Life Cycle Assessment of different BtL-Fuel Pathways from Wood, Straw and Miscanthus

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Overview

- Biomass-to-liquid fuels can be produced in different process layouts
- BTL fuels reduce climate change effect compared to fossils
- Only some production pathways comply with Swiss biofuels directive
- The type of biomass and conversion efficiency are most important for the assessment

Classification of fuels: Marketing and brand names

- Sunfuel, Sundiesel: synthetic fuels from Choren process)
- Ökodiesel, Biodiesel: mainly used for XME with biomass from different origin
- Naturgas: natural gas mixed with >10% biogas
- Kompogas: brand name of biogas plants
- 1st, 2nd, 3rd generation: unclear definition e.g. based on today market share, resource types or edibility or conversion processes

➢ Marketing and brand names do not help for a discussion on renewable fuels

Classifications of powertrain fuels

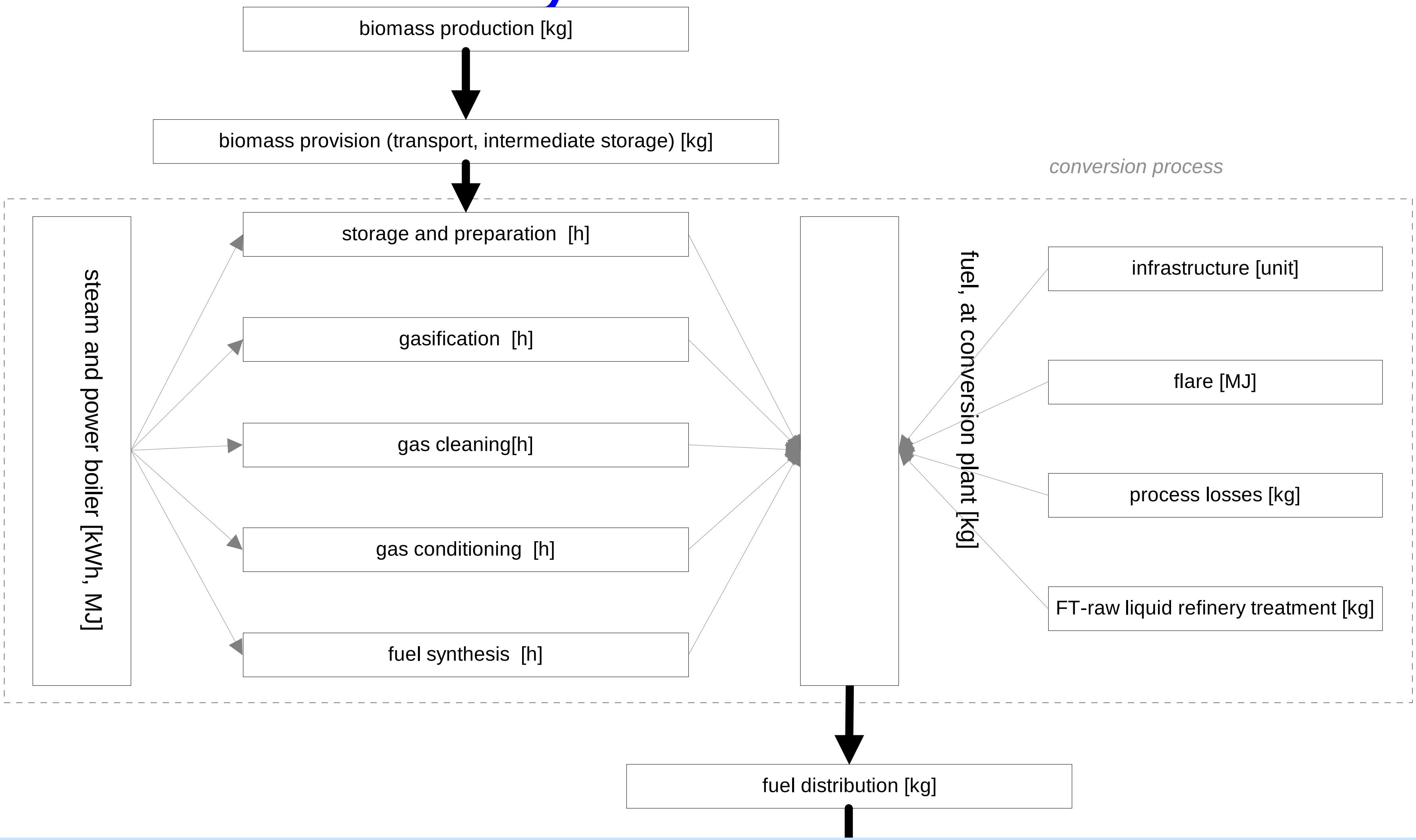
- **Resources** used
  - Non-renewable: crude oil, natural gas, coal, nuclear
  - Renewable: energy crops (edible, non-edible), algae, forest wood, biomass residues (e.g. straw), industrial residues (e.g. Black Liquor), sun, wind
- Conversion **process** technologies
  - mechanical, chemical reaction, thermal treatment, fermentation, anaerobic digestion, pyrolysis, gasification, Fischer-Tropsch synthesis, biotechnical
- Chemical classification of the **product**
  - methane, ethanol, methanol, dimethylether (DME), hydrogen, oils, methyl ester, liquids (petrol, diesel, BtL, GtL), ETBE, MTBE

> ➢ Fuels can only be classified by a combination of resource, process and product
>
> ➢ Biomass-to-liquid (BTL) fuels from black-liquor, miscanthus, wood and straw

Questions related to BTL production

- Which BTL production route is the one with the lowest environmental impacts?
- Improvement options of production routes, e.g. biomass inputs?
- Priorities for process development?
- Scenarios for technology development for BtL-production plants and influence on results?

System outline



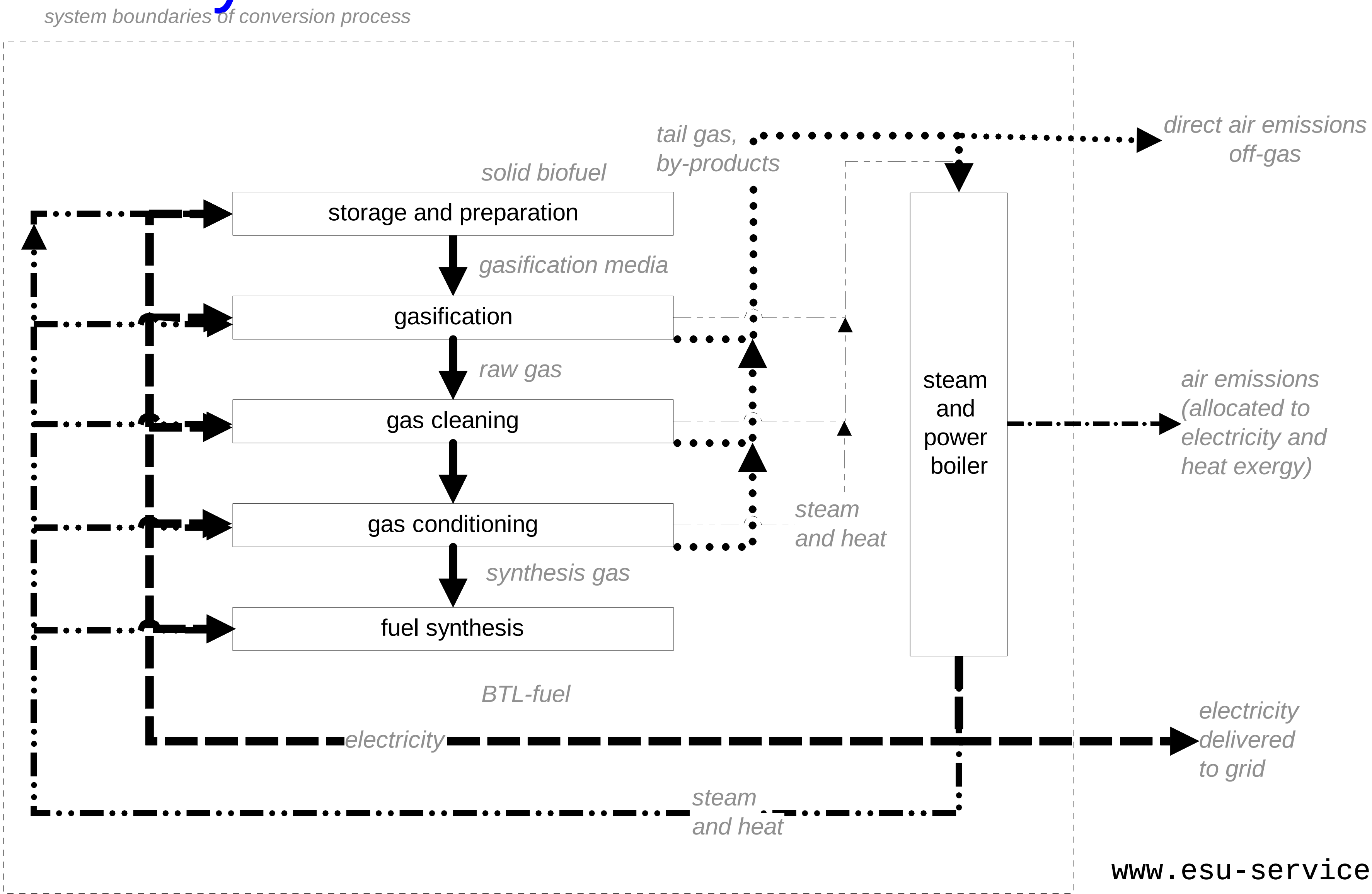
- Sometimes termed as well-to-tank

Key data biomass production

- Straw, short-rotation wood and miscanthus
- data given per kg dry substance (DS)

		bundles, short-rotation wood	bundles, short-rotation wood	miscanthus-bales	miscanthus-bales	wheat straw, bales	wheat straw, bales
		starting point	scenario 1	starting point	scenario 1	starting point	scenario 1
N-fertilizer	g/kg DS	5.2	6.3	4.0	5.6	2.2	1.8
P2O5-fertilizer	g/kg DS	4.0	3.5	3.1	2.8	1.1	0.8
K2O-fertilizer	g/kg DS	6.4	5.4	5.1	4.3	0.9	1.5
Lime	g/kg DS	6.5	5.9	3.6	2.4	4.4	2.8
diesel use	g/kg DS	5.1	4.9	4.3	3.3	2.3	1.4
yield, bioenergy resource	kg DS/ha/a	10'537	12'630	14'970	20'504	4'900	6'719
yield, wheat grains	kg DS/ha/a	-	-	-	-	3'718	4'428
energy content of biomass	MJ/kg DS	18.4	18.4	18.8	18.8	17.2	17.2
losses during storage	%	7%	4%	6%	3%	6%	3%

