JRC Scientific and Technical Reports

Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context

WTT APPENDIX 2
Description and detailed energy and GHG balance of individual pathways

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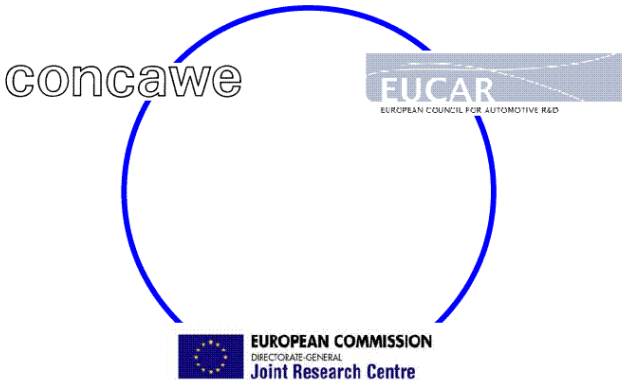

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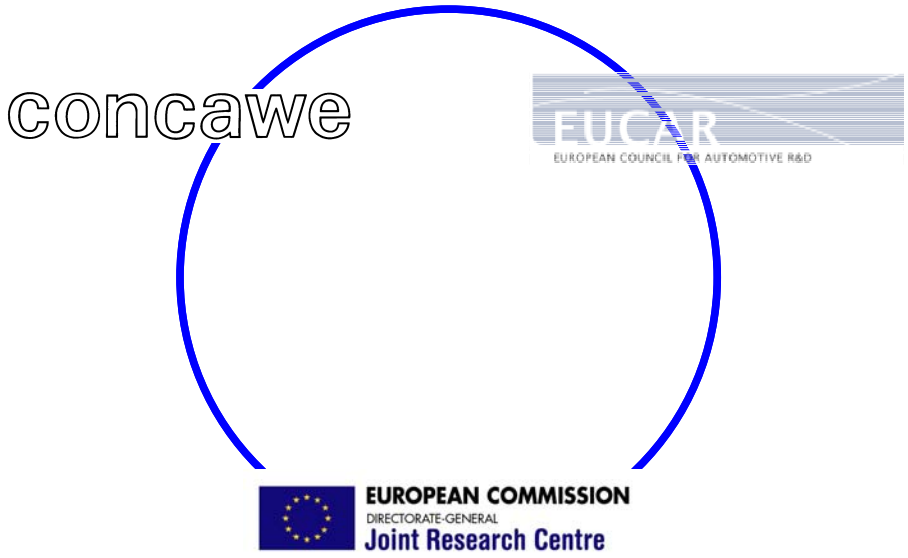

WELL-to-TANK Report - Appendix 2

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Notes on version number:

This document reports on the third release of this study replacing data made available since November 2008.

The original version 1b was published in December 2003.

Description and detailed energy and GHG balance of individual pathways

This appendix gives the detailed results of the energy and GHG balance for all pathways. Pathways new to this version 3 have been highlighted in yellow.

It details the processes included in each pathway and gives the resulting energy and GHG balance for the total pathway as well as the contribution of each of the main stages. In addition to ***WTT Appendix 1 which*** shows some of the calculations carried out by the E3 database, this version includes ***WTT Appendix 4*** which details the process-by-process input data for each pathway.

Energy figures are expressed as net energy *expended* (MJ_x) (i.e. excluding the energy transferred to the final fuel) per MJ energy content of the final fuel (MJ_f). "Total primary" refers to all energy regardless of the primary energy source, i.e. including renewable energy. The portion of this total energy that comes from fossil sources is given in the "fossil" column.

Note: the use of the EU-mix electricity as a generic power source for e.g. transport or operation of refuelling stations introduces a small amount of renewable energy in most pathways.

GHG figures are expressed in g CO_2eq/MJ_f as the sum of the contributions of CO_2, CH_4 and N_2O taking into account their respective Global Warming Potential. Individual contributions are also shown. The figures shown for each step of a pathway exclude the CO_2 emissions associated with the combustion of the final fuel when it is of fossil origin. For carbon-containing fuels of renewable origin, however, a credit is given for an amount of CO_2 equivalent to that released during combustion. In the TTW section of the study, all fuels can then be treated in the same way and allocated CO_2 emissions corresponding to their carbon content regardless of its origin. Figures without and with that credit are shown in the tables.

The figures shown for individual steps of a pathway all refer to final product i.e. as the contribution of each step to the total. This is unlike ***WTT Appendix 1*** where figures are expressed based on the product of that step.

The best estimate and the range of variability are given for both energy and GHG. The ranges are obtained via a Monte Carlo simulation combining the range of variation of individual processes (see ***WTT Appendix 1***). The minimum value is taken as P20 (20% of observed values will be below that value) and the maximum as P80. The range of energy variation is also indicated for those steps that make a significant contribution.

