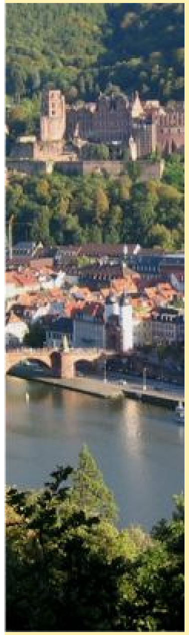
Life cycle assessments of future crops for fiber and fuels

Dr Guido Reinhardt & Nils Rettenmaier

3rd Workshop of the 4F CROPS project
Poznan, 17 November 2009

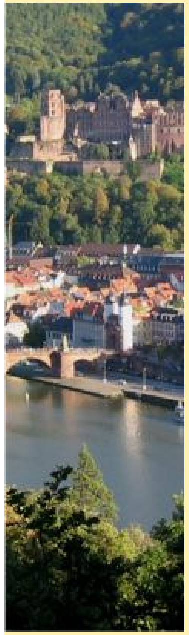
Who we are - What we do



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

- **Independent scientific research institute**
- **organised as a private non profit company with currently about 40 employees**
- **Research / consulting on environmental aspects of**
  - Energy (including Renewable Energy)
  - Transport
  - Waste Management
  - Life Cycle Analyses
  - Environmental Impact Assessment
  - Renewable Resources
  - Environmental Education

Who we are - What we do

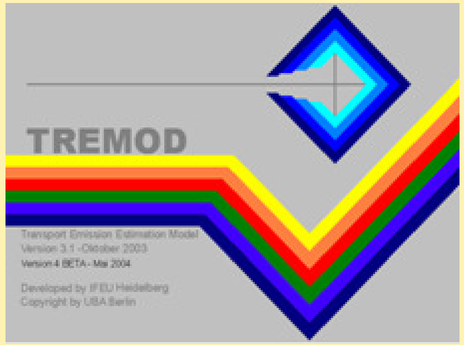


IFEU focuses regarding the topic of biomass

- **Research / consulting on environmental aspects of**
  - transport biofuels
  - biomass-based electricity and heat
  - biorefinery systems
  - biobased materials
  - agricultural goods and food
  - cultivation systems (conventional agriculture, organic farming, etc.)
- **Potentials and future scenarios**
- **Technologies / technology comparisons**
- **CO_2 avoidance costs**
- **Sustainability aspects / valuation models**

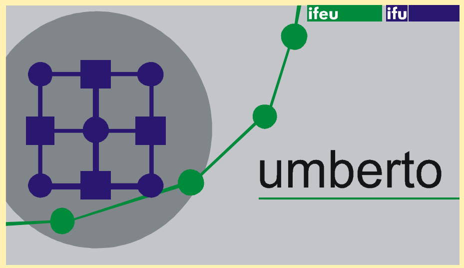
Who we are - What we do

TREMOD: Transport Emission Model



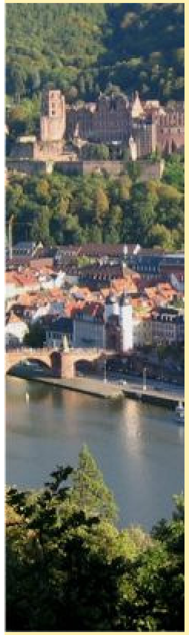
- Modelling emissions of road vehicles, trains, ships and airplanes
- Official database of the German Ministries for emission reporting

Life cycle analyses (LCA) and technology impact assessments since 1990:



- Biofuels (all biofuels, all applications)
- Alternative transportation modes
- Renewable Energy

Who we are - What we do



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

Our clients (on biomass studies)

- World Bank
- UNEP, FAO, UNFCCC, GTZ, etc.
- European Commission
- National and regional Ministries
- Associations (industrial, scientific)
- Local authorities
- WWF, Greenpeace, Friends of the Earth etc.
- Companies (Daimler, German Telecom, Shell etc.)
- Foundations (German Foundation on Environment, etc.)

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Life cycle assessments of future crops for fiber and fuels

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Poznan, 17 November 2009

Background

ifeu –
Institut für Energie- und Umweltforschung
Heidelberg gGmbH

CO_2 Mitigation through Biofuels in the Transport Sector

Status and Perspectives

Dr. Guido Reinhardt
Sven Gärtner
Markus Quirin
Martin Pehnt

Commissioned by the
Research Association for Combustion Engines (FVV)

Heidelberg, 2004

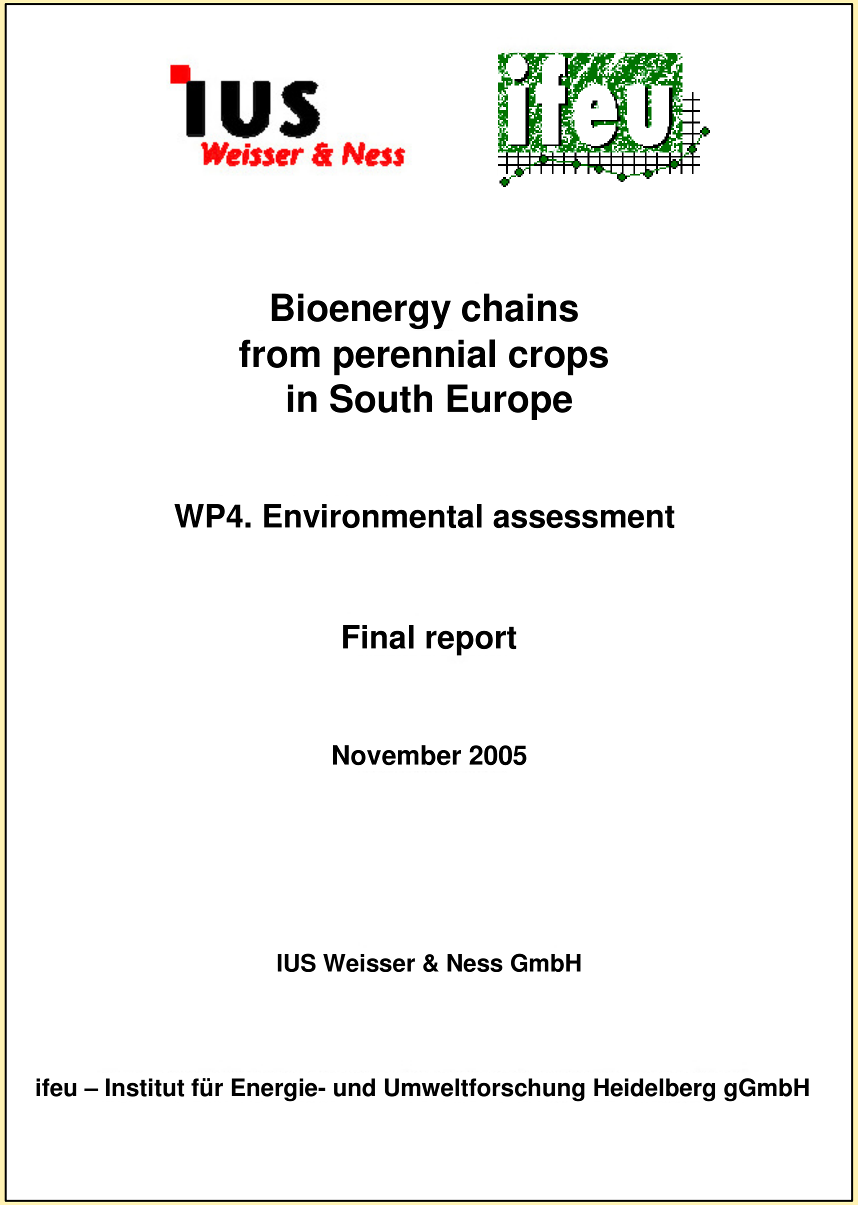
„CO_2 Mitigation through Biofuels in the Transport Sector. Status and Perspectives“

Commissioned by the Research Association for Combustion Engines (FVV), Frankfurt

Authors:
Guido Reinhardt, Sven Gärtner, Markus Quirin & Martin Pehnt

Project duration:
2003 - 2004

Background


Bioenergy chains
from perennial crops
in South Europe

WP4. Environmental assessment

Final report

November 2005

IUS Weisser & Ness GmbH

ifeu – Institut für Energie- und Umweltforschung Heidelberg gGmbH

„Bioenergy chains from perennial crops in South Europe – Environmental assessment“

Project funded by the European Commission’s FP 5 programme.

Authors:
Karl Scheuerlen, Guido Reinhardt & Sven Gärtner

Project duration:
Jan 2001 – Dec 2005

Background

ifeu –
Institut für Energie-
und Umweltforschung
Heidelberg gGmbH

Renewable raw materials for the chemical industry

Options and potentials for the future

Dr. Guido Reinhardt
Andreas Detzel
Sven Gärtner
Nils Rettenmaier
Martina Krüger

Supported by the
German chemical industry association (VCI)

Heidelberg, 2007

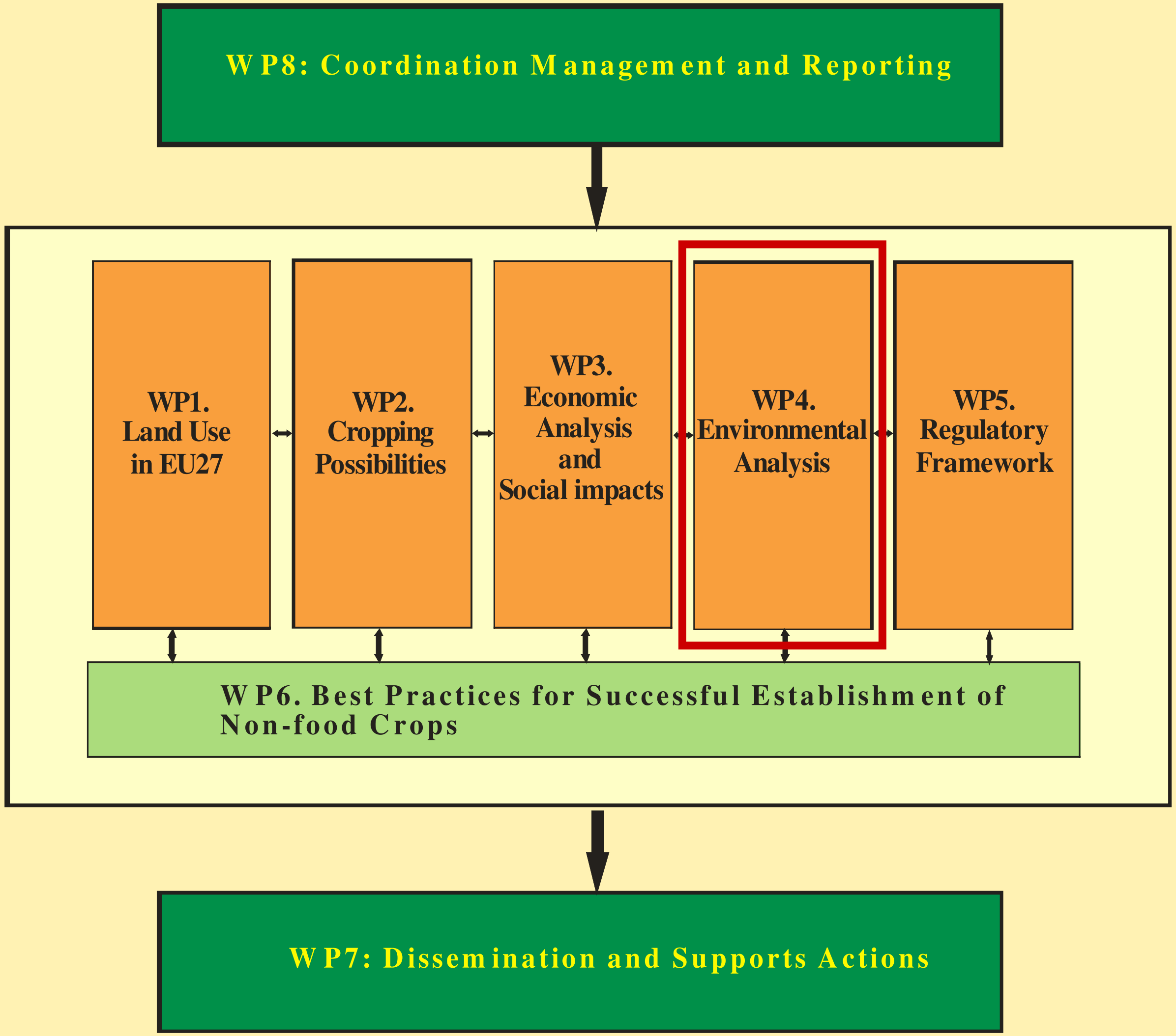
„Renewable raw mate-rials for the chemical industry – Options and potentials for the future“

Report prepared under support of the German chemical industry association (VCI), Frankfurt.

Authors:
Guido Reinhardt, Andreas Detzel, Sven Gärtner, Nils Rettenmaier & Martina Krüger

Project duration:
Dec 2005 – Jan 2007

IFEU's role in 4F CROPS



- **WP leader** of WP4
- **Task leader** of Tasks 4.2, 4.3 and 4.4

WP 4: Environmental analysis

Goal

Assessment of environmental implications and identification of best options for each region or country.

Task 4.1	Environmental impact assessment
➔ Task 4.2	Life cycle analysis
Task 4.3	Modelling of dependencies and sensibilities
Task 4.4	Identification of best options

Biofuels and bio-based materials

Environmental advantages and disadvantages:

+

- CO_2 neutral
- Save energetic resources
- Organic waste reduction
- Less transport
- etc.