System boundaries conversion



LCI and LCIA modelling principles

- No modelling of intermediate flows between conversion stages
- Emissions of power plant are allocated to heat and electricity based on exergy production
- No allocation of biomass input to by-products, like electricity
- No agreement on LCIA of pesticides and heavy metals in the project

General assumptions necessary

- Data provided are completed with general assumptions
- Emission profile of conversion based mainly on gas or wood power plants
- Waste and effluent composition available only from model calculation
- Catalyst use assessed based on literature
- All assumptions approved by process developers

Characteristics of data

Concept	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification	Entrained Flow Gasification of Black Liquor for DME-production
Abbreviation	cEF-D	CFB-D	dEF-D	ICFB-D	BLEF-DME
Developer	UET	CUTEC	FZK	TUV	CHEMREC
Biomass input	Amount and type	Amount and type	Amount and type	Amount and type	Amount and type
Biomass type	Wood, straw	Wood, straw	Straw	Wood, miscanthus	Wood, black liquor
Heat and electricity use	Provided	Provided	Provided and own assumptions	Provided	Provided
Auxiliary materials	Hydrogen, Fe(OH)2	Filter ceramic, RME, silica sand, quicklime, iron chelate	Nitrogen, silica sand	Nitrogen, RME, quicklime, silica sand	None
Catalysts	Literature	Literature	Literature	Amount of zinc catalyst	Literature
Concentration air emissions	CO	No data	H2S	CO, CH_4, NMVOC	CO, H2S, CH_4
Other air emissions	Literature for gas firing	Literature for gas firing	Literature for gas firing and own calculations	Literature for gas firing	Literature for wood firing
Amount of air emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and own assumptions on CO_2.	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions
Effluents	Amount and concentration	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants
Wastes	Amount and composition	Only amount	Only amount	Only amount	Only amount
Fuel upgrading	Included in process data	Standard RENEW model for upgrading	Standard RENEW model for upgrading	Standard RENEW model for upgrading	not necessary
Products	BTL-FT, electricity	FT-raw product, electricity	FT-raw product, electricity	FT-raw product, electricity	BTL-DME

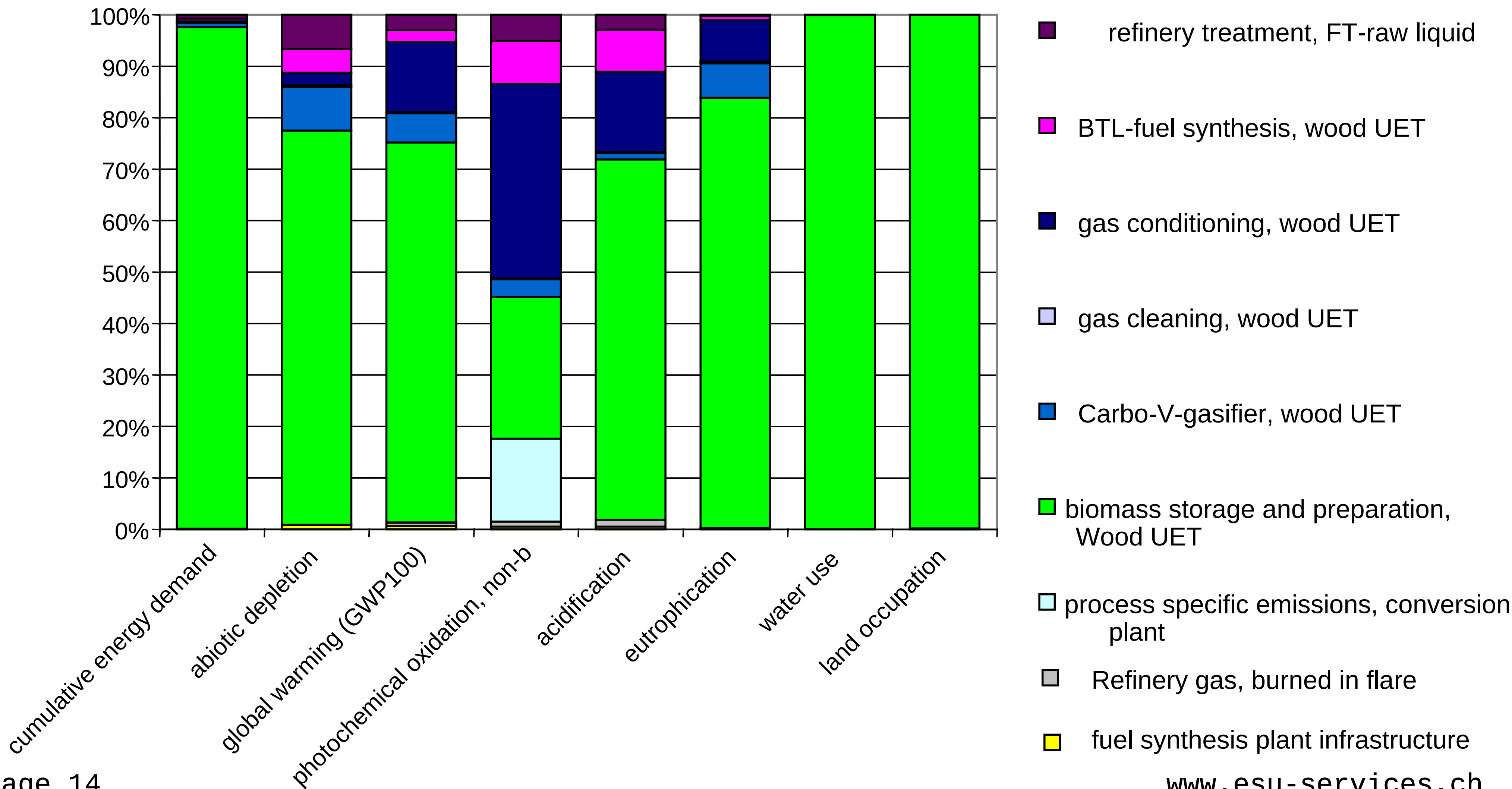
Key data of modelling conversion in 2020

				conversion rate (biomass to all liquids)	capacity biomass input (MW)	all liquid products (diesel, naphtha, DME)
Biomass	Product	Code	Developer	energy	energy	toe/h
Wood	BTL-FT	cEF-D	UET	53%	499	22.5
Straw	BTL-FT	cEF-D	UET	57%	462	22.3
Wood	BTL-FT	CFB-D	CUTEC	40%	485	16.6
Straw	BTL-FT	CFB-D	CUTEC	38%	463	15.0
Straw	BTL-FT	dEF-D	FZK	45%	455	17.5
Wood	BTL-FT	ICFB-D	TUV	26%	52	1.1
Miscanthus	BTL-FT	ICFB-D	TUV	26%	50	1.1
Wood	BTL-DME	BLEF-DME	CHEMREC	69%	500	29.0

Discussion of results for BTL-fuel production

- CML characterisation
- Evaluation of product stages
- Comparison of biomass and conversion concepts
- Peer review according to ISO14040

Contribution of sub-processes (cEF-D, wood)



Observations

- Most important are impacts from biomass production
- Direct gaseous emissions are relevant for summer smog
- Comparison within process stages is difficult

Comparisons

- cEF-D lowest impacts mainly because of conversion efficiency
- No clear ranking of all processes if CML indicators are used
- ICFB-D has highest impacts in all categories because of low conversion efficiency to fuel (but by-product electricity)
- No clear recommendation comparing wood and straw and only one conversion process using miscanthus (ICFB-D)

General improvement options for conversion process

- Improve agricultural biomass production
- Increase of the fuel yield
- Reduce direct emissions (CH_4, NMVOC, NO_x, particles) with off-gases and from the power plant
- Recycling of nutrients in slag and ashes

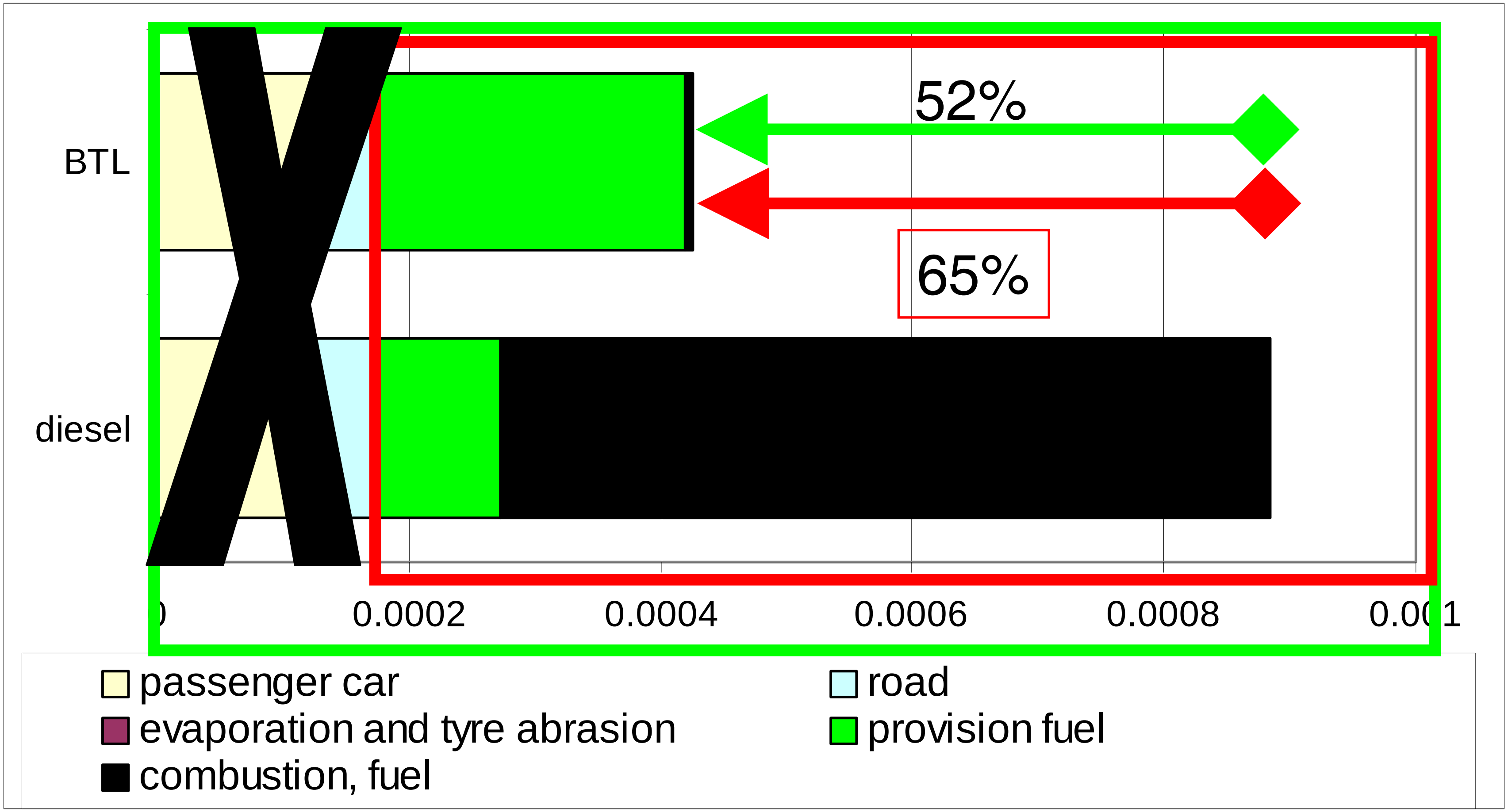
Life cycle assessment of using BTL (full life cycle)