In order to facilitate comparison of pathways of a different nature the final table regroups the actual processes into five standard stages namely:

Stage 1: Production and conditioning at source
Includes all operations required to extract, capture or cultivate the primary energy source. In most cases, the extracted or harvested energy carrier requires some form of treatment or conditioning before it can be conveniently, economically and safely transported.

Stage 2: Transformation at source
Is used for those cases where a major industrial process is carried out at or near the production site of the primary energy (e.g. gas-to-liquids plant).

Stage 3: Transportation to EU
Is relevant to energy carriers which are produced outside the EU and need to be transported over long distances. This step is also used where a significant transport vector is required to move the raw material to a processing plant (e.g. biomass).

Stage 4: Transformation in EU
Includes the processing and transformation that takes place near the market place in order to produce a final fuel according to an agreed specification (e.g. oil refineries or hydrogen reformers).

Stage 5: Conditioning and distribution
Relates to the final stages required to distribute the finished fuels from the point of import or production to the individual refuelling points (e.g. road transport) and available to the vehicle tank (e.g. compression in the case of natural gas).

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1 Conventional fuels

Pathway code		COD	COG	CON
		1	1	1
Code	Process			
Crude oil				
CO1	Crude oil production	✓	✓	✓
CO2	Crude oil transportation	✓	✓	✓
CD1	Crude oil refining, marginal diesel	✓		
CD2	Diesel transport	✓		
CD3	Diesel depot	✓		
CD4	Diesel distribution and dispensing	✓		
CG1	Crude oil refining, marginal gasoline		✓	
CG2	Gasoline transport		✓	
CG3	Gasoline depot		✓	
CG4	Gasoline distribution and dispensing		✓	
CN1	Crude oil refining, marginal naphtha			✓
CN2	Naphtha transport			✓
CN3	Naphtha depot			✓
CN4	Naphtha distribution and dispensing			✓
BDo	Heating oil domestic boiler			
BIo	Heating oil industrial boiler			

COG1 Crude oil to gasoline

COD1 Crude oil to diesel

CON1 Crude oil to naphtha

The gasoline and diesel fuel pathways are the reference against which all others need to be evaluated. Naphtha is a potential fuel for fuel cells. The figures for crude oil extraction and processing relate to conventional crudes. Reserves of non-conventional crudes (Canadian oil-sands and Venezuelan heavy crude) are very large, and these may become important in the longer term, however in the period to 2020 we expect Middle Eastern crude to remain the marginal supply source for Europe. Information on non-conventional crudes has been included for reference in the ***WTT Report*** *Section 3.1.1*.

In this version 3, the "upstream" figures (i.e. for crude oil production and processing) have been revised upwards to take into account more recent data (see ***WTT Report*** *Section 3.1.1*).

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
COG1	**Crude oil to gasoline**											
	Crude Extraction & Processing	1	0.06	0.05	0.08		5.2			5.2	0.00	0.000
	Crude Transport	3	0.01				0.9			0.9	0.00	0.000
	Refining	4	0.08	0.06	0.10		7.0			7.0	0.00	0.000
	Distribution and dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total pathway		**0.17**	0.15	0.20	**0.17**	**14.2**	12.3	16.4	14.1	0.00	0.000
COD1	**Crude oil to diesel**											
	Crude Extraction & Processing	1	0.06	0.05	0.08		5.3			5.3	0.00	0.000
	Crude Transport	3	0.01				0.9			0.9	0.00	0.000
	Refining	4	0.10	0.08	0.12		8.6			8.6	0.00	0.000
	Distribution and dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total pathway		**0.19**	0.17	0.22	**0.19**	**15.9**	12.3	16.2	15.8	0.00	0.000
CON1	**Crude oil to naphtha**											
	Crude Extraction & Processing	1	0.06	0.05	0.08		5.1			5.1	0.00	0.000
	Crude Transport	3	0.01				0.9			-0.7	0.00	0.000
	Refining	4	0.05	0.04	0.06		4.4			4.4	0.00	0.000
	Distribution and dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total pathway		**0.14**	0.12	0.16	**0.14**	**11.4**	9.6	12.9	9.7	0.00	0.000

