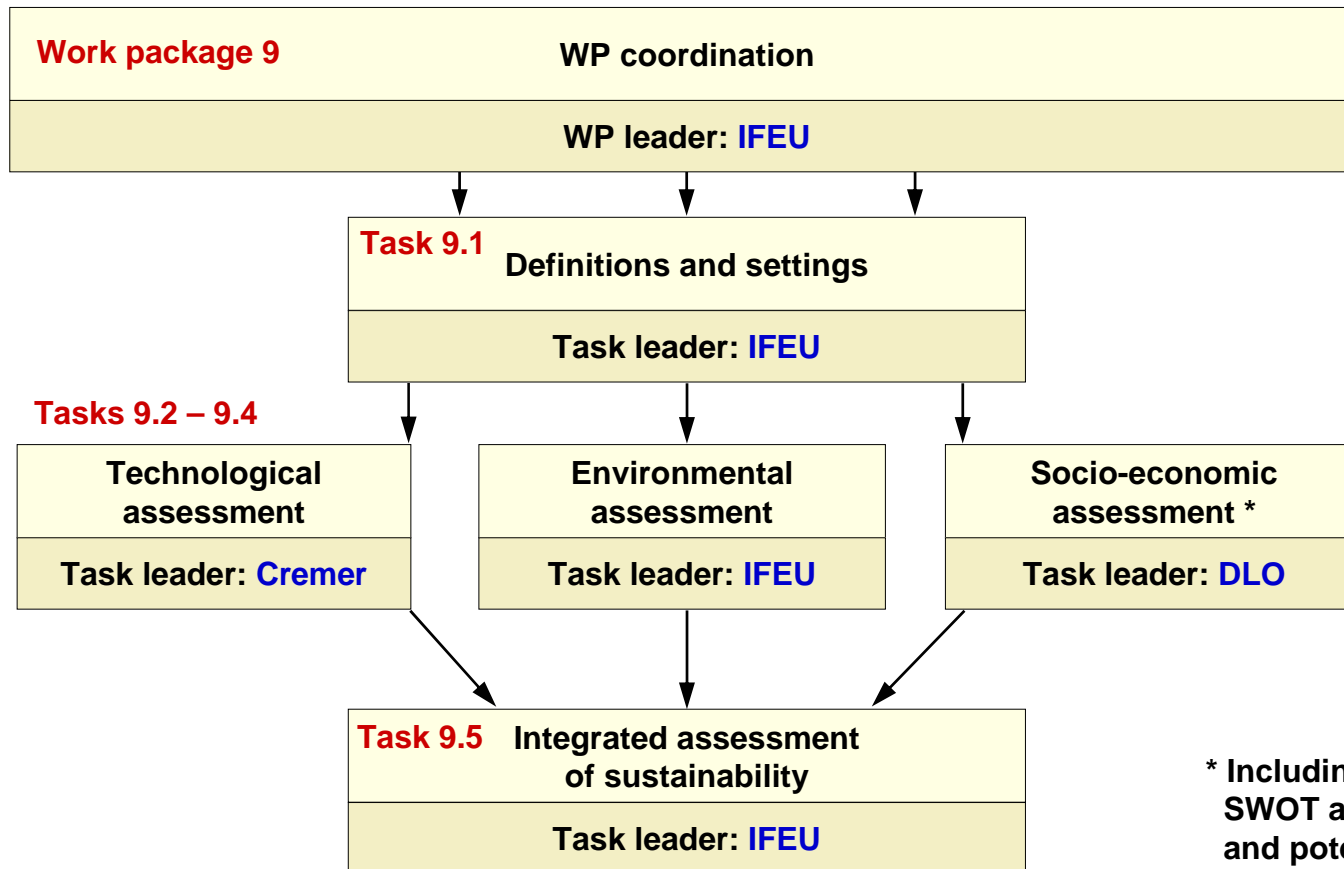
Social Life Cycle Assessment (sLCA)



Environmental Life Cycle Costing (eLCC)



WP9: Sustainability in PUFAChain



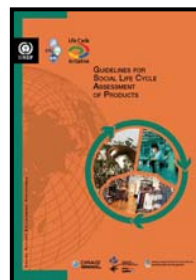
* Including SWOT analysis and potential analyses

Conclusion V and VI

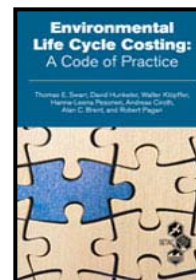
- ➔ For a conclusive sustainability assessment of algae based products, all pillars of sustainability should be investigated including technological, environmental, economic, social, political, and legal aspects.
- ➔ For this, an appropriate mix of existing and specific assessment tools may be used to address the goal and scope questions best.