- What are the environmental impacts of using BTL-fuels compared to fossil diesel?
- Importance of fuel combustion for total environmental impacts?
- GWP reduction potential
- Comparison of BTL with today biofuels?
- Yields per hectare compared to present situation?
- → Follow-up study commissioned by Swiss authorities in the framework of “Ökobilanz von Energieprodukten”

How much better are renewable fuels?

- Easy question without an easy answer ...

Exclusion of certain stages



➢ The following assessment includes the full life cycle

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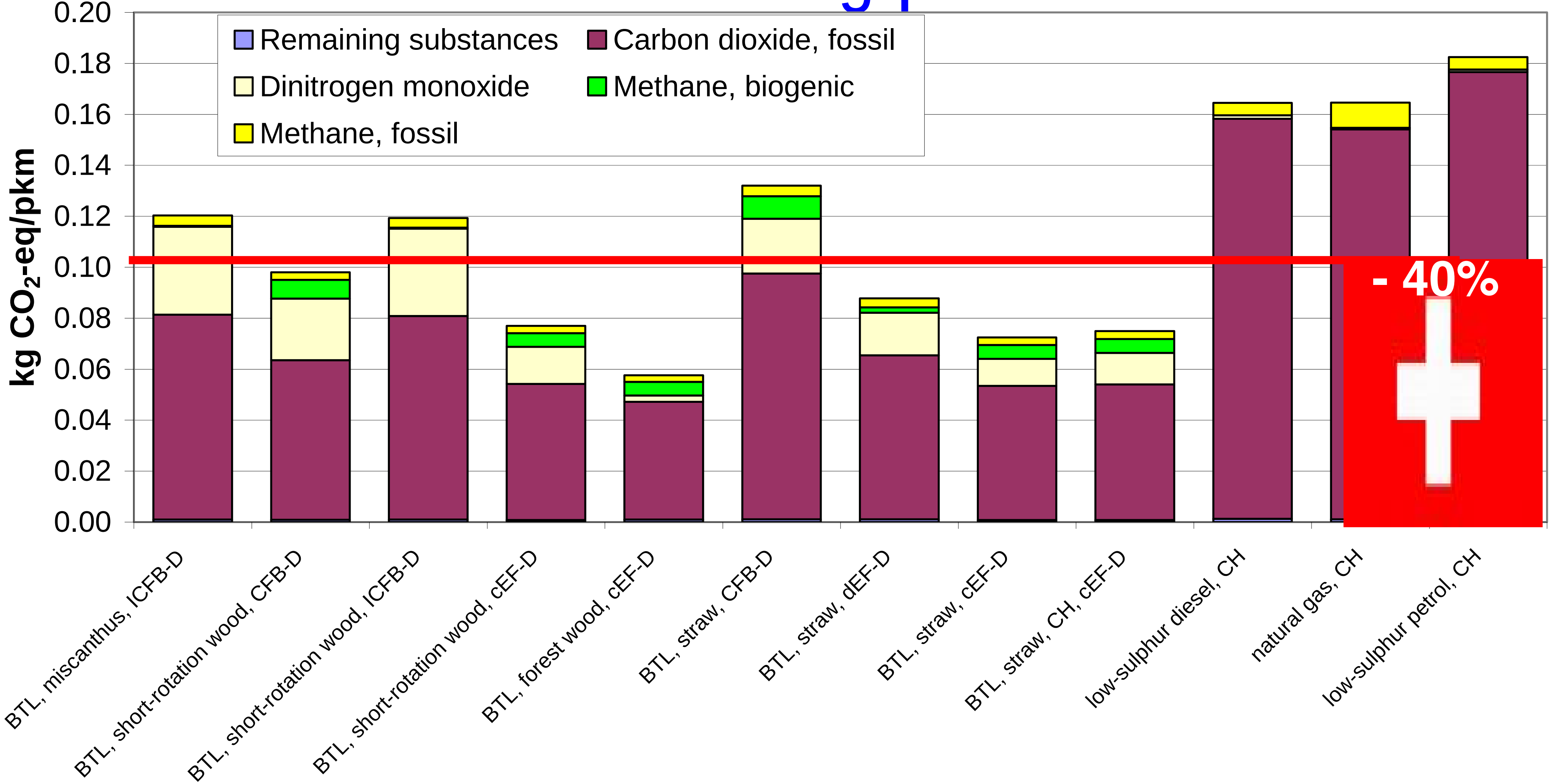
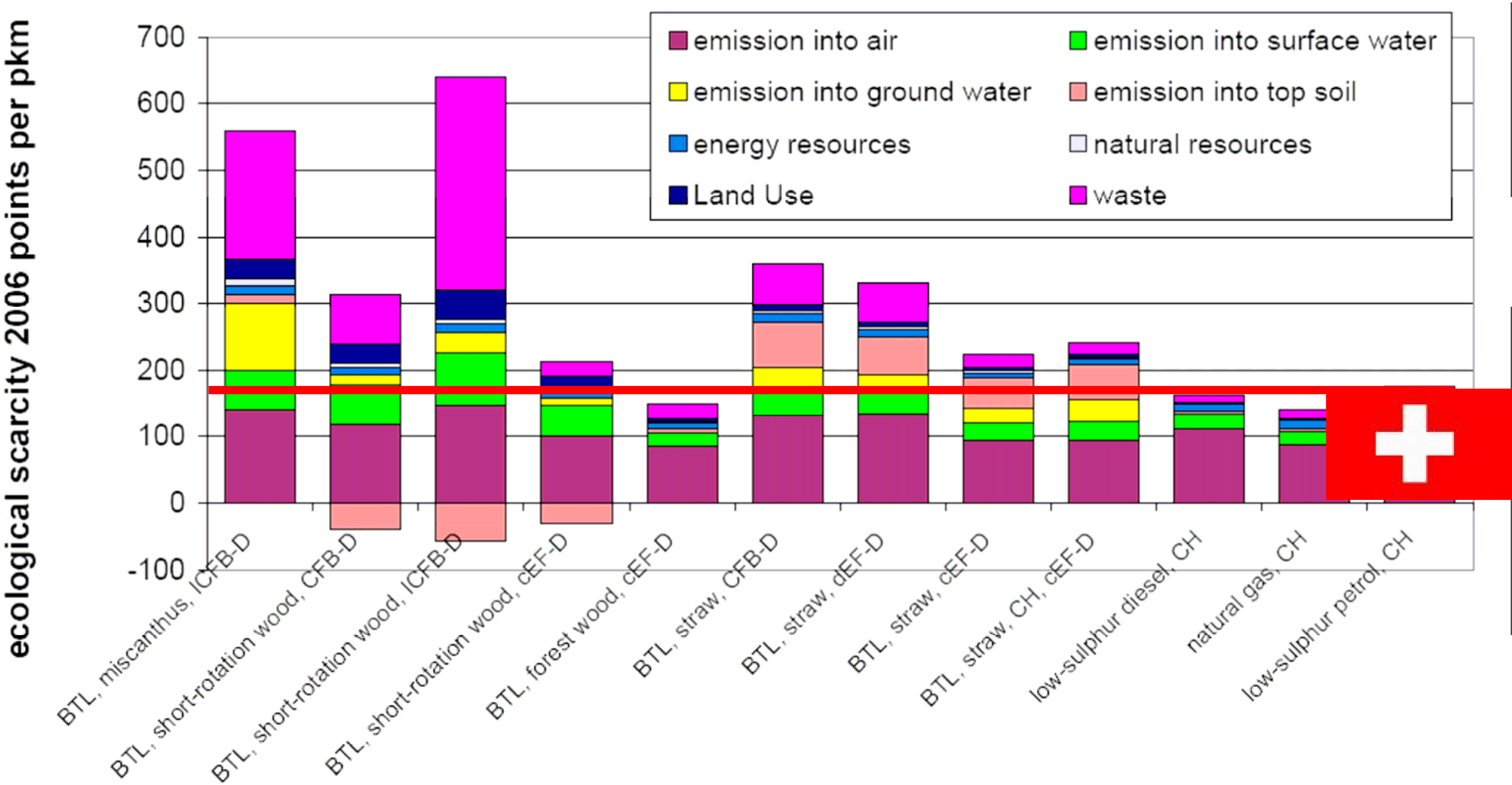
Global warming potential