2 Compressed gas from NG and biomass (CNG/CBG), LPG

2.1 Natural gas to CNG

Pathway code		GMCG	GPCG		GRCG		
		1	1a	1b	1	1C	2
Code	Process						
GG1	NG Extraction & Processing	✓	✓	✓	✓	✓	✓
NG from pipeline							
GP1a	Russian quality, 7000 km		✓				
GP1b	Average quality, 4000 km			✓			
GM1	EU-mix quality, 1000 km	✓					
LNG production & transport							
GR1	NG Liquefaction				✓		✓
GR1C	NG Liquefaction with CCS					✓	
GR2	LNG terminal (loading)				✓	✓	✓
GR3	LNG transport (average of two distances)				✓	✓	✓
GR4	LNG terminal (unloading)				✓	✓	✓
NG distribution							
GR5	LNG vaporisation				✓	✓	
GR6	LNG distribution (road tanker)						✓
GR7	LNG to CNG (vaporisation/compression)						✓
GG3	NG trunk distribution	✓	✓	✓	✓	✓	
GG4	NG local distribution	✓	✓	✓	✓	✓	
GG5	CNG dispensing (compression 0.4-25 MPa)	✓	✓	✓	✓	✓	
NG common processes							
GG2	Electricity generation from NG (CCGT)				✓	✓	✓
Common processes							
Z1	Diesel production						✓
Z2	Road tanker						✓
Z3	HFO production				✓	✓	✓
Z4	Product carrier 50 kt				✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓

GMCG1 EU-mix NG supply to CNG

For new applications such as CNG, the EU-mix is, in effect, irrelevant inasmuch as additional marginal gas needs to be used. This case is shown here for reference and to illustrate, when compared to the other cases, the large effect of the gas origin.

GPCG1a Piped NG (7000 km) to CNG

This pathway represents gas imported into the EU through pipelines from Western Siberia, one of the main current and future EU supply sources.

GPCG1b Piped NG (4000 km) to CNG

This pathway represents gas imported into the EU through pipelines from the Middle East or South Western Asia, both key regions for the future EU supplies.

GRCG1/1C LNG to CNG (gaseous distribution) (+CCS option)

LNG can be imported into the EU from various remote sources, the Middle East being one of the most promising in terms of volumes (hence the assumed shipping distance of 5500 nautical miles). In this pathway, LNG is vaporised on receipt into the EU gas grid). Optionally the CO_2 produced in the liquefaction site power plant can be captured and re-injected into a nearby gas or oil field.

GRCG2 LNG to CNG (liquid distribution)

This pathway is similar to CRGC1 but now assumes that LNG is transported as such, by road, to the refuelling stations.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GMCG1	**NG current EU-mix (1000 km)**											
	Extraction & Processing	1	0.02	0.01	0.05		3.3			1.2	0.09	0.000
	Transport	3	0.02				1.9			1.1	0.03	0.000
	Distribution	5	0.01				0.6			0.6	0.00	0.000
	Compression	5	0.06	0.08	0.04		2.9			2.7	0.01	0.000
	Total pathway		**0.12**	0.10	0.15	**0.12**	**8.7**	7.7	10.1	5.5	0.13	0.000
GPCG1a	**Piped NG, 7000 km**											
	Extraction & Processing	1	0.03	0.01	0.06		3.8			1.3	0.10	0.000
	Transport	3	0.19	0.06	0.22		15.0			10.2	0.19	0.000
	Distribution	5	0.01				0.6			0.6	0.00	0.000
	Compression	5	0.06	0.08	0.04		2.9			2.7	0.01	0.000
	Total pathway		**0.30**	0.18	0.34	**0.29**	**22.3**	15.3	25.0	14.7	0.29	0.001
GPCG1b	**Piped NG, 4000 km**											
	Extraction & Processing	1	0.03	0.01	0.05		3.5			1.2	0.09	0.000
	Transport	3	0.09	0.03	0.10		7.5			4.8	0.11	0.000
	Distribution (HP)	5	0.01				0.6			0.5	0.00	0.000
	Compression	5	0.06	0.08	0.04		2.9			2.7	0.01	0.000
	Total pathway		**0.19**	0.14	0.22	**0.19**	**14.5**	11.3	16.0	9.2	0.20	0.000
GRCG1	**LNG, gaseous distribution**											
	Extraction & Processing	1	0.03	0.01	0.05		3.5			1.2	0.09	0.000
	Liquefaction	2	0.09	0.08	0.09		5.8			4.7	0.04	0.000
	Transport (shipping)	3	0.09				5.6			5.5	0.00	0.000
	Receipt + Vaporisation	5	0.03				1.8			1.8	0.00	0.000
	Distribution	5	0.01				0.6			0.5	0.00	0.000
	Compression	5	0.06	0.08	0.04		2.9			2.7	0.01	0.000
	Total pathway		**0.31**	0.29	0.33	**0.30**	**20.2**	19.2	21.6	16.5	0.14	0.000
GRCG1C	**LNG, gaseous distribution, CCS**											
	Extraction & Processing	1	0.03	0.01	0.05		3.5			1.2	0.09	0.000
	Liquefaction (CCS)	2	0.10	0.09	0.10		2.3			1.2	0.04	0.000
	Transport (shipping)	3	0.09				5.5			5.5	0.00	0.000
	Receipt + Vaporisation	5	0.03				1.8			1.8	0.00	0.000
	Distribution	5	0.01				0.6			0.6	0.00	0.000
	Compression	5	0.06	0.08	0.04		2.9			2.7	0.01	0.000
	Total pathway		**0.32**	0.29	0.35	**0.32**	**16.7**	15.5	18.0	13.0	0.14	0.000
GRCG2	**LNG, liquid distribution (trucking)**											
	Extraction & Processing	1	0.03	0.01	0.05		3.5			1.2	0.09	0.000
	Liquefaction	2	0.09				5.8			4.7	0.04	0.000
	Transport (shipping)	3	0.09				5.6			5.5	0.00	0.000
	Receipt	5	0.01				0.7			0.7	0.00	0.000
	Distribution	5	0.02				3.8			1.2	0.10	0.000
	Compression	5	0.03				1.5			1.5	0.00	0.000
	Total pathway		**0.26**	0.25	0.29	**0.26**	**20.8**	20.3	22.1	14.8	0.24	0.000