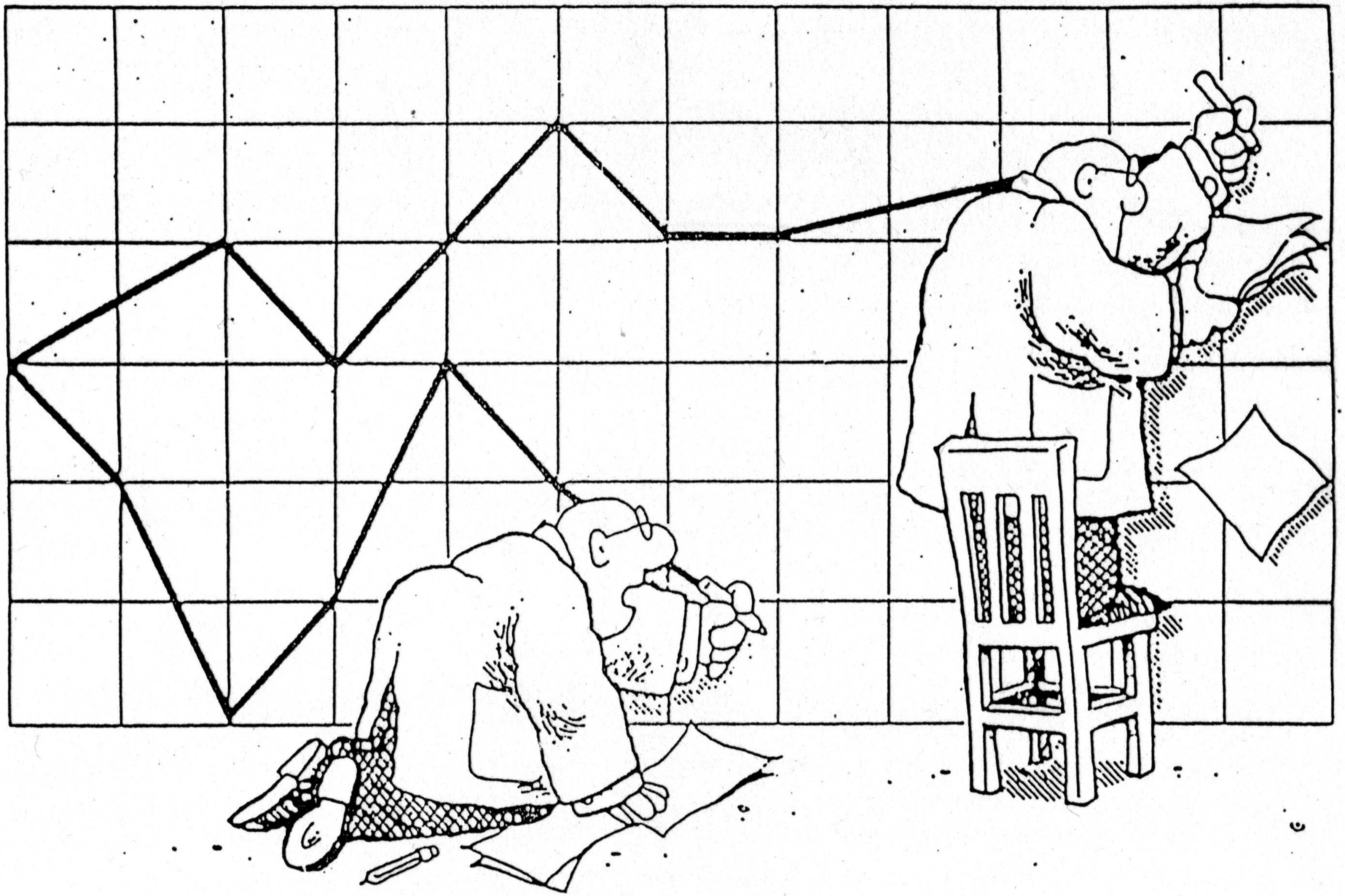
–

- Land use
- Eutrophication of surface water
- Water pollution by pesticides
- Energy intensive production
- etc.

Total:

positive or negative

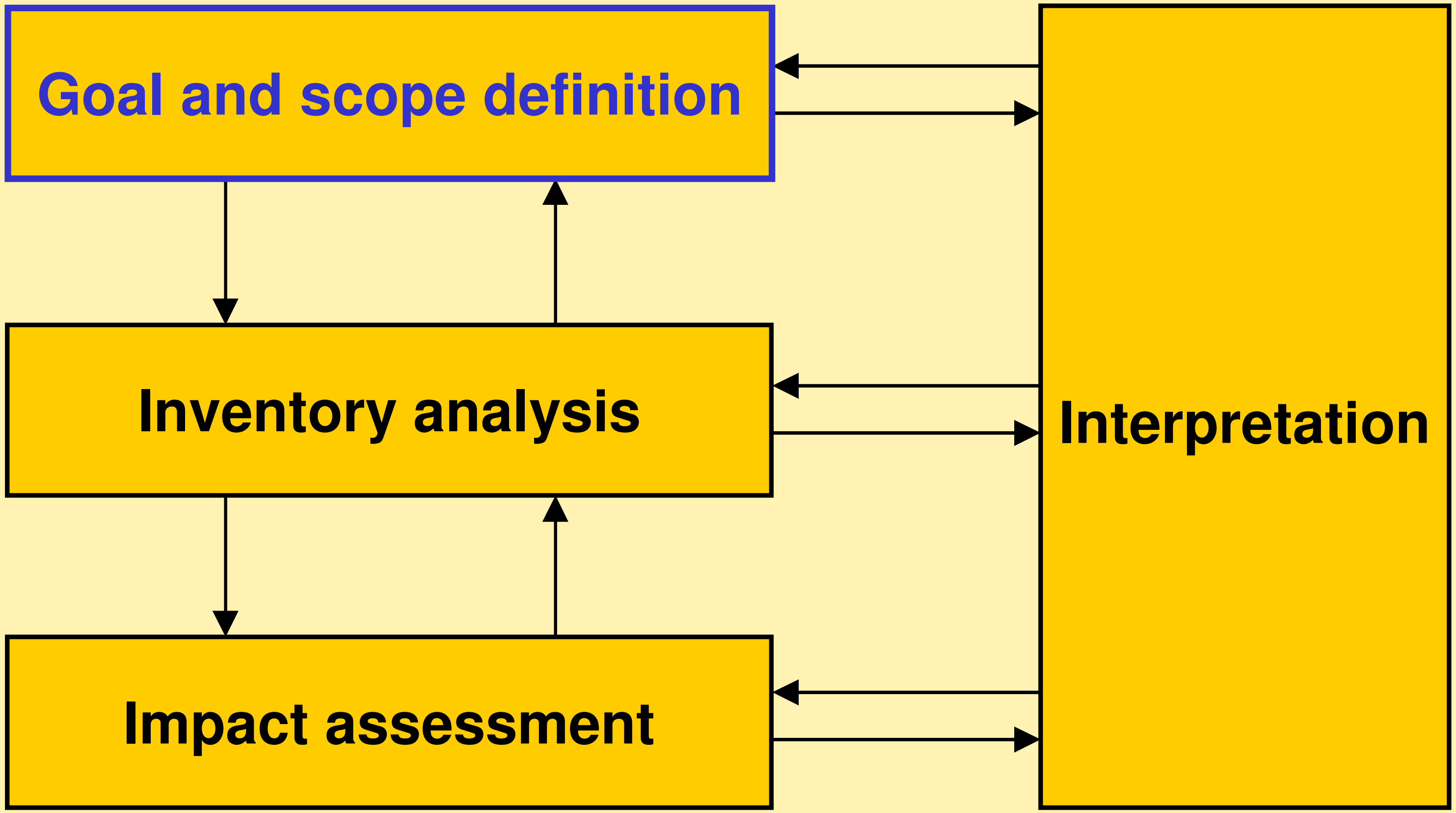
?



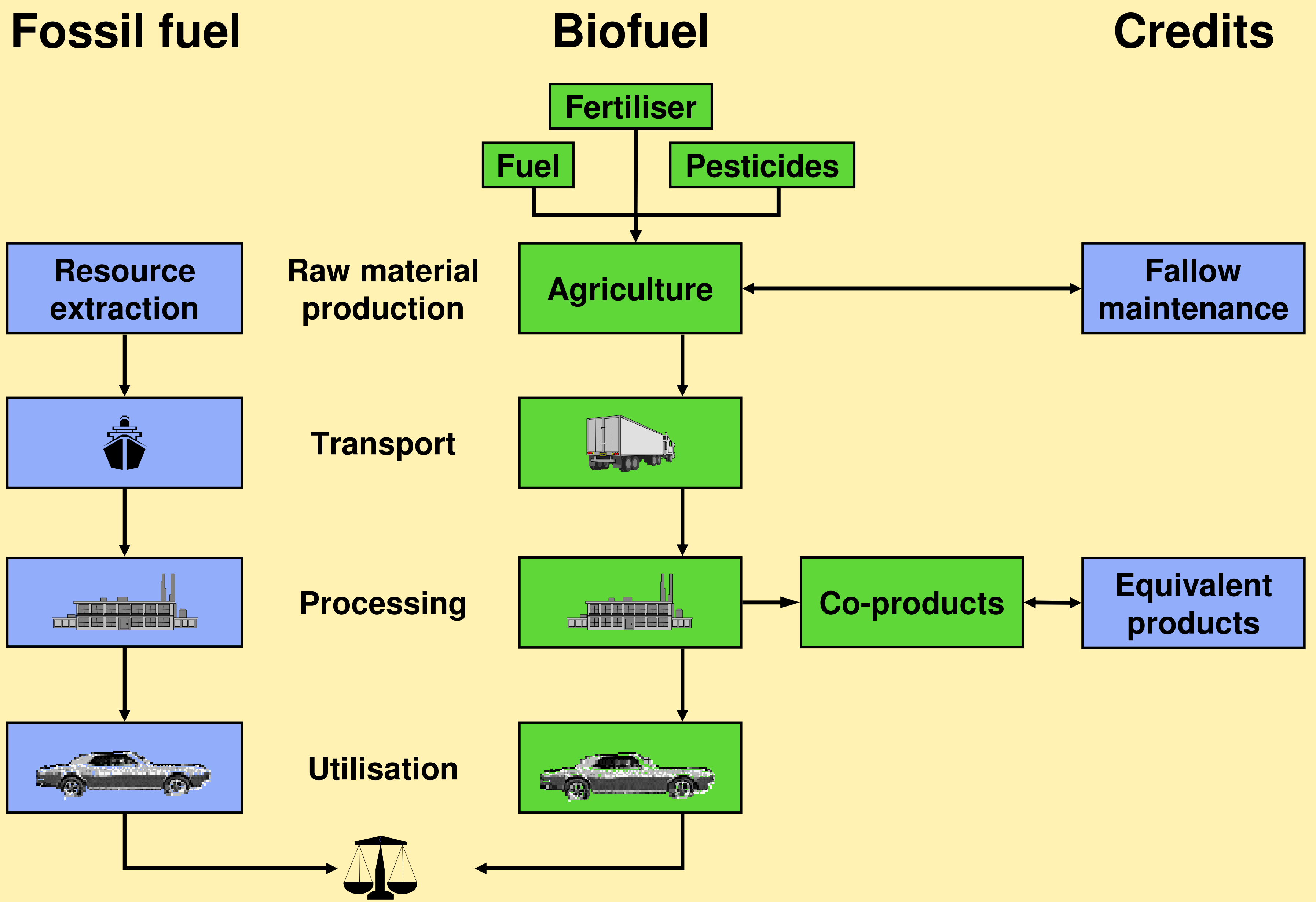
"HEY, I THOUGHT WE WERE WORKING WITH THE SAME DATA..."