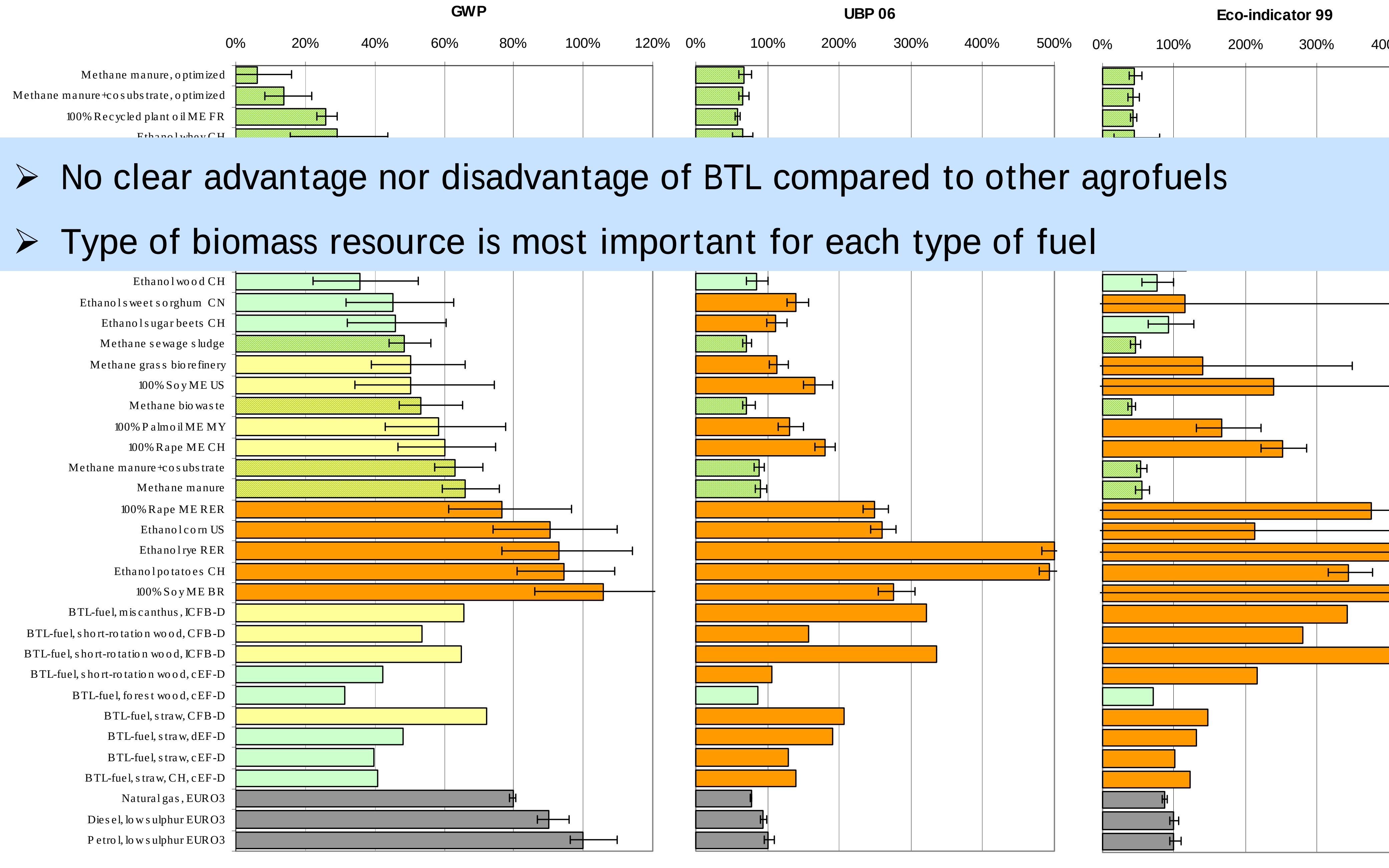
- GWP reduction between 28% and 69% → lower than what has been assumed so far

The whole picture: overall env. impact



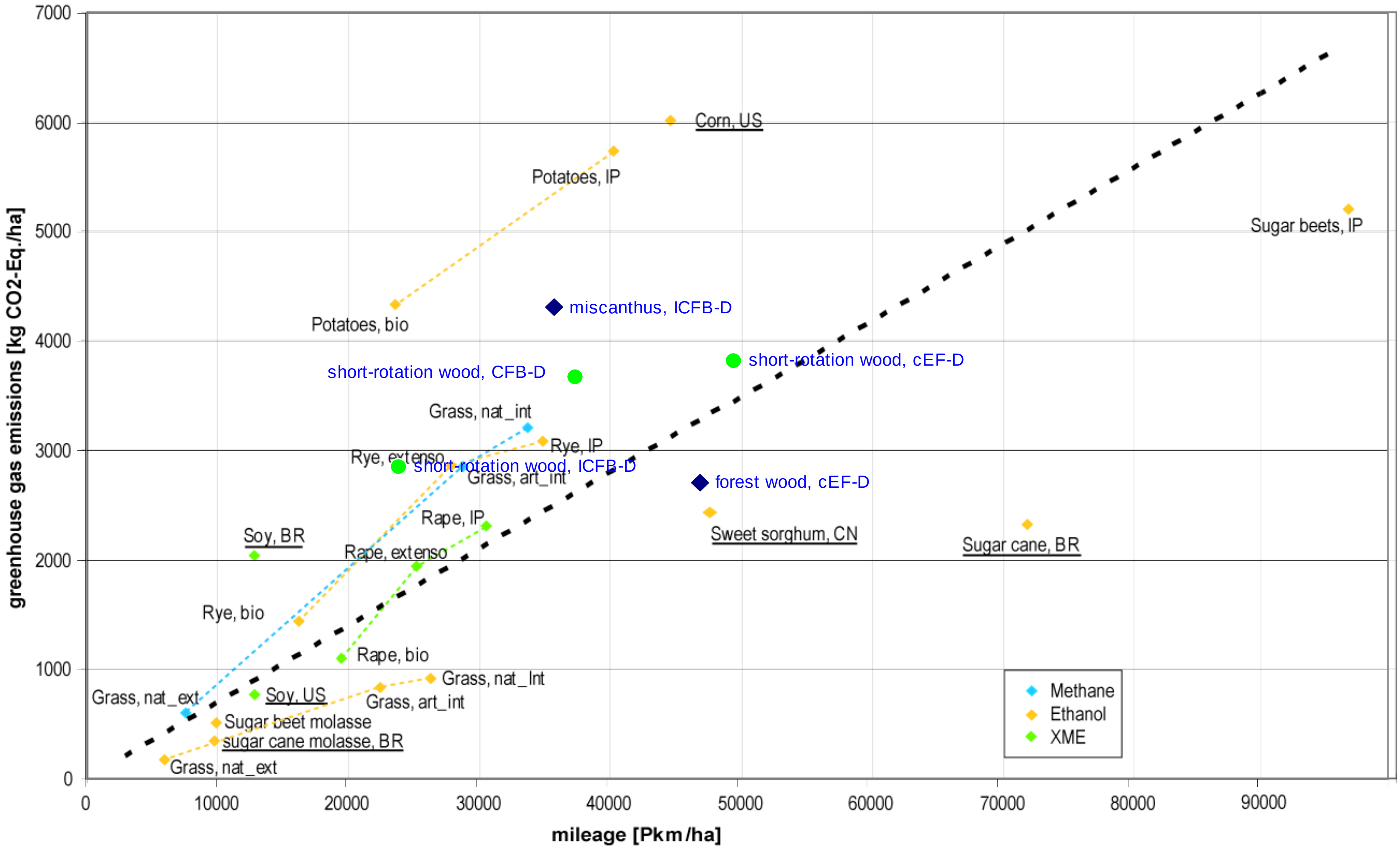
➢ Big differences between the production routes of the same biomass type

Comparison of renewable fuels



- ➢ No clear advantage nor disadvantage of BTL compared to other agrofuels
- ➢ Type of biomass resource is most important for each type of fuel

Mileage per hectare



Main observations for BtL

- Low emissions of GHG during combustion outweigh the higher impacts of fuel production for GWP
- Reduction potential for GWP and non-renewable energy is about 30% to 70% if the full life cycle is taken into account
- Other environmental impacts of BTL-fuel from agricultural biomass are higher than using fossil fuels
- Comparison with present agrofuels and evaluation of fuel yields show no generally better performance
- Type of biomass and conversion efficiency are important
- Criteria for Swiss tax exemption might be fulfilled by some production pathways

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Thank you for your attention!

Publications:

- LCA of Biomass-To-Liquid fuel production (www.esu-services.ch/renew.htm)
- LCA of Biomass-To-Liquid fuel use (www.esu-services.ch/btl)

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Annexe
LCA of BTL-production

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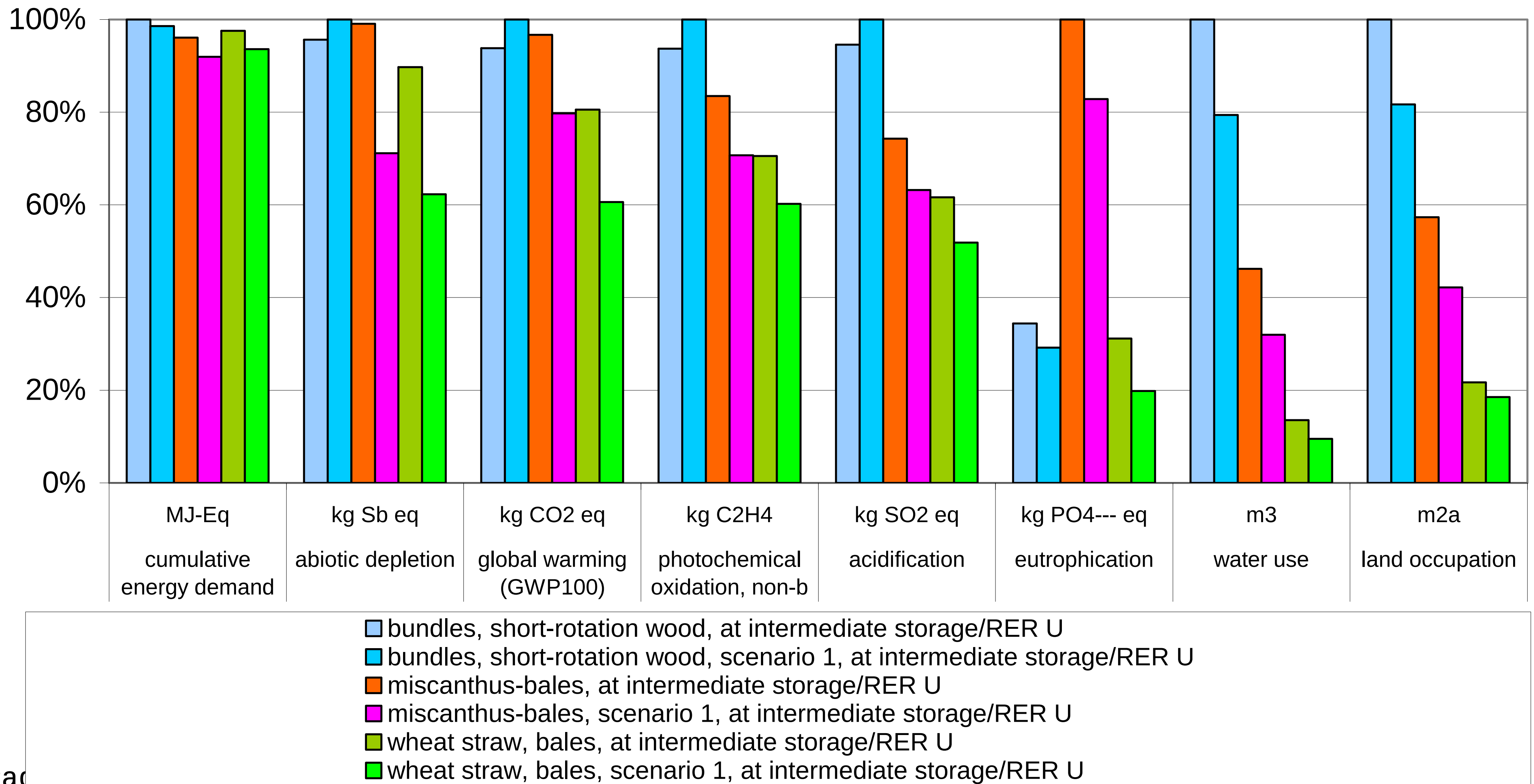
Intermediate Storage Key assumptions