2.2 Biomass to CBG

Pathway code		OWCG				
		1	2	3	4	5
Code	Process					
Biogas from waste						
BG1a	Liquid manure transport, 10 km		✓			
BG1b	Dry manure transport, 10 km			✓		
BG2a	Municipal waste to biogas (upgraded)	✓				
BG2b	Liquid manure to biogas (upgraded)		✓			
BG2c	Dry manure to biogas (upgraded)			✓		
BG3a	Municipal waste to electricity (small scale, local)	✓				
BG3b	Liquid manure to electricity (small scale, local)		✓			
BG3c	Dry manure to electricity (small scale, local)			✓		
NG distribution						
GG4	NG local distribution	✓	✓	✓	✓	✓
GG5	CNG dispensing (compression 0.4-25 MPa)	✓	✓	✓	✓	✓
Farming						
WT1b	Wheat farming (whole plant)				✓	
WT1c	Wheat farming (double cropping)					✓
Crop transport and processing						
WT2c	Wheat whole plant road transport				✓	✓
WB1	Whole wheat to biogas (upgraded)				✓	
WB2	Whole wheat to biogas, double cropping (upgraded)					✓
Common processes						
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓

OWCG1 Municipal waste to CBG

Municipal waste, already collected is turned into biogas. The biogas is treated and upgraded before being fed into an existing NG grid to be used as automotive fuel.

OWCG2/3 Municipal waste to CBG

Liquid or dry manure is collected from farms and turned into biogas in a central plant serving a small community. The biogas is treated and upgraded before being fed into an existing NG grid to be used as automotive fuel.

OWCG4 Wheat (whole plant) to CBG

The whole wheat plant is harvested and converted into biogas. There is a net fertiliser credit as the fermentation residue is send back to the field. The biogas is treated and upgraded before being fed into an existing NG grid to be used as automotive fuel.

OWCG5 Maize and barley (whole plant) to CBG, double cropping

A variant of the above using the double cropping technique to increase yield and decrease fertiliser application and, as a consequence, field N_2O emissions. Maize is followed by winter barley. Both crops are cultivated and harvested in the same year and

organic agriculture is assumed. The fertilizer requirement is met by the residue of the downstream biogas plant.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
OWCG1	**CBG: municipal waste**											
	Production, treating and upgrading	4	0.81				12.69			3.1	0.45	-0.006
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.86			2.7	0.01	0.000
	Total WTT GHG emitted						**15.5**	12.6	18.5	5.8	0.46	-0.006
	Credit for renewable combustion CO_2						-55.0			-55.0		
	Total pathway		**0.87**	0.74	1.03	**0.17**	**-39.5**	-42.4	-36.5			
OWCG2	**CBG: liquid manure**											
	Manure transport	2	0.03				-94.67			2.1	-3.87	0.000
	Production, treating and upgrading	4	0.88				6.25			-4.3	0.47	-0.004
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.86			2.7	0.01	0.000
	Total WTT GHG emitted						**-85.6**	-110.0	-55.1	0.5	-3.39	-0.004
	Credit for renewable combustion CO_2						-55.0			-55.0		
	Total pathway		**0.97**	0.80	1.13	**0.03**	**-140.6**	-165.0	-110.1			
OWCG3	**CBG: dry manure**											
	Manure transport	2	0.01				-9.00			0.7	-0.39	0.000
	Production, treating and upgrading	4	0.88				6.25			-4.3	0.47	-0.004
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.86			2.7	0.01	0.000
	Total WTT GHG emitted						**0.1**	-3.0	3.0	-0.9	0.09	-0.004
	Credit for renewable combustion CO_2						-55.0			-55.0		
	Total pathway		**0.95**	0.80	1.10	**0.01**	**-54.9**	-58.0	-52.0			
OWCG4	**CBG: wheat (whole plant)**											
	Cultivation	1	0.17				23.38			10.6	0.02	0.041
	Manure transport	2	0.00				0.35			0.3	0.00	0.000
	Production, treating and upgrading	4	0.97				-6.39			-12.6	0.46	-0.018
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.86			2.7	0.01	0.000
	Total WTT GHG emitted						**20.2**	16.7	23.3	-9.6	0.46	-0.018
	Credit for renewable combustion CO_2						-55.0			-55.0		
	Total pathway		**1.20**	1.17	1.23	**0.01**	**-34.8**	-38.3	-31.7			
OWCG5	**CBG: corn and barley, double cropping**											
	Cultivation	1	0.10				17.42			11.8	0.01	0.018
	Manure transport	2	0.00				0.26			0.3	0.00	0.000
	Production, treating and upgrading	4	1.17				2.92			-7.5	0.47	-0.005
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.86			2.7	0.01	0.000
	Total WTT GHG emitted						**23.5**	20.4	36.6	-4.6	0.48	-0.005
	Credit for renewable combustion CO_2						-55.0			-55.0		
	Total pathway		**1.34**	1.31	1.36	**0.03**	**-31.5**	-34.6	-18.4			