Life cycle analysis (LCA)

ISO 14040 & 14044

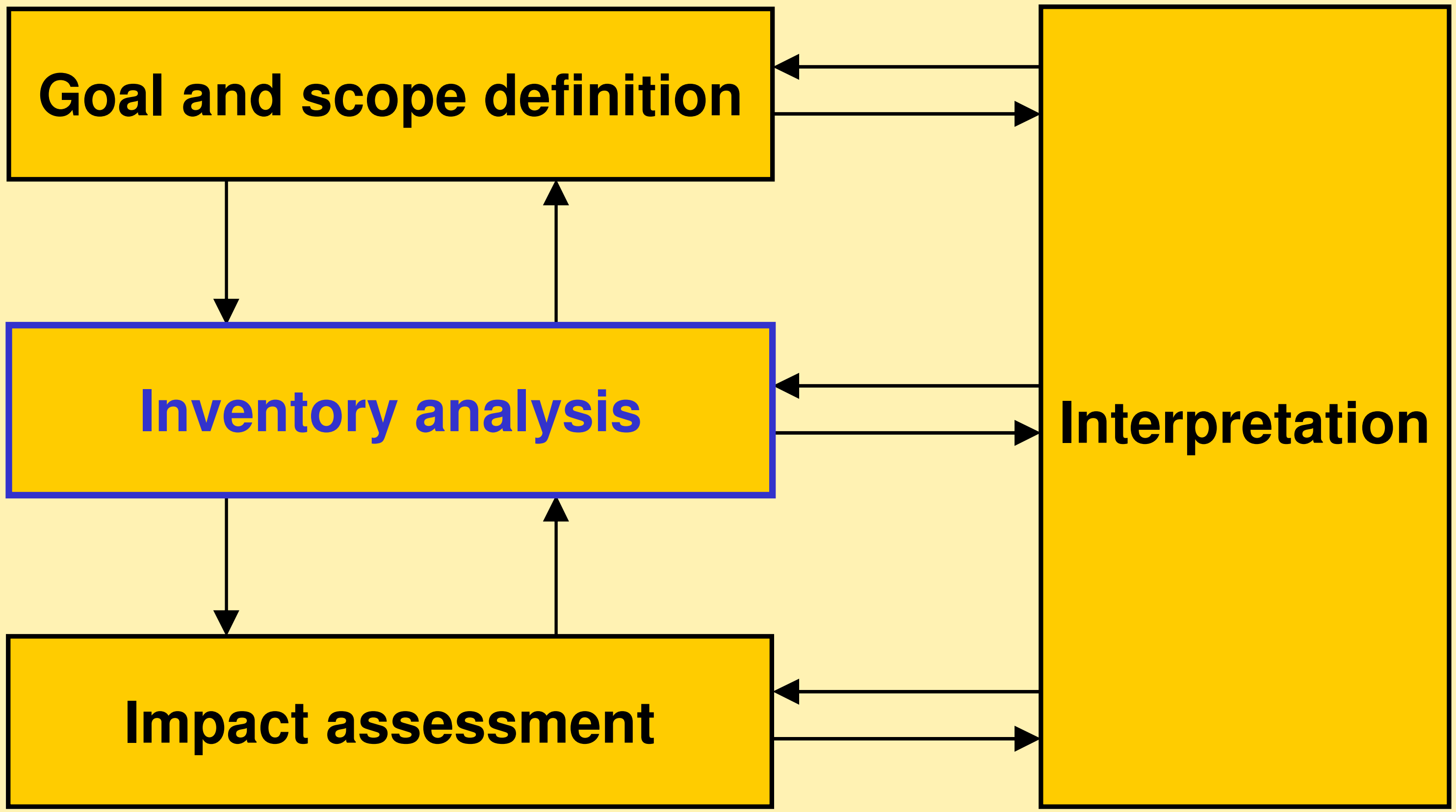


LCA: Life cycle comparison



Life cycle analysis (LCA)

ISO 14040 & 14044

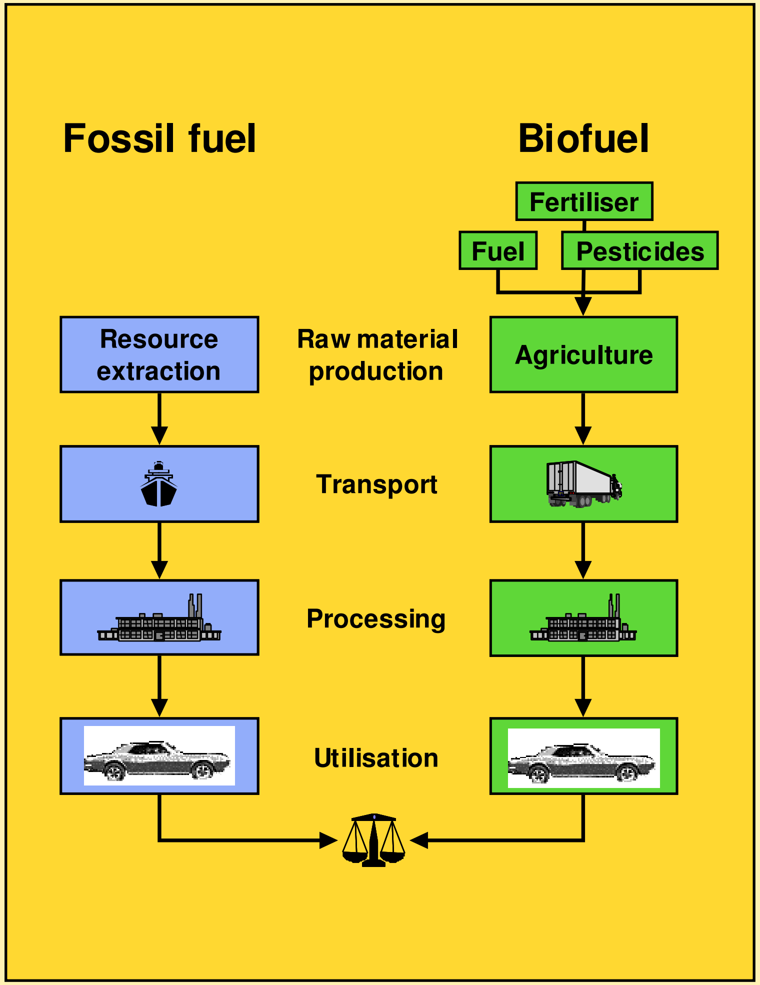


LCA: Inventory Analysis

Inputs

e.g.:

- natural gas
- crude oil
- brown coal
- hard coal
- uranium
- water



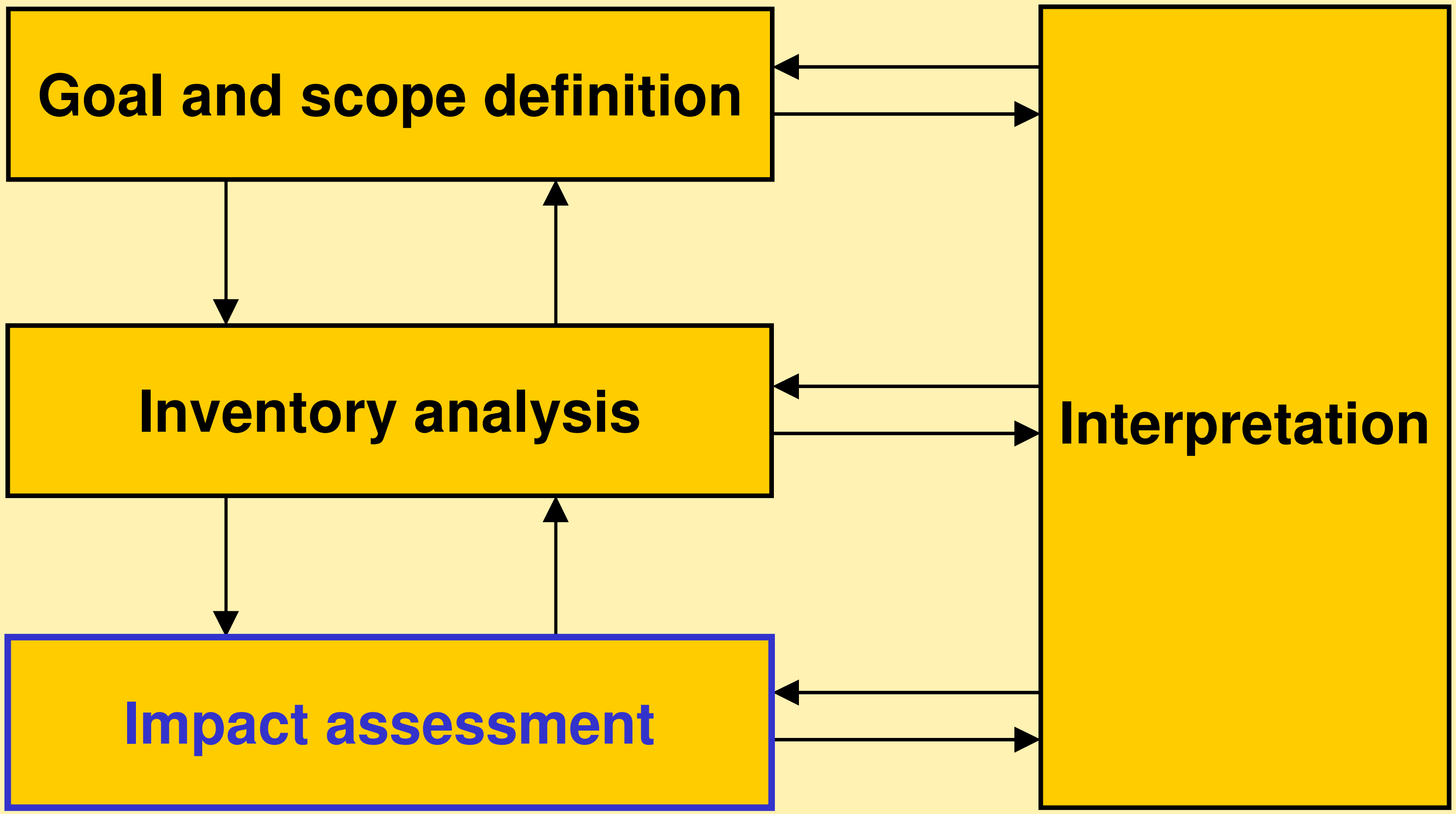
Outputs

e.g.:

- CO_2
- SO_2
- CH_4
- NO_X
- NH_3
- N_2O
- HCl
- CO
- C_6H_6
- VOC

Life cycle analysis (LCA)

ISO 14040 & 14044



LCA: Impact assessment

Impact category	Parameter	Substances (LCI)
Resource demand	Sum of depletable primary energy carriers Mineral resources	Crude oil, natural gas, coal, Uranium, … Lime, clay, metal ores, salt, pyrite, …
Greenhouse effect	CO_2 equivalents	Carbon dioxide, dinitrogen monoxide, methane, different CFCs, methyl bromide, …
Ozone depletion	CFC-11 equivalents	Dinitrogen monoxide, CFC, halone, methyl bromide, …
Acidification	SO_2 equivalents	Sulphur dioxide, hydrogen chloride, nitrogen oxides, ammonia, …
Eutrophication	PO_4 equivalents	Nitrogen oxides, ammonia, phosphate, nitrate
Photosmog	C_2H_4 equivalents	Hydrocarbons, nitrogen oxides, carbon monoxide, chlorinated hydrocarbons, …
Human toxicity	PM10 equivalents	Nitrogen oxides, carbon monoxide, hydrogen chloride, diesel particles, dust, ammonia, benzene, benzo(a)pyrene, sulphur dioxide, dioxines (TCDD), …

Life cycle analyses for 4F CROPS

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Heidelberg gGmbH

4F Crops:
Future Crops for Food, Feed, Fiber and Fuel

D 13: Life cycle analyses (LCA)

WP leader: ifeu-Institute for Energy and Environmental Research Heidelberg GmbH
Dr. Guido Reinhardt

Grant agreement no: 212811
Duration: 01/07/2008 – 30/06/2010

Heidelberg, November 2009

4F CROPS deliverable D13:

Life cycle analyses (LCA)

Authors:
Guido Reinhardt, Nils Rettenmaier, Susanne Köppen, Sven Gärtner & Sebastian Häfele