Name	Unit	miscanthus-bales, at intermediate storage	miscanthus-bales, scenario 1, at intermediate storage	bundles, short-rotation wood, at intermediate storage	bundles, short-rotation wood, scenario 1, at intermediate storage	wheat straw, bales, at intermediate storage	wheat straw, bales, scenario 1, at intermediate storage	UncertaintyType StandardDeviation 95%	GeneralComment
Location		RER	RER	RER	RER	RER	RER		
InfrastructureProcess		0	0	0	0	0	0		
Unit		kg	kg	kg	kg	kg	kg		
biomass losses during storage	%	6%	3%	7%	4%	6%	3%		Expert guess
water content of biomass	%	30%	30%	20%	20%	15%	15%	15	km transport distance 1st gathering point (Ganko 2006)
share of bales with plastic foil	%	90%	10%	0%	0%	90%	10%	175	kg dry matter biomass per bale
share of closed storage	%	10%	90%	10%	90%	10%	90%		Expert guess
share on open ground	%	90%	10%	90%	10%	90%	10%	400	kg storage good per m2
carbon content	%	47%	47%	48%	48%	46%	46%		boundary conditions
lower heating value	MJ	13.64	13.64	12.16	12.16	13.10	13.10		Boundary conditions

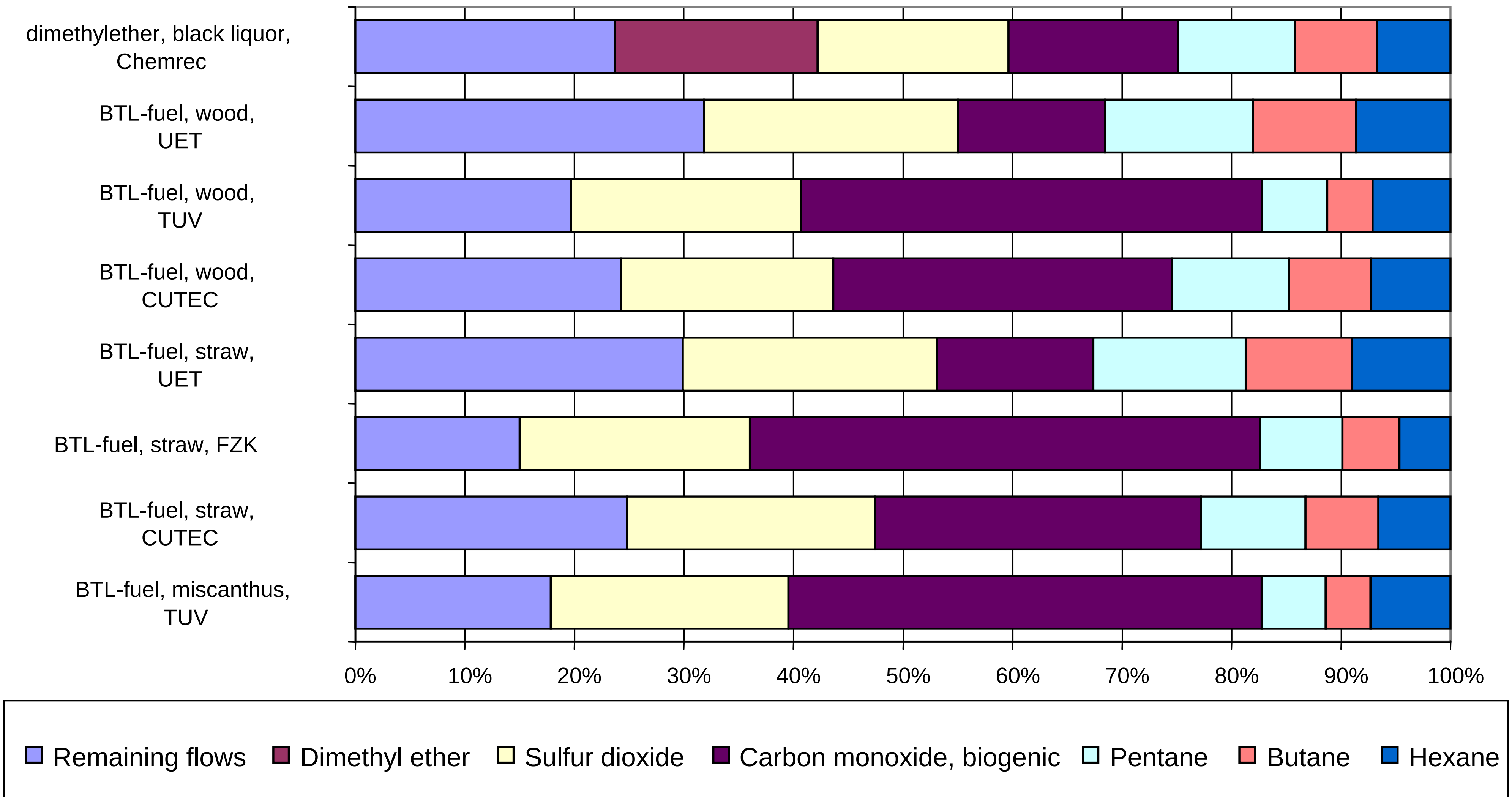
Biomass, at intermediate storage (per MJ biomass energy)



Interpretation for biomass production

- Main factors are fertilizer and diesel use and emissions due to use of fertilizers
- Small variations in scenarios
- General uncertainty in agricultural data is higher than the differences between scenarios
- Straw has lower impacts due to economic allocation, wood has higher or about the same impacts as miscanthus except for eutrophication

Analysis of individual pollutants, i.e. Photochemical Oxidation



Scenarios

- Starting point scenario provides a good basis for comparison of different conversion concepts
- Scenario 1 shows what would be possible if fuel yield should be maximized at a certain place. Hydrogen produced with wind power is used to maximize the fuel production

Key data scenario 1

				conversion rate (biomass to all liquids)	capacity biomass input (MW)	external electricity, including H2 production	hydrogen input conversion	all liquid products (diesel, naphtha, DME)
Biomass	Product	Code	Developer	energy	energy	MW	kg/kg product	toe/h
Wood	BTL-FT	cEF-D	UET	108%	499	489	0.24	45.6
Wood	BTL-FT	CFB-D	CUTEC	57%	485	135	0.13	23.4
Straw	BTL-FT	CFB-D	CUTEC	56%	464	149	0.13	21.9
Straw	BTL-FT	dEF-D	FZK	91%	455	515	0.34	34.9
Wood	BTL-FT	ICFB-D	TUV	55%	518	-	-	24.1
Miscanthus	BTL-FT	ICFB-D	TUV	57%	498	-	-	24.0

Well to tank comparison

Category indicator	Biomass	Miscanthus	Straw	Straw	Straw	Wood	Wood	Wood	Wood
	Process	Allothermal Circulating Fluidized Bed Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Allothermal Circulating Fluidized Bed Gasification	Centralized Entrained Flow Gasification	Entrained Flow Gasification of Black Liquor for DME-production
	Code	ICFB-D	CFB-D	dEF-D	cEF-D	CFB-D	ICFB-D	cEF-D	BLEF-DME
	Company	TUV	CUTEC	FZK	UET	CUTEC	TUV	UET	CHEMREC
	Product	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-DME
cumulative energy demand	MJ-Eq	*252%*	*186%*	147%	115%	*169%*	*263%*	128%	100%
abiotic depletion	kg Sb eq	*255%*	*260%*	*155%*	121%	*165%*	*257%*	128%	100%
global warming (GWP100)	kg CO2 eq	*226%*	*252%*	128%	104%	*171%*	*224%*	116%	100%
photochemical oxidation, non-b	kg C2H4	*244%*	*361%*	*258%*	100%	*292%*	*245%*	104%	141%
acidification	kg SO2 eq	*256%*	*192%*	*190%*	100%	*181%*	*289%*	130%	133%
eutrophication	kg PO4--- eq	*453%*	*207%*	*162%*	106%	*176%*	*300%*	117%	100%
water use	m3	*780%*	*151%*	127%	100%	*672%*	*1034%*	*508%*	*396%*
land competition	m2a	*631%*	*155%*	139%	100%	*610%*	*959%*	*458%*	*358%*

	Min	Max
Lowest impacts	100%	115%
Low impact	116%	150%
High impact	*151%*	*250%*
Highest impacts	*251%*	

- Best efficiency gives lowest results, but also some differences depending on biomass and specific impacts