2.3 LPG

LRLP1 Gas field condensate to LPG

C3 and C4 condensates from remote gas production are separated treated and liquefied prior to shipping to Europe and distribution as automotive LPG.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
LRLP1	**LPG from gas field (remote)**											
	Extraction & Processing	1	0.05				3.5			3.1	0.02	0.000
	Liquefaction	2	0.01				0.3			0.3	0.00	0.000
	Transport (shipping)	3	0.03				2.5			2.5	0.00	0.000
	Distribution	5	0.02				1.3			1.3	0.00	0.000
	Compression	5	0.01				0.4			0.4	0.00	0.000
	Total pathway		**0.12**	0.12	0.13	**0.12**	**8.0**	8.0	8.5	7.5	0.02	0.000

3 Ethanol

		Sugar beet			Wheat									Sugar cane		Straw	Farmed wood	Waste wood
Pathway code		SBET			WTET									SCET		STET	WFET	WWET
		1a	1b	3	1a	1b	2a	2b	3a	3b	4a	4b	5	1a	1b	1	1	1
Code	Process																	
Farming																		
SB1	Sugar Beet Farming	✓	✓	✓														
WT1a	Wheat farming (grain)				✓	✓	✓	✓	✓	✓	✓	✓	✓					
SC1	Sugar cane farming (Brazil)													✓	✓			
Crop transport and processing																		
SB2	Sugar beet road transport	✓	✓	✓														
SB3a	Sugar beet to ethanol, pulp to animal feed, slops not used	✓																
SB3b	Sugar beet to ethanol, pulp to animal feed, slops to biogas		✓															
SB3c	Sugar beet to ethanol, pulp and slop to biogas digestor and			✓														
WT2a	Wheat grain road transport				✓	✓	✓	✓	✓	✓	✓	✓	✓					
WT2b	Wheat straw road transport										✓	✓				✓		
WT3	Wheat grain handling				✓	✓	✓	✓	✓	✓	✓	✓	✓					
WT4a	Wheat grain to ethanol, conventional boiler				✓	✓												
WT4b	Wheat grain to ethanol, NG CCGT						✓	✓										
WT4c	Wheat grain to ethanol, Lignite CHP								✓	✓								
WT4d	Wheat grain to ethanol, Straw CHP										✓	✓						
WT4e	Wheat grain to ethanol, DDGS to biogas												✓					
WTDa	Credit for DDGS as animal feed				✓		✓		✓		✓							
WTDb	Credit for DDGS as fuel					✓		✓		✓		✓						
W3k	Wheat straw to ethanol (Iogen)															✓		
SC2	Sugar cane road transport													✓	✓			
SC3a	Sugar cane to ethanol, heat credit for surplus bagasse													✓				
SC3b	Sugar cane to ethanol, no credit for surplus bagasse														✓			
SC4a	Sugar cane ethanol road transport to port													✓	✓			
SC4b	Sugar cane ethanol shipping from Brazil													✓	✓			
Wood (farmed)																		
WF1	Wood farming and chipping																✓	
Wood (waste)																		
WW1	Forest residuals to wood chips																	✓
Wood transport & processing (all sources)																		
WC2a	Wood chips road transport, 50 km																✓	✓
WC2c	Coastal/river shipping wood chips (200MW plant)																	✓
W3j	Woody biomass to ethanol (SSCF)																✓	✓
Biofuels transport & distribution																		
ETd	Ethanol distribution (blended)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Common processes																		
Z1	Diesel production	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z3	HFO production													✓	✓			
Z4	Product carrier 50 kt													✓	✓			
Z6	Marginal NG for general use (4000 km piped)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