Selection of crops

WP 2: Selection of crops, provision of yields according to env. zone

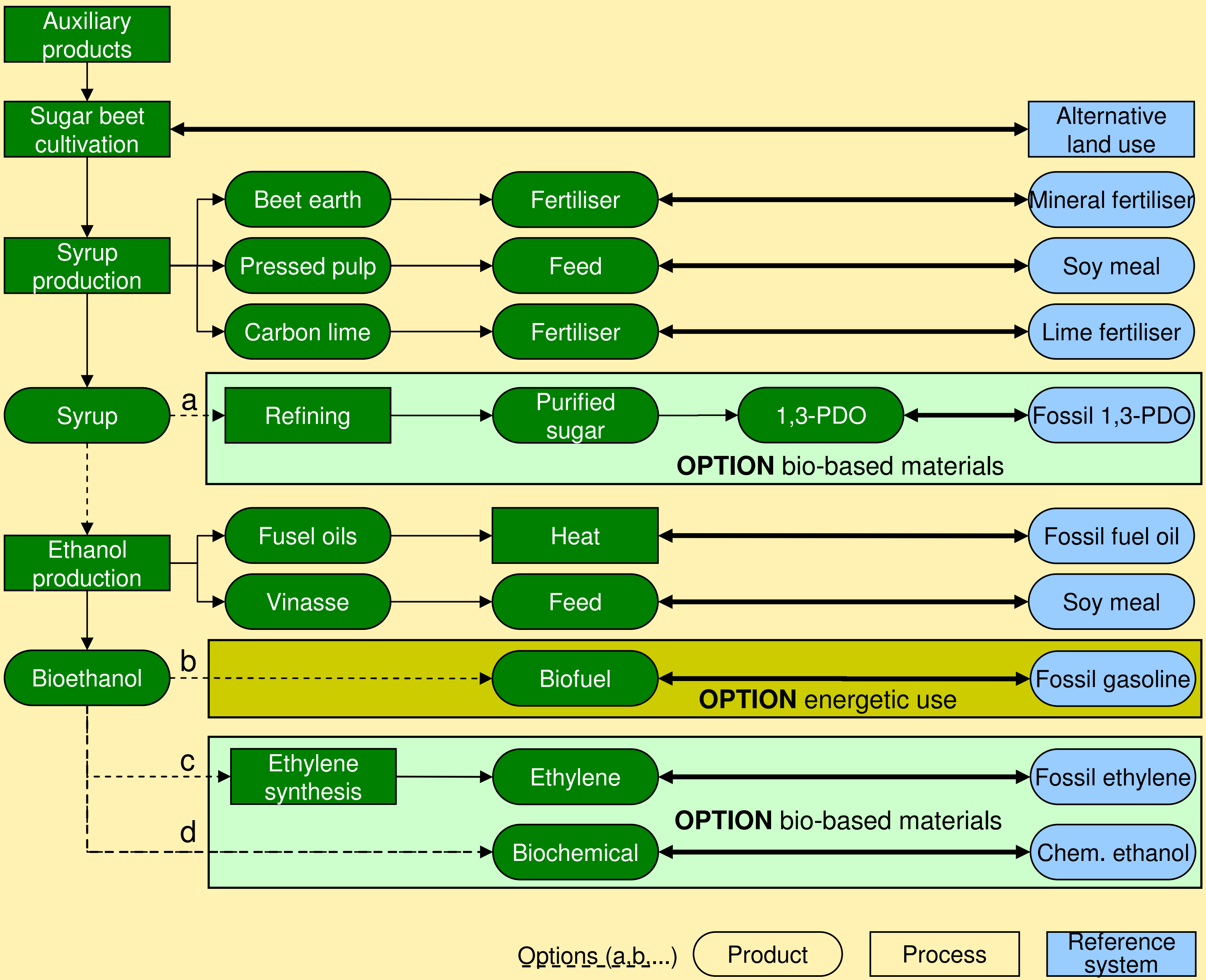
MAIN PRODUCT	CLIMATIC AREA						
	Nemoral	Continental	Atlantic Central	Atlantic North	Lusitanian	Mediterranean North	Mediterranean South
Oil	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Sunflower (*Helianthus annuus* L.)	Ethiopian mustard (*Brassica cari-nata* A. Braun)
Fiber	Hemp (*Cannabis sativa* L.)	Flax (*Linum usita-tissimum* L.)	Flax (*Linum usita-tissimum* L.)	Hemp (*Cannabis sativa* L.)	Hemp (*Cannabis sativa* L.)	Hemp (*Cannabis sativa* L.)	Flax (*Linum usita-issimum* L.)
SRF	Poplar (*Populus* spp.)	Willow (*Salix humilis* Marsh.)	Poplar (*Populus* spp.)	Willow (*Salix humilis* Marsh.)	Willow (*Salix humilis* Marsh.)	Poplar (*Populus* spp.)	Eucalyptus (*Eucalyptus spp.*)
Lignocellulosic	Reed canary grass (*Phalaris arundinacea* L.)	Miscanthus (*Miscanthus x giganteus* Greef. et Deu.)	Miscanthus (*Miscanthus x giganteus* Greef. et Deu.) Switchgrass (*Panicum virgatum* L.)		Miscanthus (*Miscanthus x giganteus* Greef. et Deu.)	Giant reed (*Arundo donax* L.)	Cardoon (*Cynara cardunculus* L. var. *altilis*)
Sugar	-	Sugar beet (*Beta vulgaris* L.)	Sugar beet (*Beta vulgaris* L.)	-	Sweet Sorghum (*Sorghum bicolor* L. Moench)	Sweet Sorghum (*Sorghum bicolor* L. Moench)	Sweet Sorghum (*Sorghum bicolor* L. Moench

Source: IFEU 2009

Selection of conversions & products

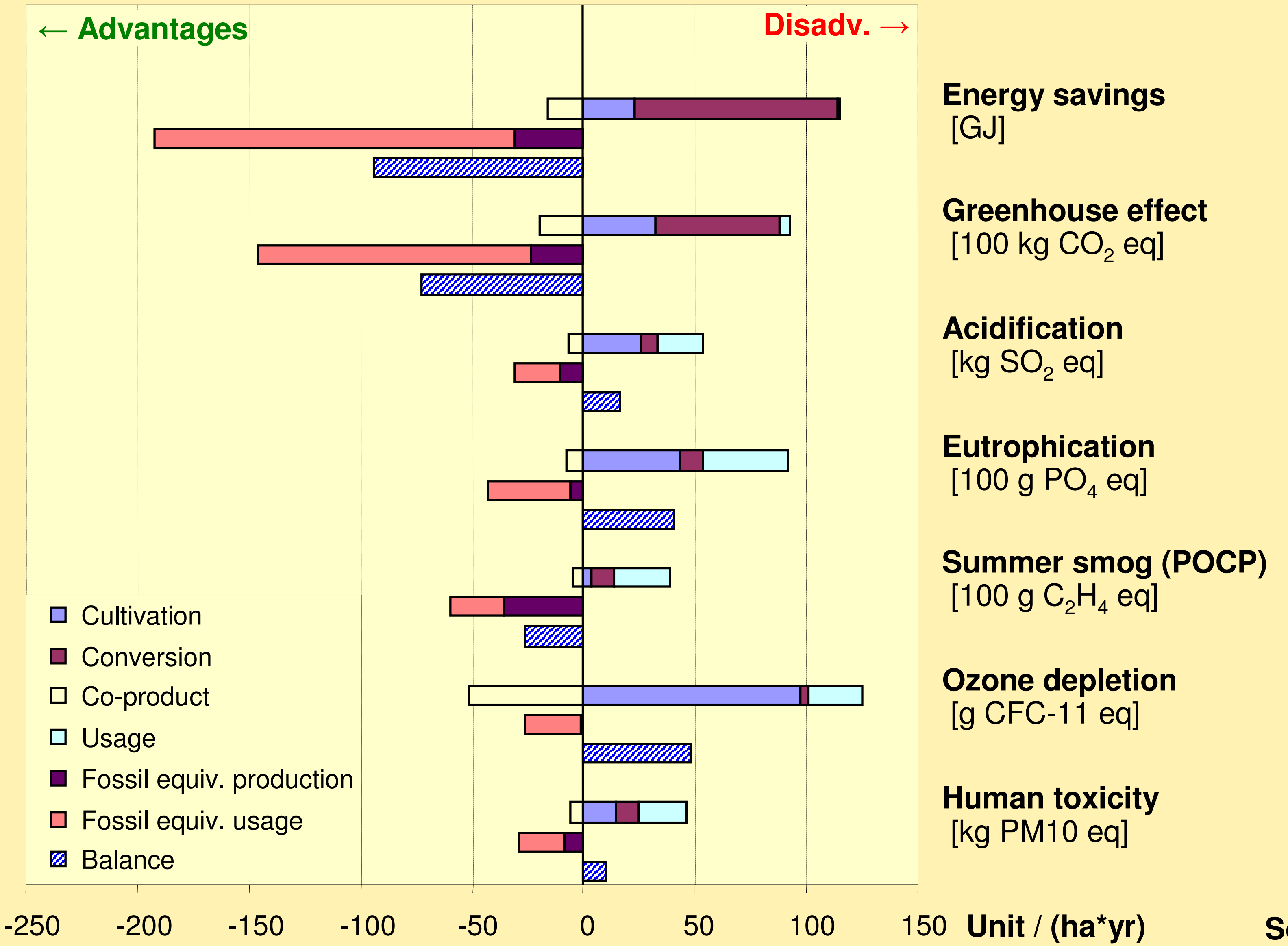
Crop category	Conversion path	Main product	Use
Oil crops	Combustion	Heat and / or power	Bioenergy
	Transesterification	Biodiesel (FAME)	
	Hydrotreatment	Biofuel (HVO)	
		Lubricant	Biomaterial
		Surfactant	
Fiber crops	Fleece production	Fiber composite	Biomaterial
		Insulation mat	
Lignocellulose from woody and herbaceous biomass	Combustion	Heat and / or power	Bioenergy
	Thermochemical conversion (gasification)	FT-diesel	
		Ethylene	Biomaterial
	Biochemical conversion (biorefinery)	Fuel ethanol	Bioenergy
		Chemical ethanol	Biomaterial
		1,3-PDO	
		Ethylene	
Sugar crops	Refining	1,3-PDO	Biomaterial
	Fermentation	Fuel ethanol	Bioenergy
		Chemical ethanol	Biomaterial
		Ethylene	