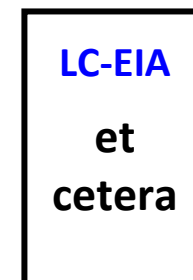
LCA



sLCA



eLCC



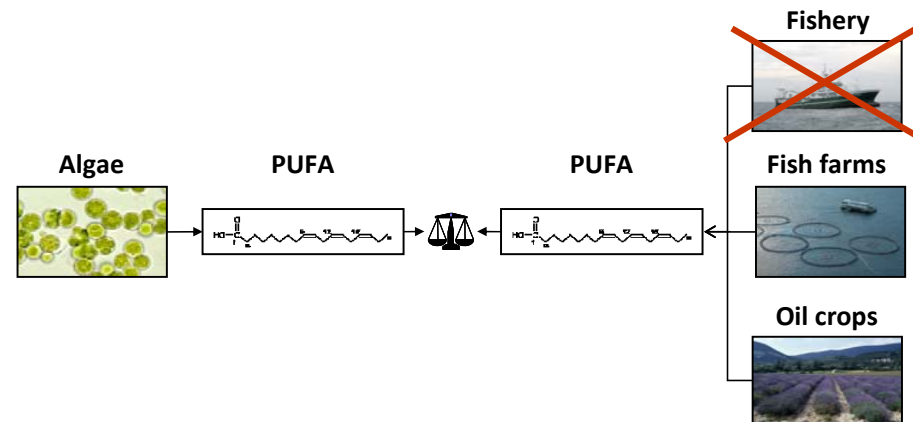
Others

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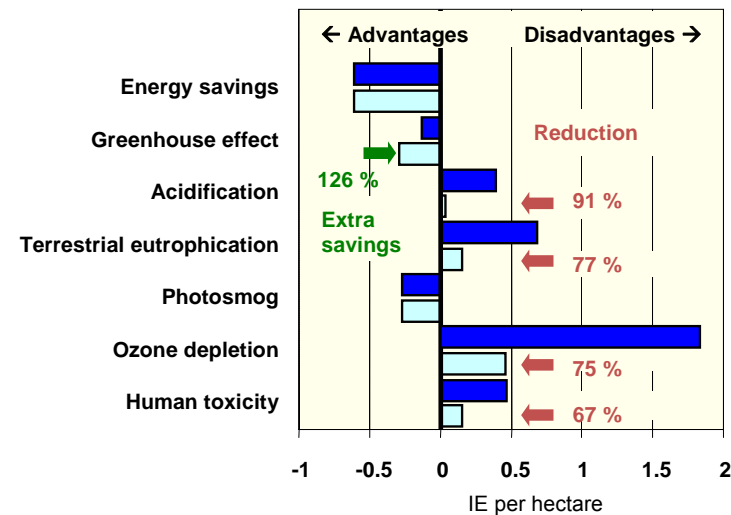
Conclusions

- ➔ For the sustainability assessment of algae based products, the complete life cycle comparisons should be investigated by consideration of the full basket of commodities (“system expansion” instead of “allocation”).



Conclusions

- ➔ Not all bio-products from algae such as bio-energy, bio-chemicals or bio-nutrients are associated with environmental benefits – just because they are “bio”.
- ➔ There is a high potential – far above average – for algae based products being environmental friendly.
- ➔ For their identification and optimization, the simultaneous application of both, LCA and LC-EIA, are appropriate.

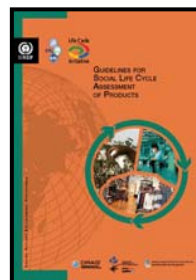


Recommendations

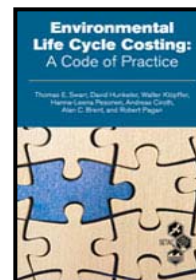
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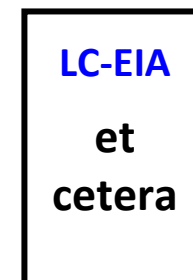
LCA



sLCA



eLCC



Others

LC-EIA and integrated sustainability assessment

Interested ?

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Downloads:

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Sustainability assessment

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Homepage

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