SBET1/3 Sugar beet to ethanol

The three pathways cover three alternative uses for the pulp and slops by-products. In SBET1a/b the pulp is used as animal feed while slops are either not valorised or used as feedstock to biogas. In SBET3 both pulp and slops are used for producing biogas. The latter is used for cogeneration partially covering the plant heat requirement in SBET1b and covering the whole plant heat requirement in SBET3 while also generating export electricity (excess heat does not generate a credit). Note that all data for these pathways, including farming and manufacturing, has been extensively reviewed and updated.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
SBET1a	**EtOH from sugar beet, pulp to animal feed, slops not used**											
	Cultivation	1	0.11				16.21			7.2	0.01	0.029
	Road transport	3	0.02				1.18			1.2	0.00	0.000
	Ethanol plant	4	1.25				18.71			21.0	0.07	-0.013
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**37.6**	34.5	42.4	30.9	0.08	0.016
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.40**	1.30	1.48	**0.55**	**-33.7**	-36.9	-29.0			
SBET1b	**Ethanol from Sugar beet, pulp to animal feed, slops to biogas**											
	Cultivation	1	0.11				16.21			7.2	0.01	0.029
	Road transport	3	0.02				1.18			1.2	0.00	0.000
	Ethanol plant	4	1.03				5.54			8.9	0.03	-0.014
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**24.5**	21.2	30.0	18.7	0.04	0.016
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.18**	1.09	1.29	**0.34**	**-46.9**	-50.1	-41.4			
SBET3	**Ethanol from Sugar beet, pulp to heat /slops to biogas**											
	Cultivation	1	0.11				16.21			7.2	0.01	0.029
	Road transport	3	0.02				1.18			1.2	0.00	0.000
	Ethanol plant	4	0.73				-5.05			-4.7	-0.01	0.000
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**13.9**	11.4	19.1	5.2	0.00	0.029
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**0.88**	0.77	0.97	**0.04**	**-57.5**	-60.0	-52.3			

WTET Wheat grain to ethanol

1a/b This is the conventional process where heat for the ethanol plant is provided by a NG-fired steam boiler and electricity is imported from the grid. DDGS is used as either as animal feed (a) or as co-fuel in a coal power station (b). The straw is not used and assumed to be ploughed back into the field (the fertiliser inputs are adjusted accordingly).

2a/b The energy to the ethanol plant is provided by a NG-fired CCGT sized to provide the required heat. Surplus electricity is produced and exported, which generates a credit calculated by comparison to a state-of-the-art stand-alone NG-fired CCGT (the benefit stems from the use of CHP in the ethanol plant). DDGS is used either as animal feed (a) or as co-fuel in a coal power station (b). Although option b is more favourable from an energy point of view, option a is likely to be preferred for economic reasons. The straw is not used (see 1a).

3a/b The energy for the ethanol plant is provided by a lignite (or brown coal) -fired CHP power plant sized to provide the required heat. Surplus electricity is produced and exported, which generates a credit calculated by comparison to a state-of-the-art stand-alone lignite power plant (the benefit stems from the use of CHP in the ethanol plant). Both DDGS use options are presented (see 3a/b) and straw is not used (see 1a).

4a/b The energy for the ethanol plant is provided by a straw-fired CHP power plant sized to provide the required heat. Surplus electricity is produced and exported, which generates a credit calculated by comparison to a state-of-the-art stand-alone straw power plant (the benefit stems from the use of CHP in the ethanol plant). The fertiliser inputs are adjusted to compensate for the loss of soil nutrients from straw. Both DDGS use options are presented (see 3a/b).