Well to tank comparison
Scenario 1

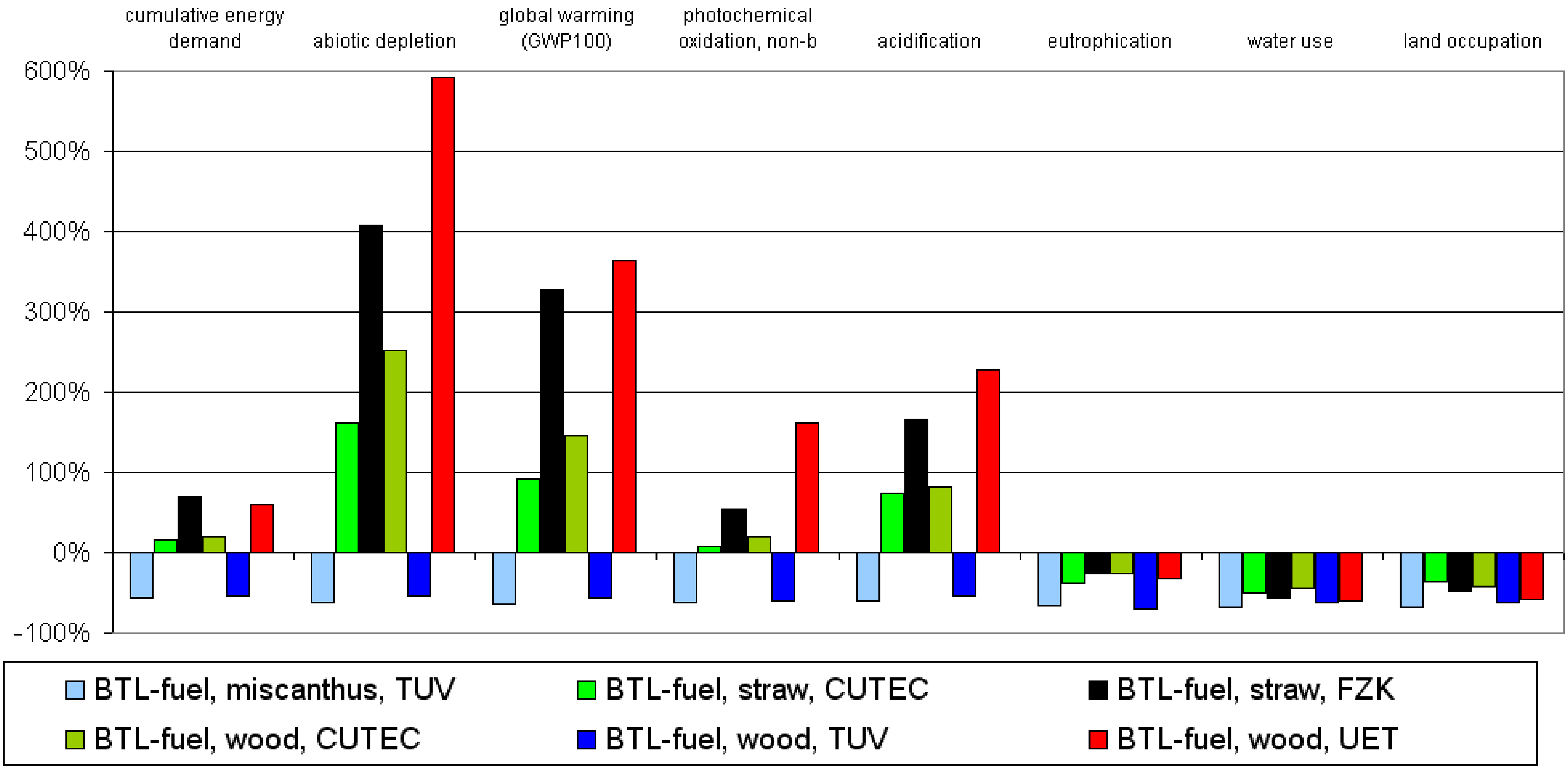
	Biomass	Miscanthus	Straw	Straw	Wood	Wood	Wood
	Process	Allothermal Circulating Fluidized Bed Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Allothermal Circulating Fluidized Bed Gasification	Centralized Entrained Flow Gasification
	Code	ICFB-D	CFB-D	dEF-D	CFB-D	ICFB-D	cEF-D
	Company	TUV	CUTEC	FZK	CUTEC	TUV	UET
Category indicator	Product	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT
cumulative energy demand	MJ-Eq	100%	*219%*	*290%*	*206%*	112%	*217%*
abiotic depletion	kg Sb eq	107%	*263%*	*164%*	*257%*	134%	100%
global warming (GWP100)	kg CO2 eq	123%	*265%*	138%	*254%*	*151%*	100%
photochemical oxidation, non-b	kg C2H4	141%	*240%*	*176%*	*226%*	*156%*	100%
acidification	kg SO2 eq	128%	*166%*	122%	*209%*	*175%*	100%
eutrophication	kg PO4--- eq	*506%*	*209%*	100%	*234%*	*208%*	100%
water use	m3	*573%*	*164%*	100%	*1332%*	*1375%*	*701%*
land competition	m2a	*331%*	148%	100%	*610%*	*622%*	*320%*

	Min	Max
Lowest impacts	100%	115%
Low impact	116%	150%
High impact	*151%*	*250%*
Highest impacts	*251%*	

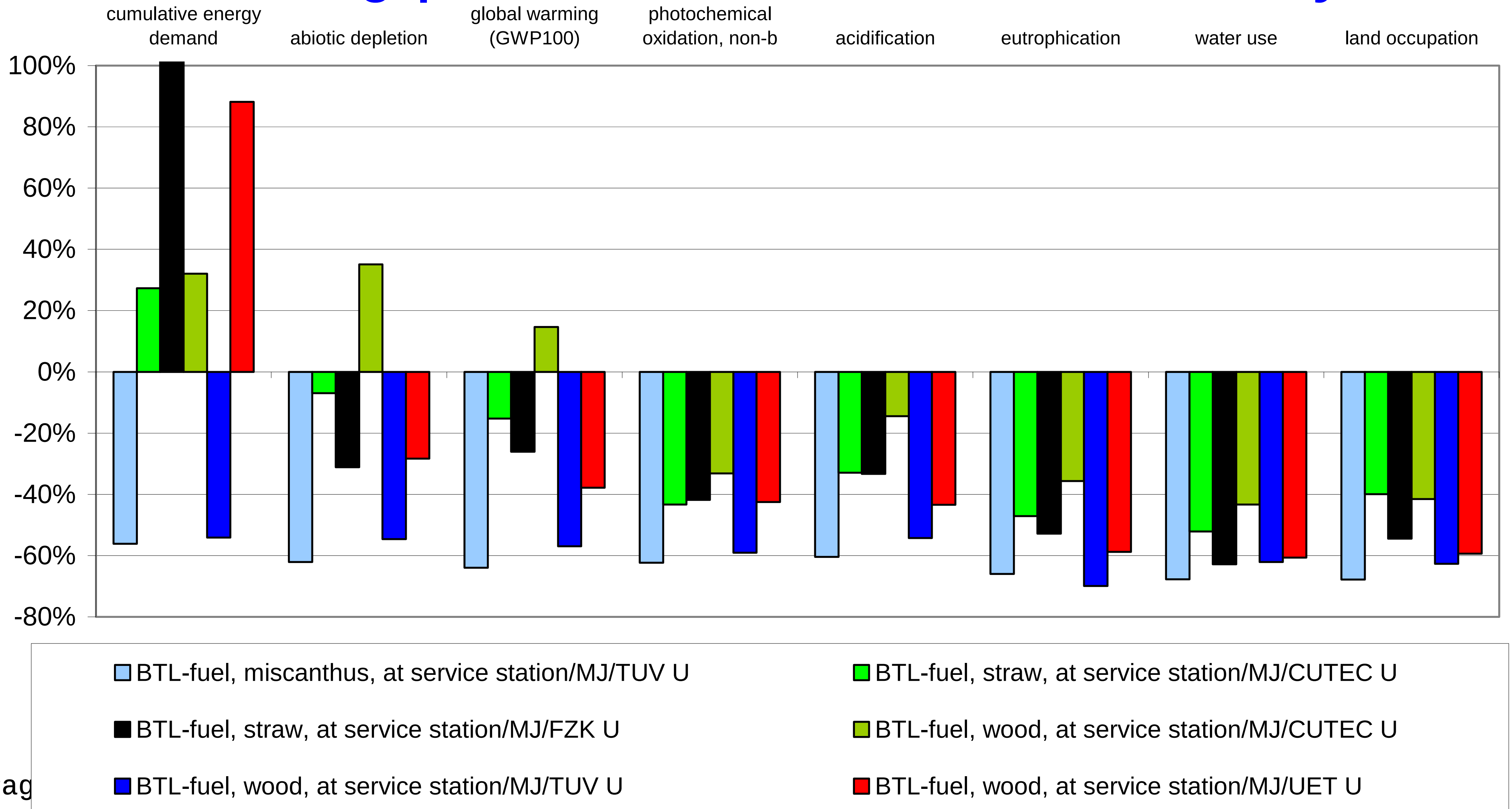
Interpretation, Scenario 1

- Only preferable if electricity supplied by wind power, but in this case high demand for capacity and supply security or flexibility
- Higher impacts in case of external hydrogen production with European electricity mix
- No clear ranking because of different advantages and disadvantages