Basic scenarios: Sugar crops I



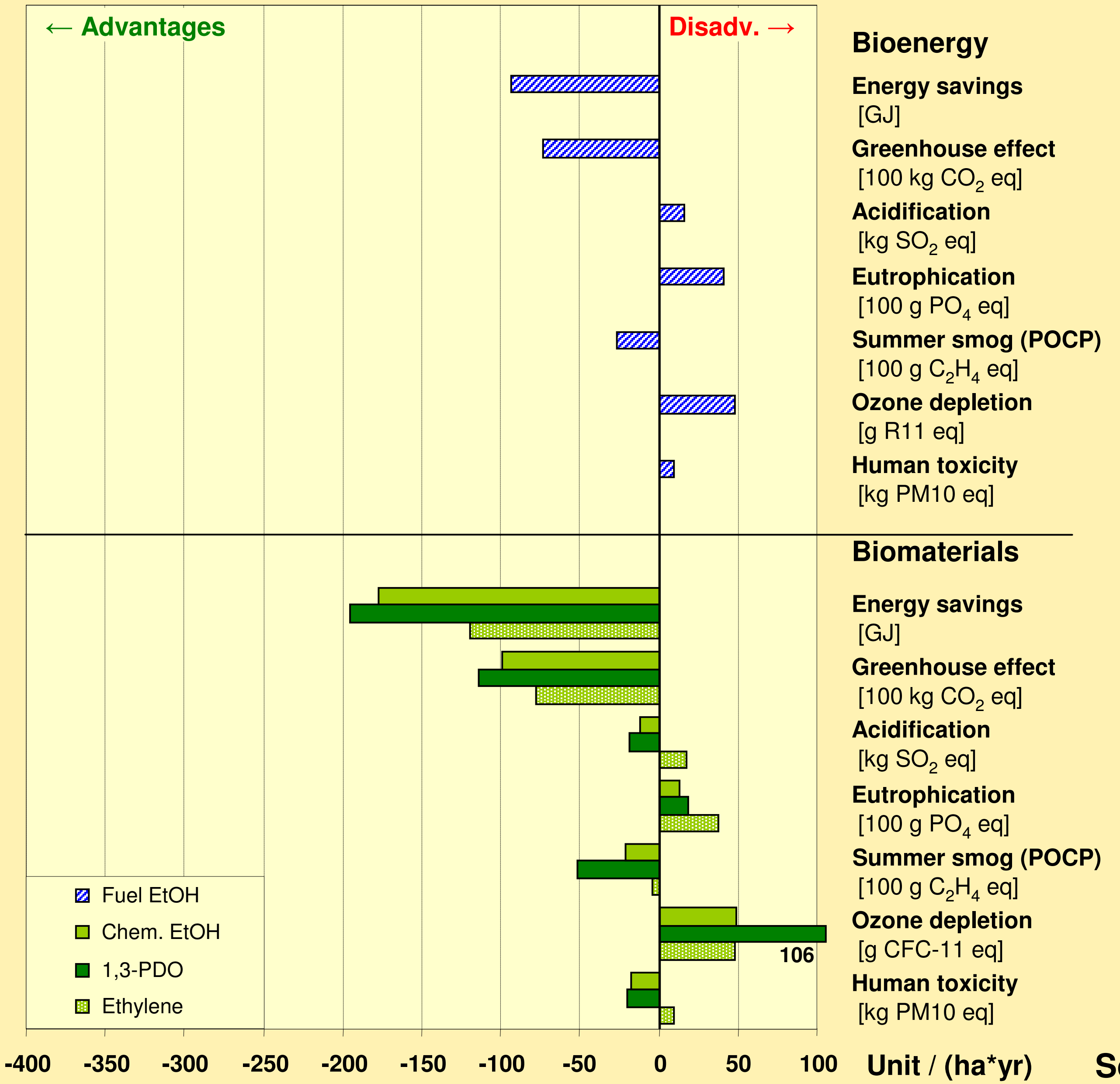
Detailed results: Sugar beet

Sugar beet – Fuel ethanol



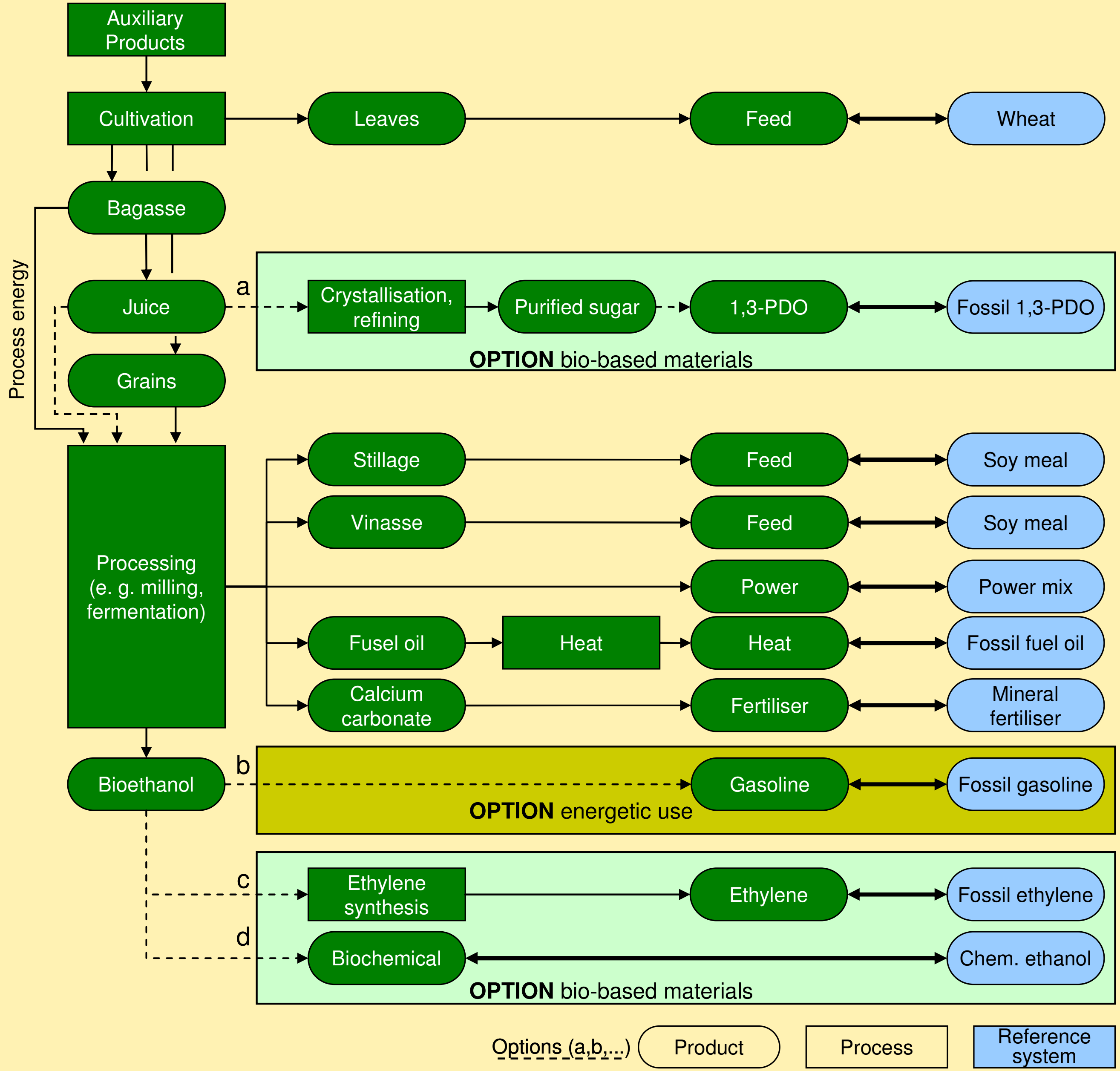
Source: IFEU 2009

Results: Sugar beet

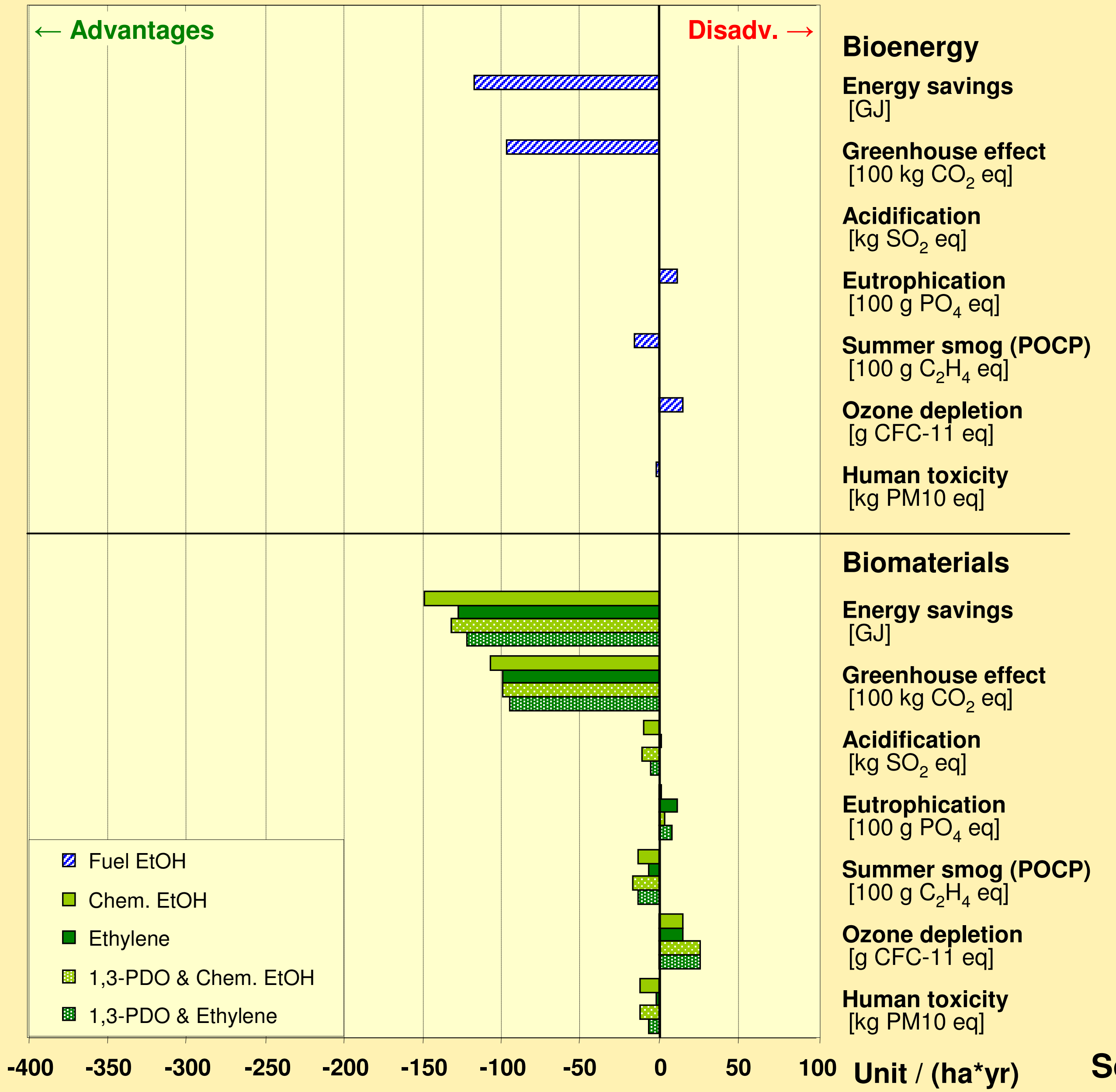


Source: IFEU 2009

Basic scenarios: Sugar crops II

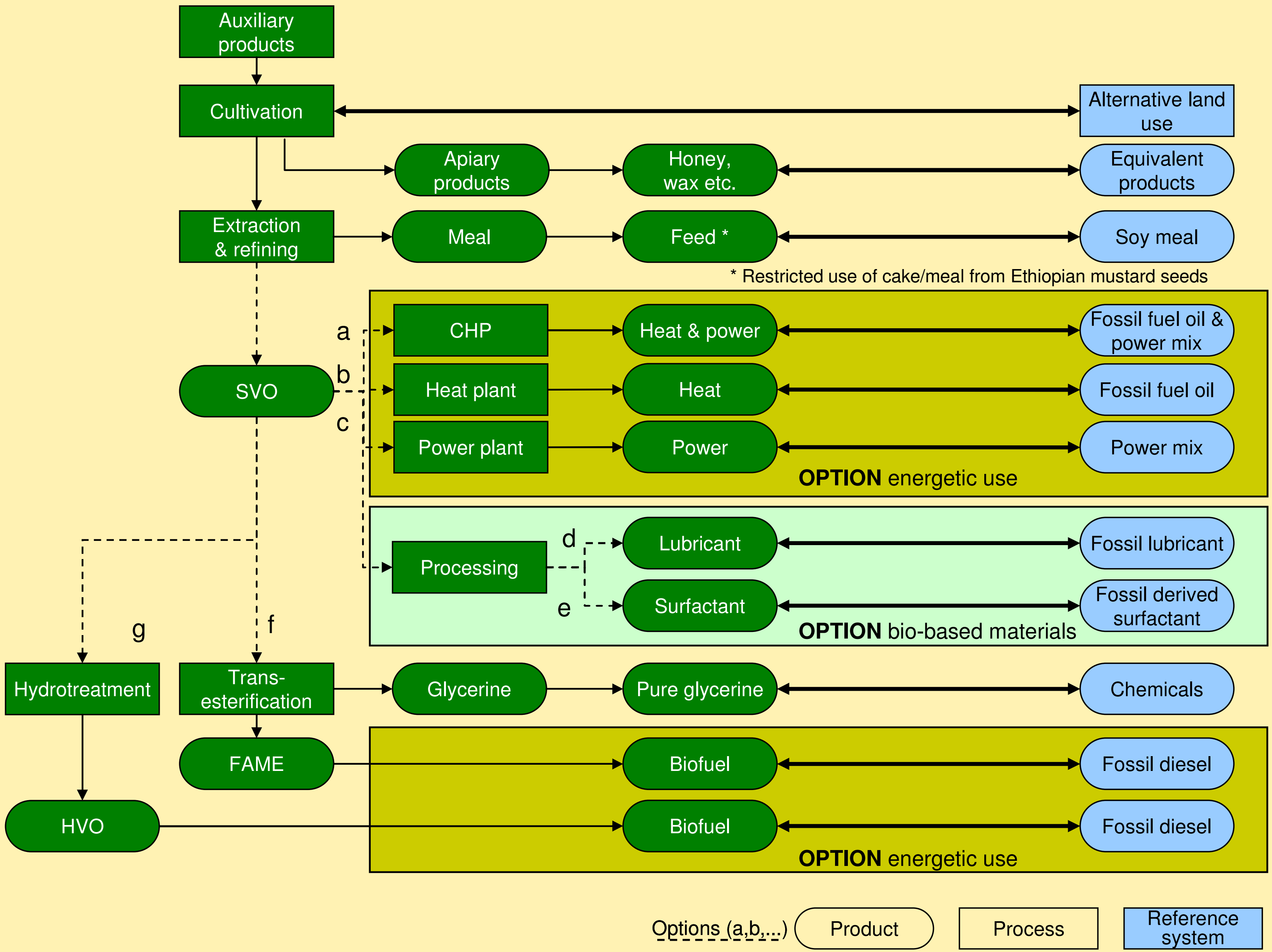


Results: Sweet sorghum

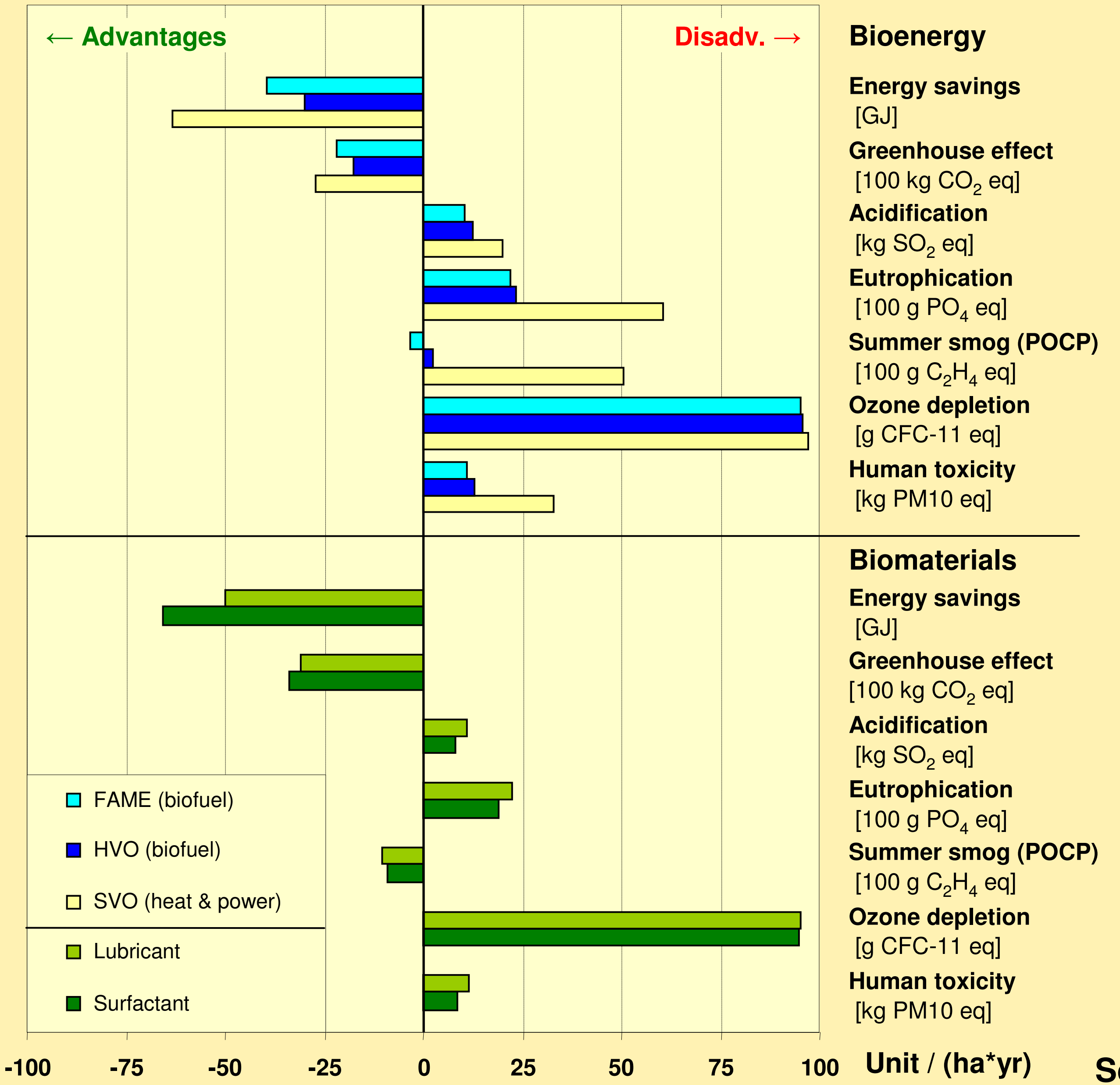


Source: IFEU 2009

Basic scenarios: Oil crops

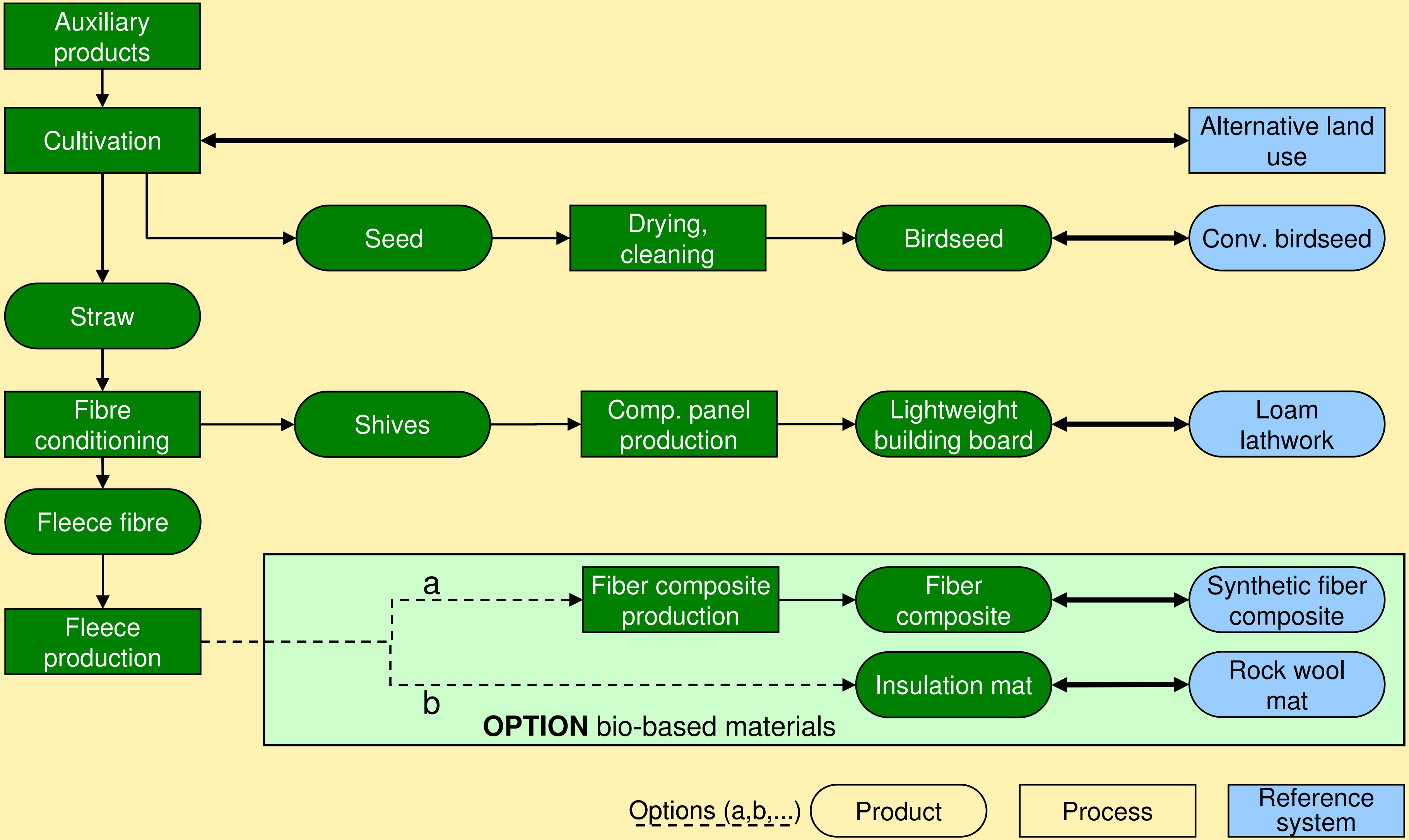


Results: Rapeseed oil

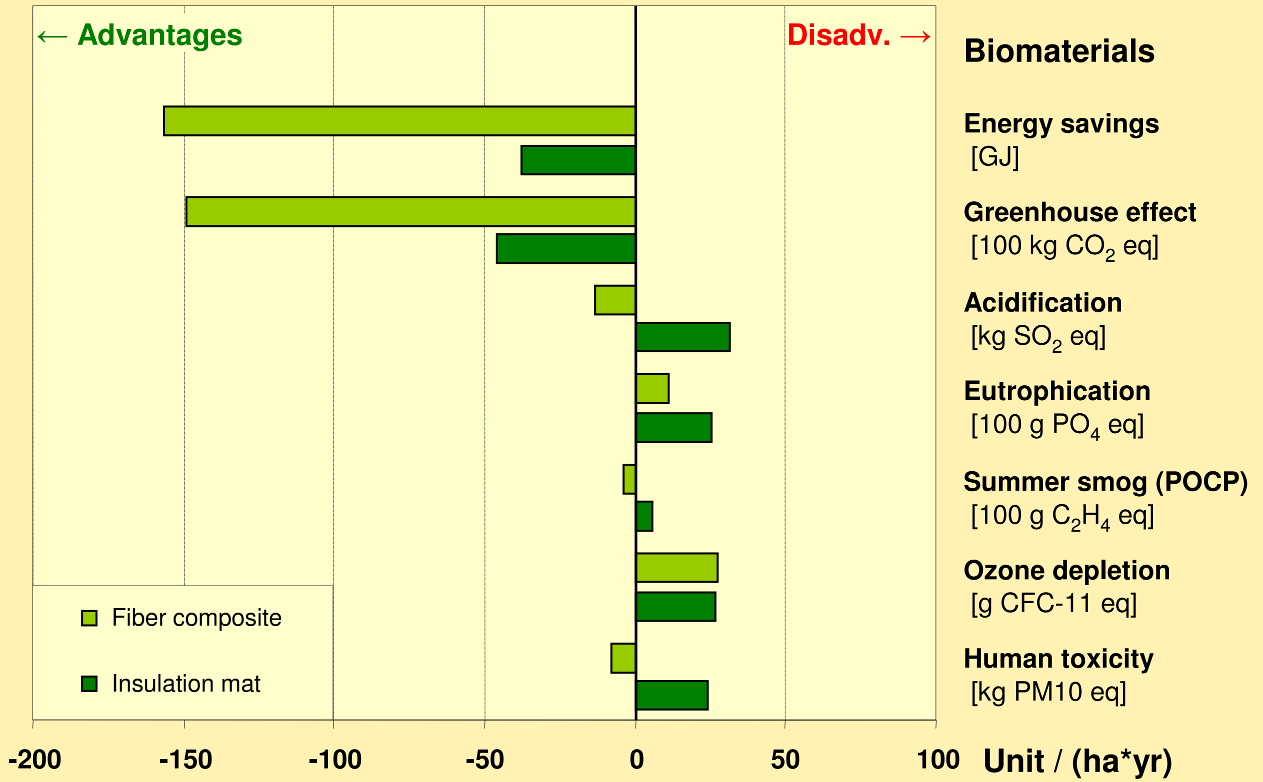


Source: IFEU 2009

Basic scenarios: Fiber crops

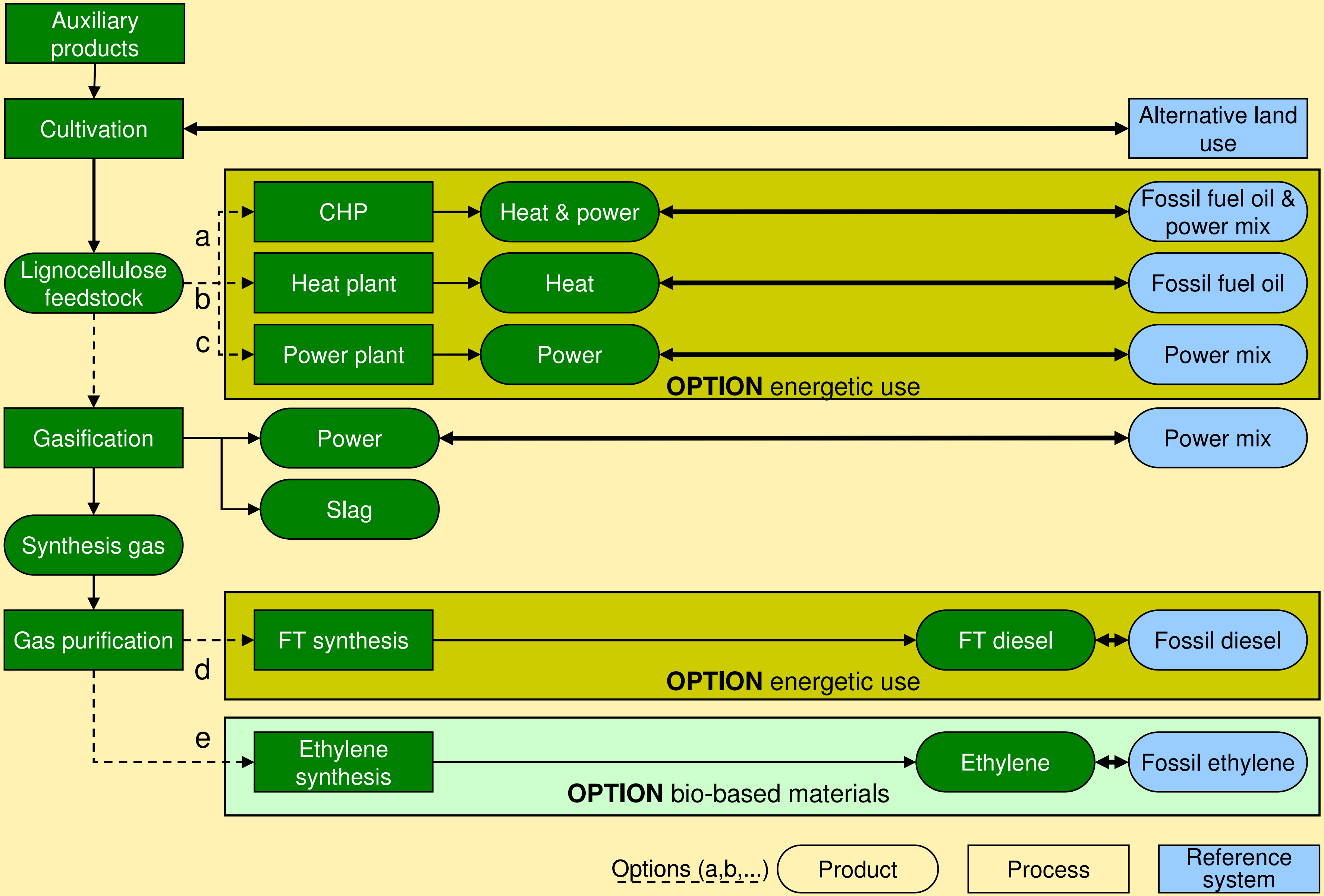


Results: Flax

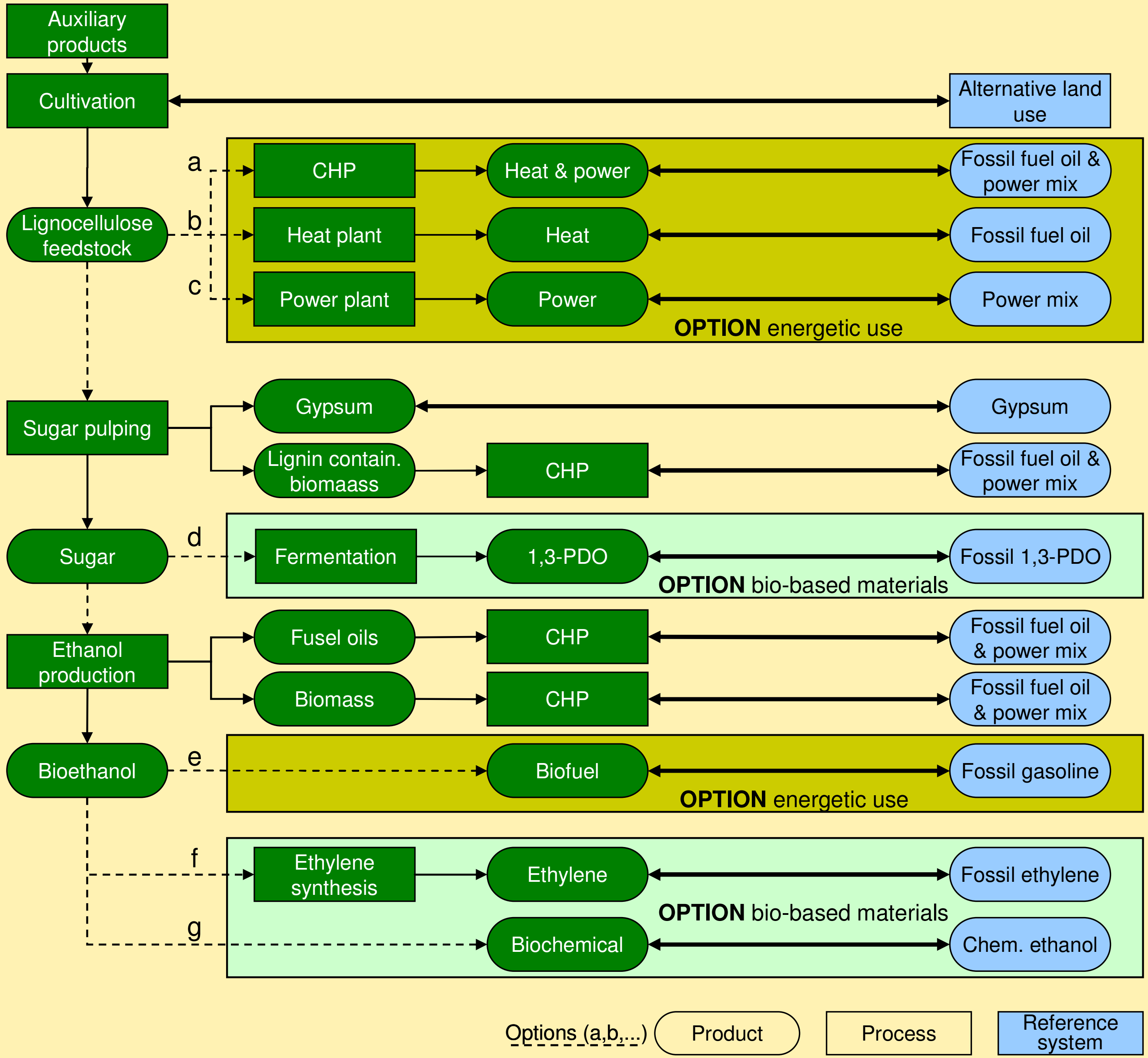


Source: IFEU 2009

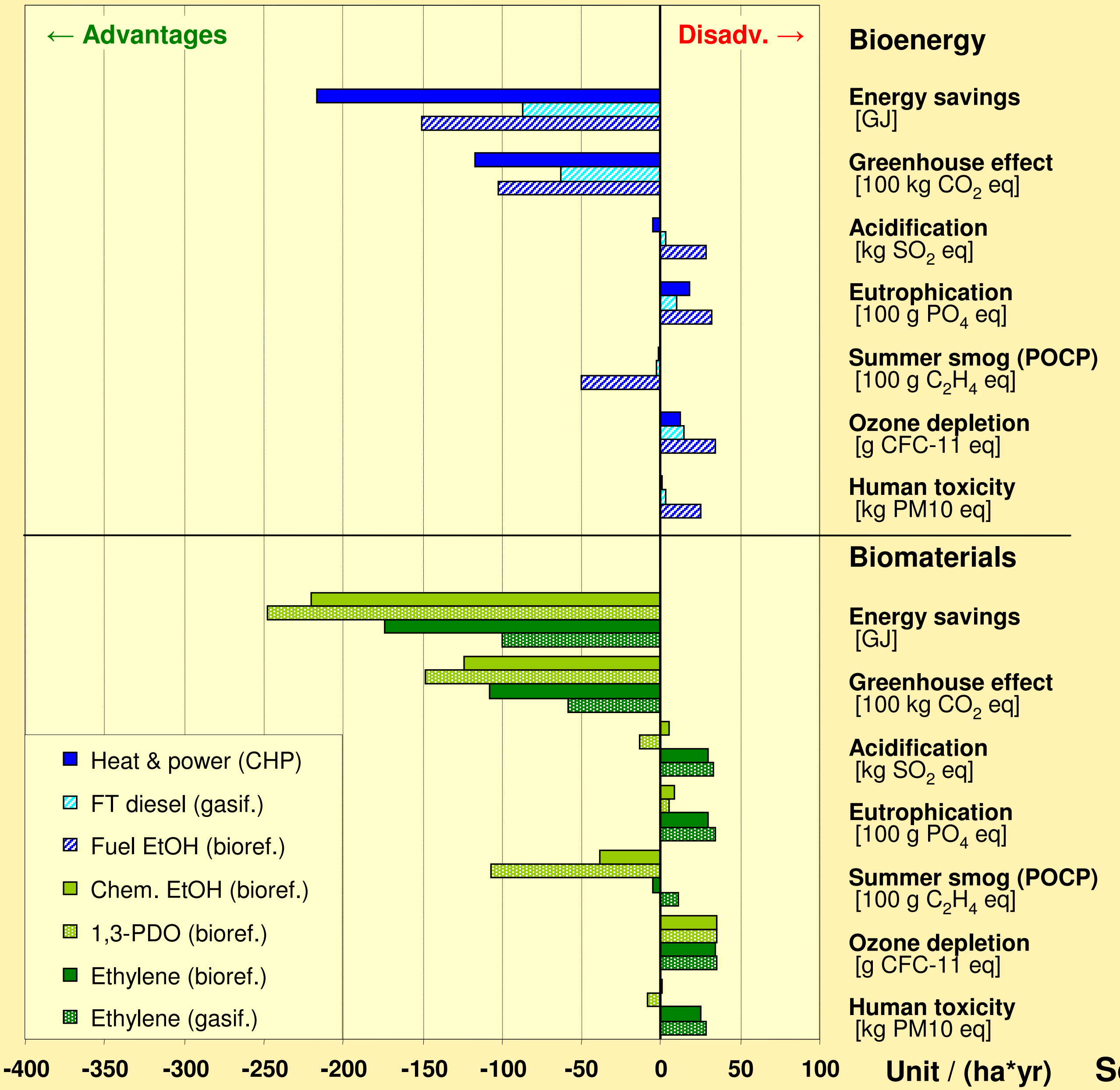
Basic scen.: Lignocellulosic crops I



Basic scen.: Lignocellulosic crops II



Results: Miscanthus



Source: IFEU 2009

Synopsis of LCIA results: Fuels

Biofuel	Energy savings	Green-house effect	Acidifi-cation	Eutro-phication	Summer smog	Ozone depletion	Human toxicity
Rapeseed – FAME	+	+	–	–	+	–	–
Rapeseed – HVO	+	+	–	–	–	–	–
Rapeseed – SVO	+	+	–	–	–	–	–
Miscanthus – CHP	+	+	+	–	+ / –	–	+ / –
Miscanthus – FT diesel	+	+	+ / –	–	+ / –	–	+ / –
Miscanthus – Ethanol	+	+	–	–	+	–	–
Sugar beet – Ethanol	+	+	–	–	+	–	–
Sweet sorghum – Ethanol	+	+	+ / –	–	+	–	+ / –