5 The heat and power requirement of the ethanol plant is provided by biogas produced from DDGS. A small electricity import is still required. A credit is generated for export of fermentation residue returned to the wheat field as fertiliser.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
WTET1a	**Ethanol from Wheat, Conv NG boiler, DDGS as animal feed**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	1.34				16.81			22.5	0.09	-0.026
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**58.4**	51.5	70.0	42.0	0.12	0.045
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.66**	1.64	1.69	**0.77**	**-12.9**	-19.9	-1.4			
WTET1b	**Ethanol from Wheat, Conv NG boiler, DDGS as fuel**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	0.92				9.48			8.6	0.04	0.000
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**51.1**	45.8	61.2	28.0	0.07	0.071
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.24**	1.22	1.27	**0.38**	**-20.3**	-25.6	-10.2			
WTET2a	**Ethanol from Wheat, NG GT+CHP, DDGS as animal feed**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	1.09				4.14			11.1	0.05	-0.028
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**45.8**	38.3	57.1	30.6	0.09	0.044
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.42**	1.40	1.44	**0.53**	**-25.6**	-33.1	-14.3			
WTET2b	**Ethanol from Wheat, NG GT+CHP, DDGS as fuel**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	0.67				-3.20			-2.8	0.01	-0.002
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**38.4**	31.3	48.7	16.7	0.04	0.070
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.00**	0.98	1.02	**0.14**	**-33.0**	-40.1	-22.7			
WTET3a	**Ethanol from Wheat, lignite CHP, DDGS as animal feed**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	1.16				34.87			41.8	-0.01	-0.023
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**76.5**	69.0	87.3	61.3	0.02	0.049
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.49**	1.48	1.49	**0.60**	**5.1**	-2.4	16.0			
WTET3b	**Ethanol from Wheat, Lignite CHP, DDGS as fuel**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	0.74				27.54			27.9	-0.05	0.003
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**69.2**	63.4	80.4	47.4	-0.02	0.075
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.07**	1.06	1.07	**0.21**	**-2.2**	-8.0	9.0			
WTET4a	**Ethanol from Wheat, Straw CHP, DDGS as animal feed**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	1.25				-17.70			-9.4	-0.01	-0.027
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**23.9**	16.9	35.2	10.0	0.02	0.045
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.58**	1.57	1.58	**0.16**	**-47.5**	-54.5	-36.2			
WTET4b	**Ethanol from Wheat, Straw CHP, DDGS as fuel**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	0.83				-25.02			-23.4	-0.06	-0.001
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**16.6**	10.5	28.2	-3.9	-0.03	0.071
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.16**	1.15	1.16	**-0.23**	**-54.8**	-60.9	-43.2			
WTET5	**Ethanol from Wheat, DDGS to biogas**											
	Cultivation	1	0.27				39.45			17.3	0.03	0.072
	Road transport	3	0.03				0.63			0.6	0.00	0.000
	Ethanol plant	4	0.77				-12.96			-6.0	-0.02	-0.022
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**28.7**	22.1	38.8	13.5	0.01	0.050
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.10**	1.10	1.10	**0.21**	**-42.7**	-49.2	-32.6			

SCET1a/b Sugar cane to ethanol (Brazil)

Sugar cane is grown and turned into ethanol in Brazil. The bagasse is used as fuel (as is current practice). Ethanol is shipped into Europe where it is blended with gasoline.

In variant 1a surplus bagasse is used externally to generate heat, displacing fossil diesel. In variant 1b (new to this version) this option is disallowed and no corresponding credit is generated.

STET1 Wheat straw to ethanol

This pathway specifically refers to the Iogen process [*Iogen 2003*] which hydrolyses cellulose into fermentable sugars. Additional agricultural inputs to compensate for the removal of straw from soils are taken into account.

W/F-WET1 Waste/Farmed wood to ethanol

These are more generic cellulose-to-ethanol pathways where wood (poplar) is a proxy for a number of possible feedstocks (e.g. perennial grasses). The process is based on an earlier reference from NERL [*Wooley 1999*].

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
SCET1a	**EtOH from sugar cane (Brazil), HFO credit for excess bagasse**											
	Cultivation	1	0.06				14.45			3.7	0.15	0.023
	Road transport	3	0.01				0.85			0.8	0.00	0.000
	Ethanol plant	4	1.63				-9.84			-10.2	0.00	0.001
	Ethanol shipping	5	0.10				7.69			7.7	0.00	0.000
	Distribution & retail	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**13.6**	10.4	30.6	2.4	0.16	0.024
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.81**	1.81	1.82	**0.04**	**-57.8**	-60.9	-40.8			
SCET1b	**EtOH from sugar cane (Brazil), no credit for excess bagasse**											
	Cultivation	1	0.06				14.45			3.7	0.15	0.023
	Road transport	3	0.01				0.85			0.8	0.00	0.000
	Ethanol plant	4	1.78				1.20			0.7	0.00	0.001
	Ethanol shipping	5	0.10				7.69			7.7	0.00	0.000
	Distribution & retail	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**24.6**	21.6	41.9	13.4	0.16	0.025
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.96**	1.95	1.96	**0.18**	**-46.8**	-49.8	-29.5			
WWET1	**Ethanol from waste wood**											
	Waste collection and chipping	1	0.08				0.95			0.9	0.00	0.000
	Transport (road + sea)	3	0.04				3.19			3.0	0.01	0.000
	Ethanol plant	4	1.81				13.33			13.5	0.02	-0.002
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**19.0**	18.8	19.2	18.9	0.03	-0.002
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.95**	1.85	2.06	**0.28**	**-52.4**	-52.5	-52.2			
WFET1	**EtOH from farmed wood**											
	Cultivation	1	0.11				6.28			3.1	0.00	0.010
	Road transport	3	0.01				0.88			0.9	0.00	0.000
	Ethanol plant	4	1.81				13.33			13.5	0.02	-0.002
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**22.0**	19.9	37.4	19.0	0.02	0.008
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.96**	1.85	2.06	**0.28**	**-49.4**	-51.5	-34.0			
STET1	**EtOH from wheat straw (logen)**											
	Collection	3	0.04				3.08			3.0	0.00	0.000
	Road transport	3	0.01				0.62			0.6	0.00	0.000
	Ethanol plant	4	1.24				3.72			3.3	0.01	0.001
	Distribution & retail	5	0.03				1.54			1.5	0.00	0.000
	Total WTT GHG emitted						**9.0**	8.9	9.0	8.4	0.01	0.001
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.32**	1.32	1.32	**0.10**	**-62.4**	-62.5	-62.4			