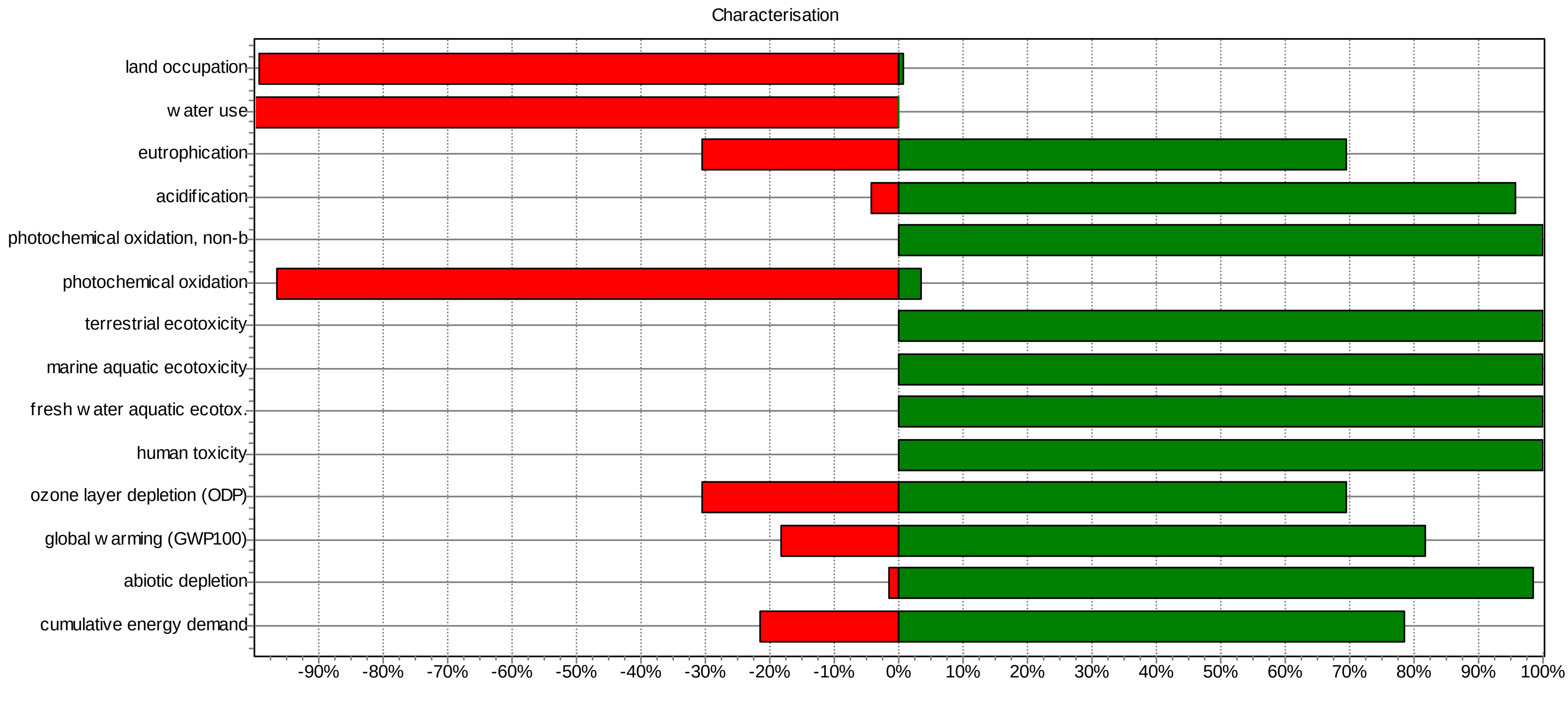
Change of results
Starting point -> Sc1,



Change of results
Starting point -> Sc1, wind electricity

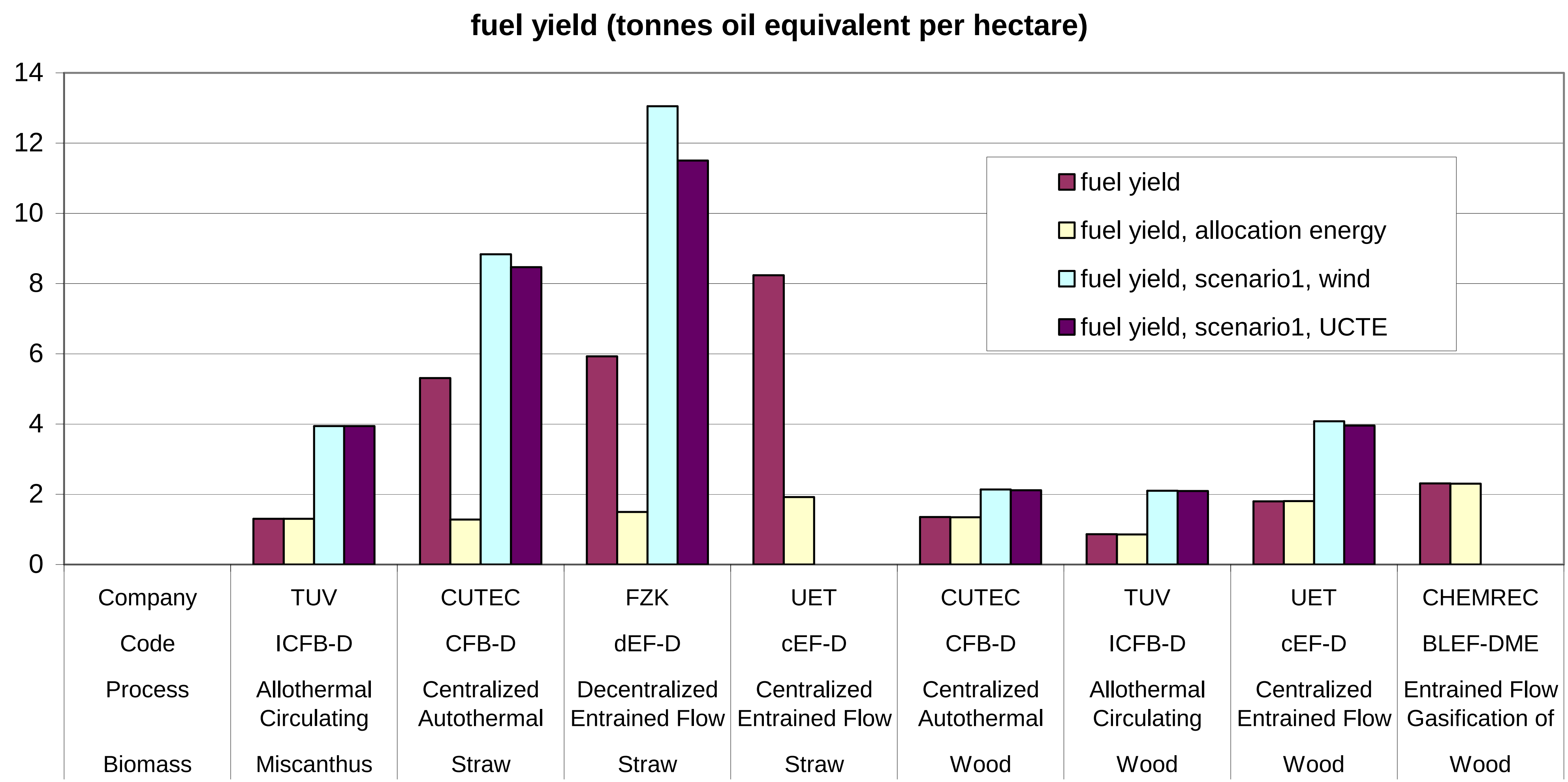


Uncertainties
Straw, FZK against Wood, UET

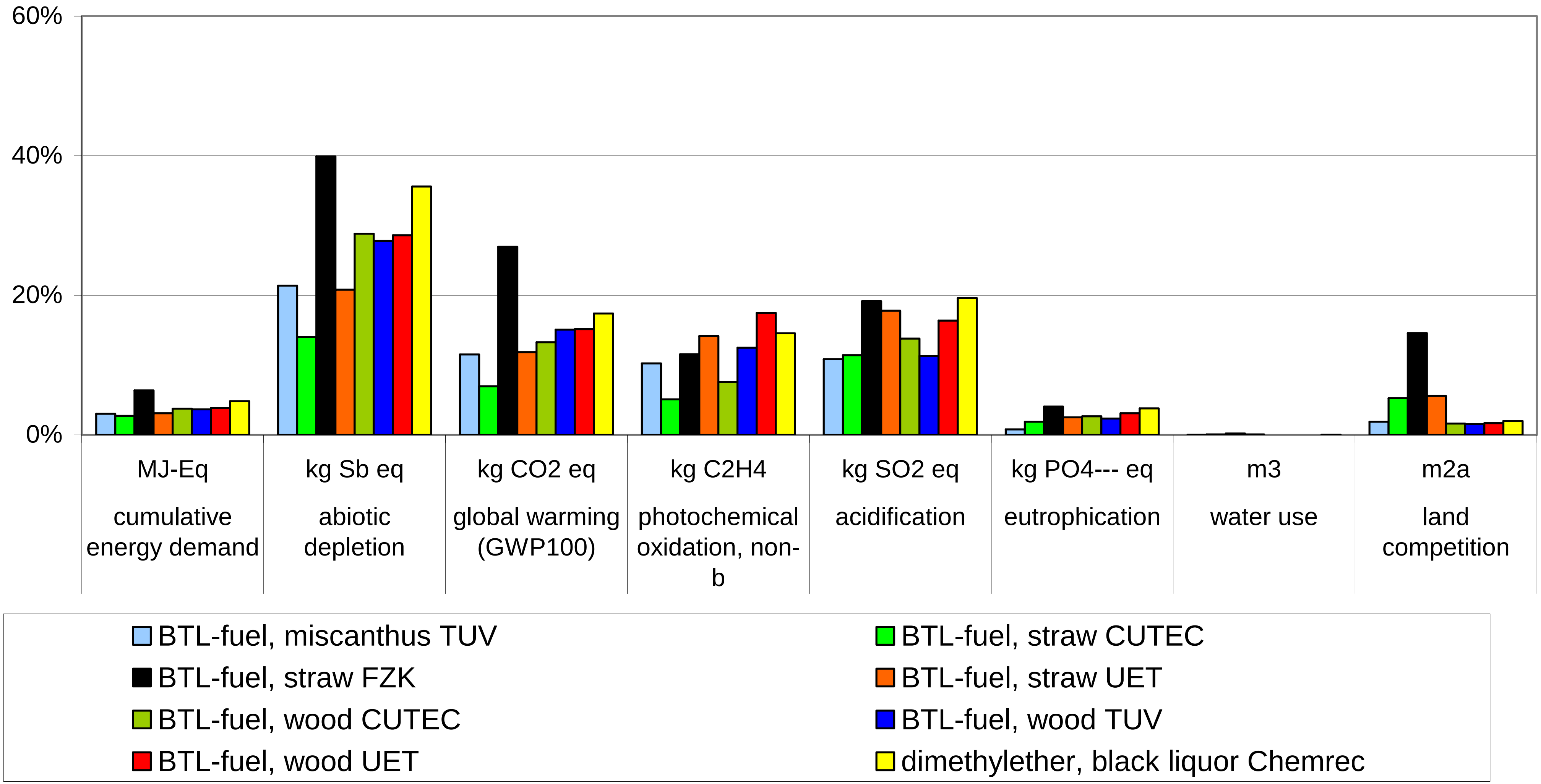


Uncertainty analysis of 1 MJ material 'BTL-fuel, straw, at regional storage/MJ/FZK U' (A) minus
1 MJ material 'BTL-fuel, wood, at regional storage/MJ/UET U' (B),
method: CML 2 baseline 2000 V2.03 / RENEW, West Europe, 1995 , confidence interval: 95