\+ Advantage for biofuel – Disadvantage for biofuel +/– Insignificant or ambiguous

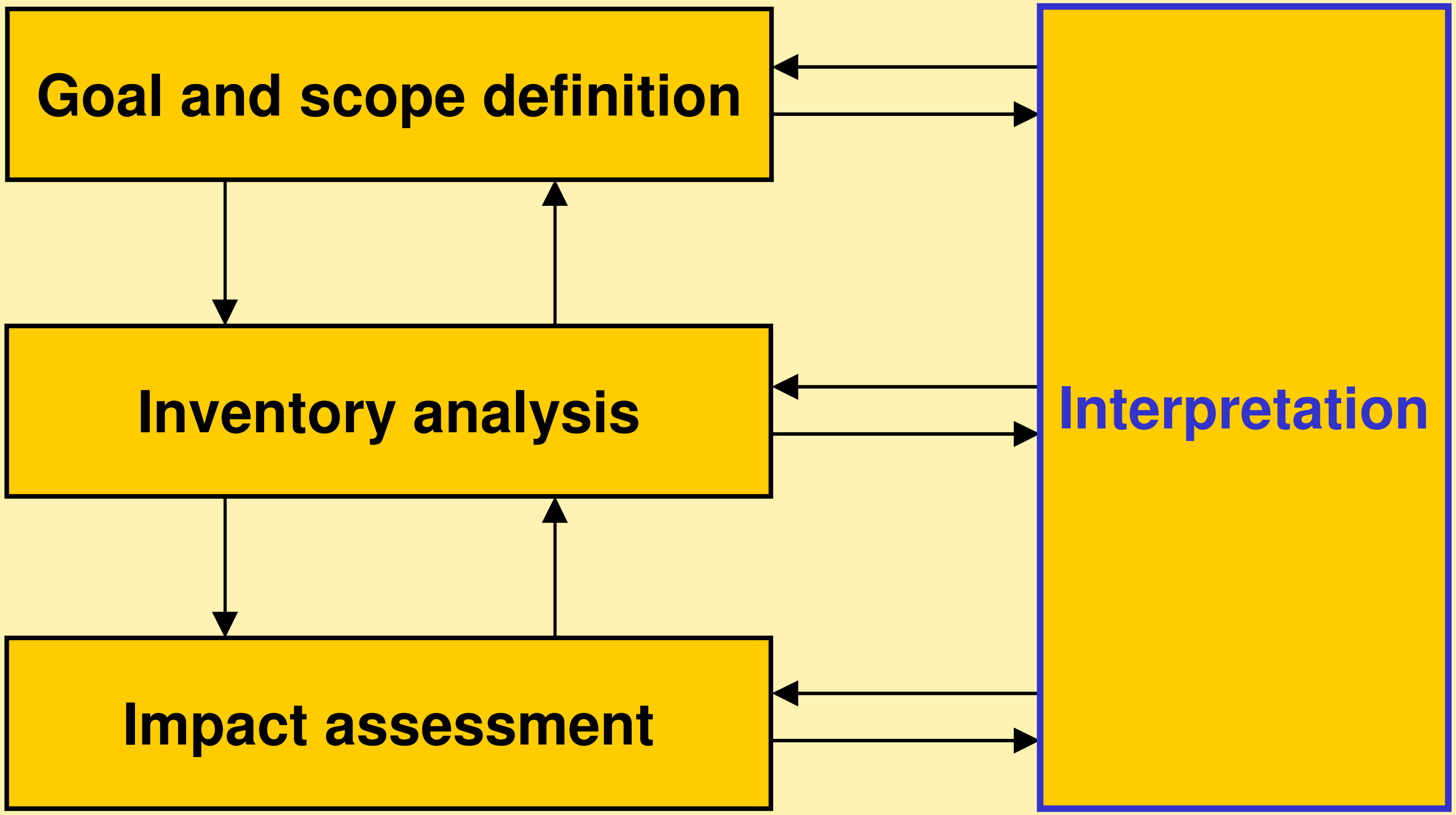
Synopsis of LCIA results: Fibers

Biomaterials	Energy savings	Green-house effect	Acidifi-cation	Eutro-phication	Summer smog	Ozone depletion	Human toxicity
Rapeseed – Lubricant	+	+	–	–	+	–	–
Rapeseed – Surfactant	+	+	–	–	+	–	–
Flax – Fiber composite	+	+	+	–	+	–	+
Flax – Insulation mat	+	+	–	–	–	–	–
Miscanthus – Ethanol	+	+	–	–	+	–	+ / –
Miscanthus – 1,3-PDO	+	+	+	–	+	–	+
Miscan. – Ethylene (bioref.)	+	+	–	–	+	–	–
Miscan. – Ethylene (gasif.)	+	+	–	–	–	–	–
Sugar beet – Ethanol	+	+	+	–	+	–	+
Sugar beet – 1,3-PDO	+	+	+	–	+	–	+
Sugar beet – Ethylene	+	+	–	–	+	–	–
Sweet sorghum – Ethanol	+	+	+	+ / –	+	–	+
Sweet sorghum – Ethylene	+	+	+ / –	–	+	–	+ / –
Sw. sorgh. – 1,3-PDO & EtOH	+	+	+	+ / –	+	–	+
Sw. sorgh. – 1,3-PDO & Ethylene	+	+	+	–	+	–	+

\+ Advantage for biomat. – Disadvantage for biomat. +/– Insignificant or ambiguous

Life cycle analysis (LCA)

ISO 14040 & 14044



LCA: Interpretation

Statistics about Heidelberg

Inhabitants	130.000
School buildings (including university)	180
Bridges	5
Dogs	220
Tourists per day	5.500
Total	**135.905**

LCA: Interpretation

Impact category	Parameter	Ecological significance
Resource demand	Cumulative energy demand (non-renew.)	important
Greenhouse effect	CO_2 equivalents	very important
Ozone depletion	CFC-11 equivalents	(very) important
Acidification	SO_2 equivalents	medium relevance
Eutrophication	PO_4 equivalents	medium relevance
Human- and Ecotoxicity	Nitrogen oxide	medium relevance
Human- and Ecotoxicity	Diesel particulates	very important

Results: Bio vs. non-renewable

1. All assessed biofuels and biomaterials show environmental advantages as well as disad-vantages when compared to their fossil / con-ventional equivalents.
2. Most biofuels and biomaterials show advantages with regard to energy savings, greenhouse effect and summer smog.
3. In contrast, most biofuels and biomaterials show disadvantages with regard to acidification, eutrophication and ozone depletion.
4. The results don‘t show clear tendencies with regard to human toxicity.

Results: Bio vs. non-renewable

5. An objective decision for or against a particular fuel or biomaterial cannot be made. However, based on a subjective value system a decision is possible.
6. If, for example, energy savings and greenhouse effect is given the highest priority, all biofuel and biomaterial applications assessed are to be preferred over their fossil equivalents.
7. The amount of energy and greenhouse gases that can be saved greatly differs depending on the crops, conversion paths and main products.

WP 4: Environmental analysis

Goal

Assessment of environmental implications and identification of best options for each region or country.