Fuel yields


fuel yield (tonnes oil equivalent per hectare)
14
12
10
8
6
4
2
0
fuel yield
fuel yield, allocation energy
fuel yield, scenario1, wind
fuel yield, scenario1, UCTE
Company
Code
Process
Biomass
TUV
ICFB-D
Allothermal Circulating
Miscanthus
CUTEC
CFB-D
Centralized Autothermal
Straw
FZK
dEF-D
Decentralized Entrained Flow
Straw
UET
cEF-D
Centralized Entrained Flow
Straw
CUTEC
CFB-D
Centralized Autothermal
Wood
TUV
ICFB-D
Allothermal Circulating
Wood
UET
cEF-D
Centralized Entrained Flow
Wood
CHEMREC
BLEF-DME
Entrained Flow Gasification of
Wood

Share capital goods (starting point, MJ fuel)



Capital goods

- Share up to 40%
- Exclusion would give wrong picture
- Article published in the Int.J.LCA that gives further details and recommendations

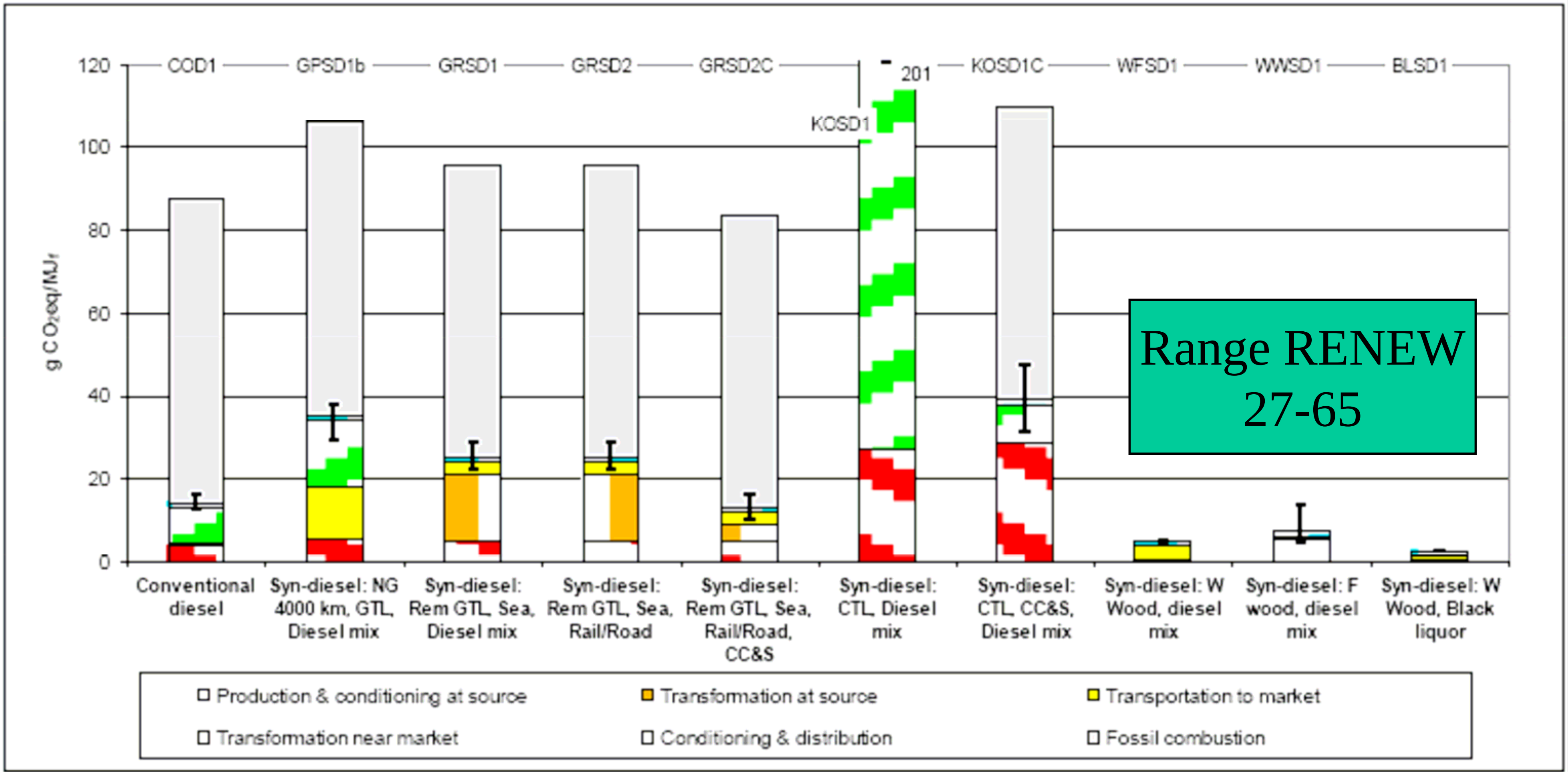
Frischknecht R, Althaus H-J, Bauer C, Doka G, et al., *The environmental relevance of capital goods in life cycle assessments of products and services.* Int. J. LCA, 2007. **Online first**. DOI: http://dx.doi.org/10.1065/lca2007.02.309.

Limitations of the study

- Pesticides, heavy metals and impacts of land occupation for biomass production not considered in the assessment
- No agreement on reliability of assessment methodologies of toxicity impacts

Concawe compared to RENEW results (fuel production)

Figure 4.6.2-3 *WTT GHG balance of syn-diesel pathways (including fossil CO_2 content of final fuels)*



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Differences with Concawe study

- Higher nitrogen input in RENEW study (5-6 vs. 2.5 g N/kg DS) ↗ ca. +50% N2O
- Direct emissions (CH4 and N2O) lower because no data for conversion in Concawe study ↗ ca. +10-20% in RENEW
- No infrastructure in Concawe study ↗ +10-20%
- Credits for electricity production with biomass power plant - mainly relevant for TUV

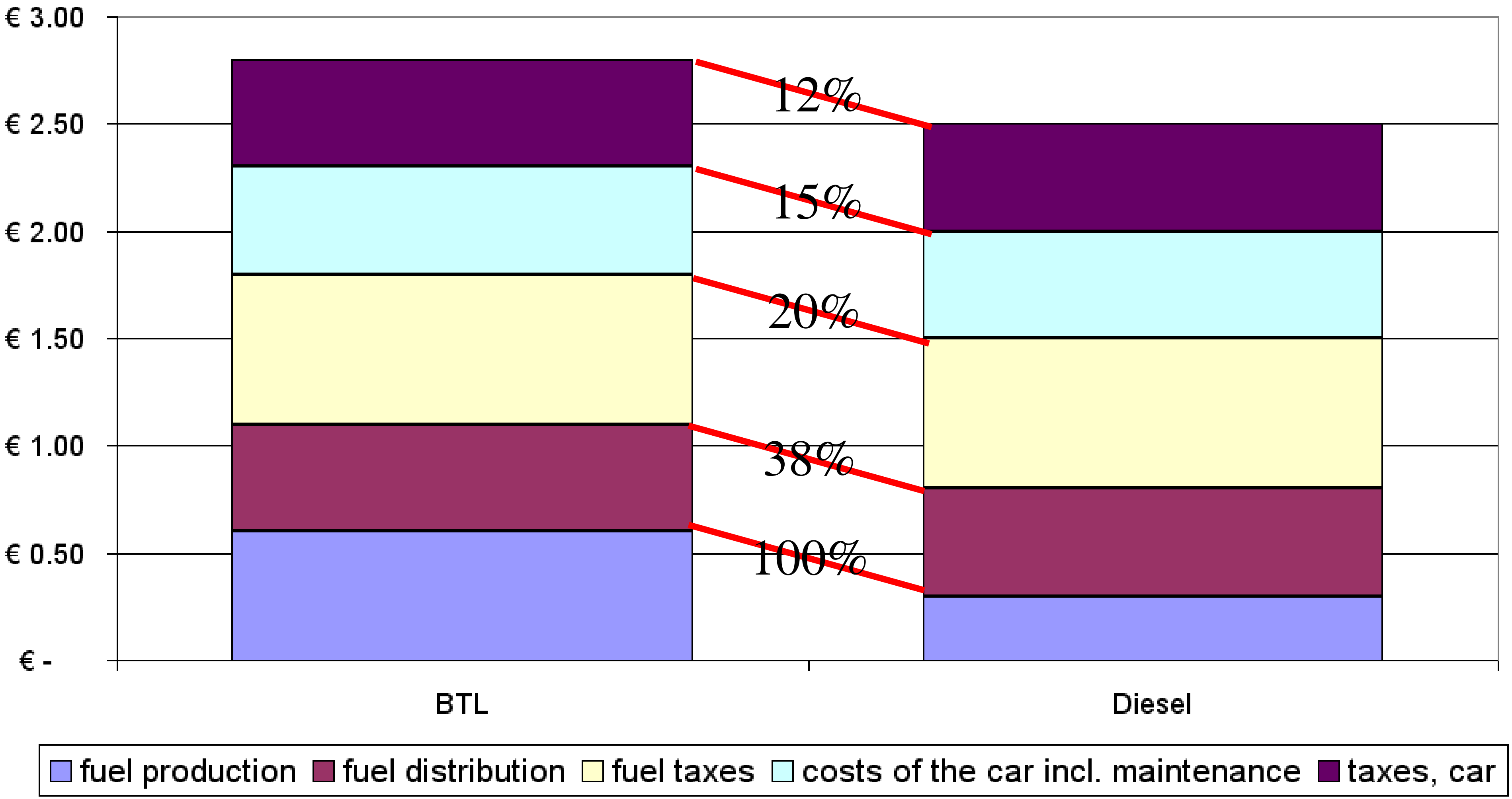
Peer Review
LCA of BTL-fuel production

- Peer review according to ISO14040 in general quite positive:
  - Requirements are fulfilled
  - Data structure and results are exemplary
- Main critics are
  - No impact assessment for toxicological effects
  - No full cradle-to-grave LCA
  - No comparison to fossil fuel
- Reports have been finalized and published on the RENEW homepage together with full review comment

Questions to be answered

- Using BTL reduces the GWP by X% compared to fossil fuel
- Using a specific amount (e.g. 1 MJ or 1 kg) of BTL reduces the GWP by Y kg (or another appropriate unit) compared to fossil fuel

Calculations of potential reduction



And again: How much better are biofuels?

- If we want an answer like „the use of biofuel has ???% lower GWP than fossil fuels“ than we have to include the all parts of the life cycle, e.g. for transports also cars and streets
- Neglecting certain parts of the life cycle, even if the same for both options, will bias the results
- System boundaries must be stated correctly if comparing reduction figures, e.g. well-to-wheel should include the wheel
- See www.esu-services.ch/btl/ for background paper

BTL from short-rotation wood (IFEU study)