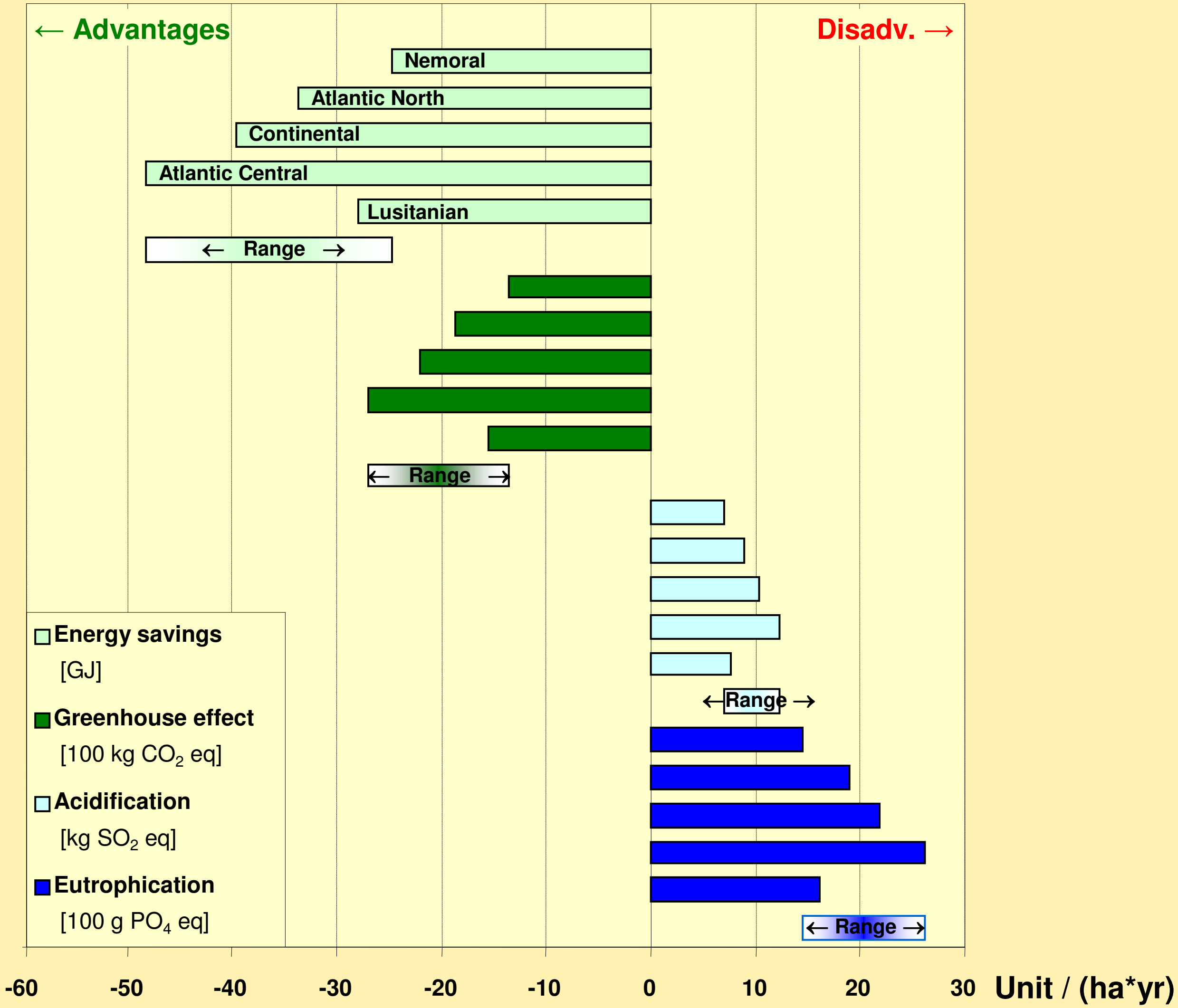
Task 4.1	**Environmental impact assessment**
Task 4.2	**Life cycle analysis**
➔ **Task 4.3**	**Modelling of dependencies and sensibilities**
Task 4.4	**Identification of best options**

Variations & sensitivity analyses

Variations & sensitivity analyses to be done:

- Variation of yields
  - Geographical differences (between environmental zones)
  - Yield increase over time (2008 vs. 2020 vs. 2030)
- Variation of co-product use
- Variation of co-product allocation
- Variation of substituted fossil energy source
- Variation of substituted power mix

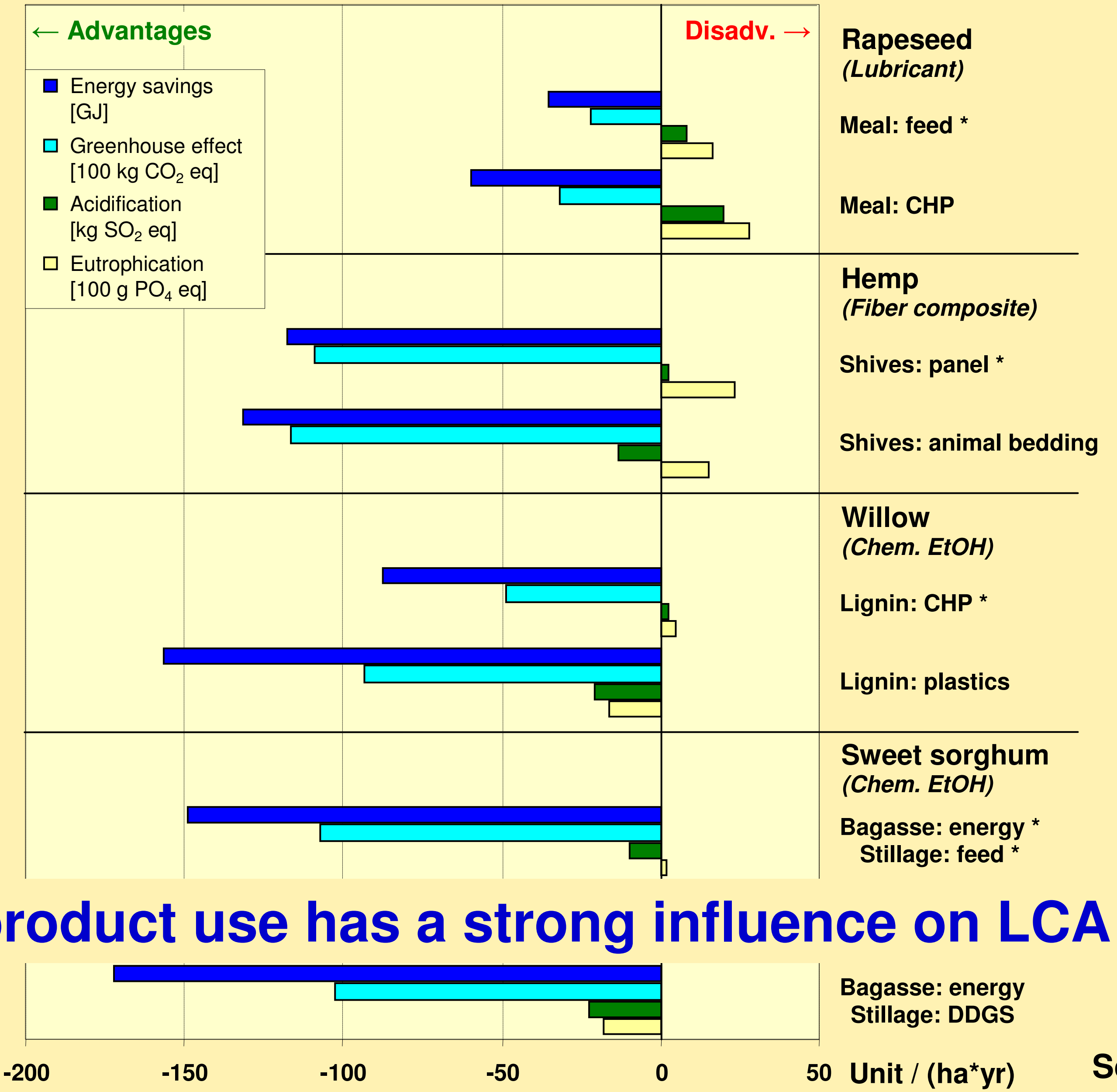
Sensitivity analysis: Yield



➔ **Yield significantly influences the LCA results**

Source: IFEU 2009

Sensitivity analysis: Co-product use



➔ **Co-product use has a strong influence on LCA results**

Source: IFEU 2009

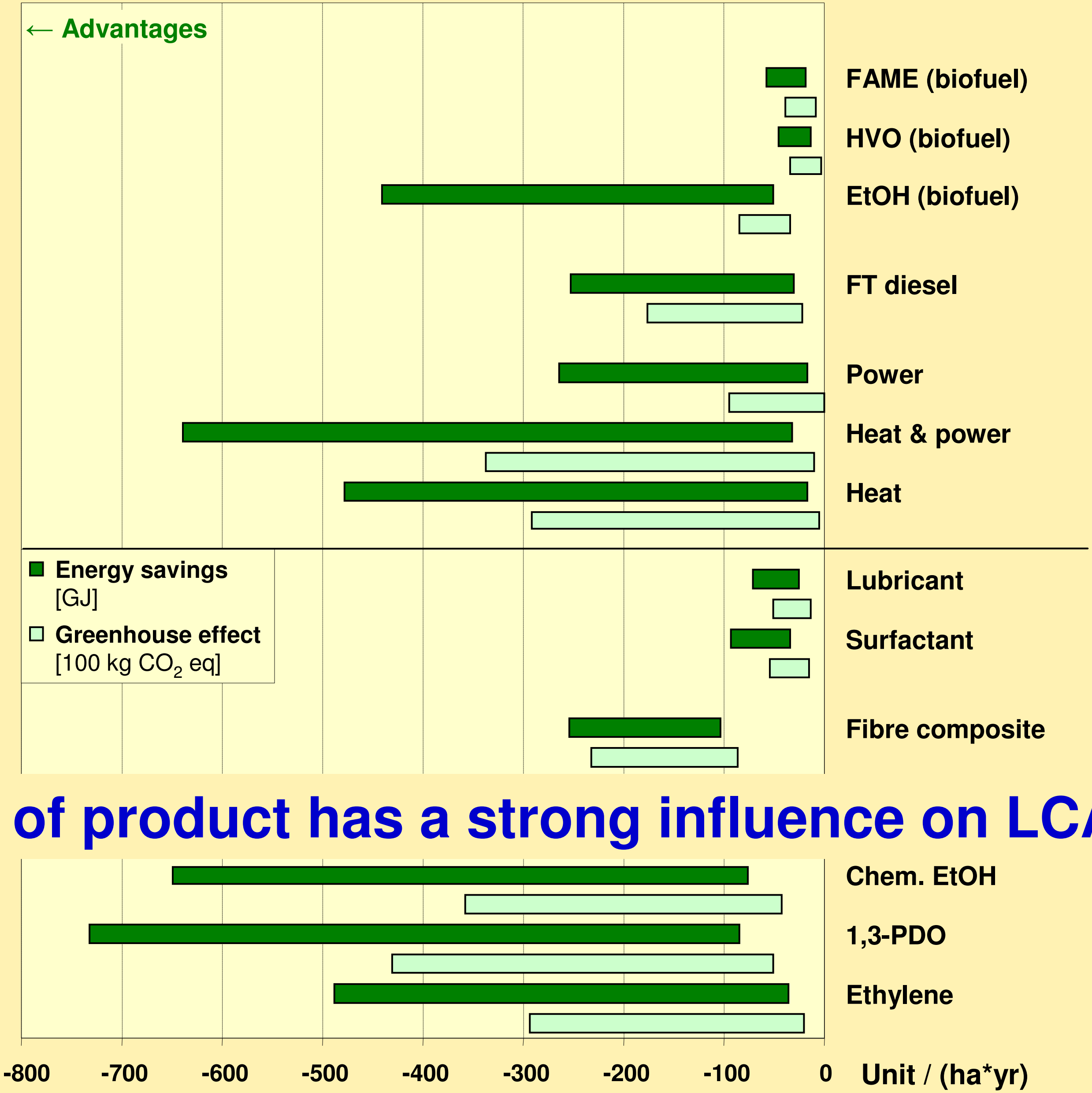
WP 4: Environmental analysis

Goal

Assessment of environmental implications and identification of best options for each region or country.

Task 4.1	**Environmental impact assessment**
Task 4.2	**Life cycle analysis**
Task 4.3	**Modelling of dependencies and sensibilities**
➔ **Task 4.4**	**Identification of best options**

Synopsis: Which products to make?



➔ **Type of product has a strong influence on LCA results**

Source: IFEU 2009

Results: Optimisation potentials

1. The use of biomass can be significantly optimized from an environmental point of view by taking into account different different biomass and co-product uses or site-specific conditions, e.g. power mixes in different countries
2. As land-use competitions are increasing, it is necessary to allocate the limited amount of biomass to the different sectors (food / feed / fiber and fuel) in such a way which achieves the highest environmental benefits.

Thank you for your attention !

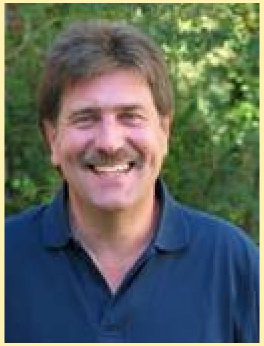
Sven Gärtner

Susanne Köppen

Nils Rettenmaier

Regine Vogt

Horst Fehrenbach



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