4 Bio-diesel

		Rape seed											Sunf seed					Soy				Palm							
Pathway code		ROFA				ROHY			ROFE				SOFA				SOHY	SYFA				POFA				POHY			
		1	2	3	4	1a	1b	4a	1	2	3	4	1	2	3	4	1	1	1a	1c	3	1a	1b	1c	2	1a	1b	1c
NG to Hydrogen																													
GH1b	NG to hydrogen (reforming, central plant, 100-300 MW hydrogen)					✓	✓	✓									✓									✓	✓	✓
Farming																													
WT1a	Wheat farming (grain)								✓	✓	✓	✓							✓										
RF1	Rapeseed Farming	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓																	
SF1	Sunflower seed Farming												✓	✓	✓	✓	✓												
SY1	Soya bean Farming (Brazil, for oil																	✓	✓	✓	✓								
CR1	Corn farming Brazil (mass based)																	✓			✓								
PO1	Oil palm tree plantation (FFB)																					✓	✓	✓	✓	✓	✓	✓
Crop transport and processing																													
RO2	Rapeseed road transport	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓																	
RO3a	Rapeseed to raw oil: extraction	✓	✓	✓		✓	✓		✓	✓	✓																		
RO3b	Rapeseed to raw oil: extraction, meal to				✓			✓				✓																	
SO2	Sunflower seed road transport												✓	✓	✓	✓	✓												
SO3a	Sunflower seed to raw oil: extraction												✓	✓	✓	✓	✓												
PO2	Palm FFB road transport																					✓	✓	✓	✓	✓	✓	✓
PO3	Palm FFB to raw oil: extraction																					✓	✓	✓	✓	✓	✓	✓
PO3a	Methane emissions from waste																					✓		✓		✓		✓
PO3b	Credit for surplus heat (diesel)																					✓	✓					
PO4a	Palm oil road transport to port																					✓	✓	✓	✓	✓	✓	✓
PO4b	Vegetable oil shipping																					✓	✓	✓	✓	✓	✓	✓
RO4	Raw oil to refined oil	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓			
SY2	Soya bean road transport (Brazil)																	✓	✓	✓	✓							
SY3a	Soya beans to raw oil: extraction, meal substituting wheat																		✓									
SY3b	Soya beans to raw oil: extraction, meal substituting corn																	✓			✓							
RO5a	Refined oil to FAME: esterification																					✓	✓	✓				
5a	Glycerine as chemical	✓							✓				✓					✓	✓									
5b	Glycerine as animal feed		✓							✓				✓														
RO5c	Refined oil to FAME: esterification with glycerine to biogas			✓	✓						✓	✓			✓	✓		✓	✓	✓	✓				✓			
OY1a	Plant oil hydrotreating (NexBTL)					✓		✓									✓									✓	✓	✓
OY1b	Plant oil hydrotreating (UOP)						✓																					
Syn diesel transport & distribution																													
SDd	Bio-(synthetic diesel) distribution (blended)					✓	✓	✓									✓									✓	✓	✓
Biofuels transport & distribution																													
FAd	Bio-diesel distribution (blended)	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			
Common processes																													
Z1	Diesel production	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z3	HFO production																	✓	✓	✓	✓							
Z4	Product carrier 50 kt																	✓	✓	✓	✓							
Z6b	Marginal NG for general use	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

ROFA1/2/3/4 Rapeseed to FAME (RME)

Four alternatives disposal routes for the meal and glycerine co-products are considered. Meal is either used as animal feed (variant 1/2/3) or to generate biogas to provide heat and power for the plant (variant 4). Glycerine is used either as a chemical (replacing a bulk chemical such as propylene glycol, variant 1) or as animal feed (variant 2) or to generate biogas (variant 3 and 4). Surplus biogas is used to generate electricity for export. No credit is given for surplus heat.

ROFE1/2/3/4 Rape to FAEE (REE)

The same pathways as ROFA above where methanol has been replaced by (bio)ethanol. Although this is technically feasible, this process has not been commercially used so far. It has been assumed that the process energy is the same for both alcohols.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
ROFA1	**RME, glycerine as chemical, meal as animal feed**											
	Cultivation	1	0.27				48.65			16.9	0.03	0.104
	Drying	1	0.02				0.72			0.7	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	Oil mill	4	0.59				-13.58			-6.4	0.00	-0.024
	Esterification	4	0.17				4.75			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**42.1**	32.6	55.3	16.9	0.06	0.079
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.09**	0.99	1.20	**0.36**	**-34.1**	-43.6	-20.8			
ROFA2	**RME, glycerine and meal as animal feed**											
	Cultivation	1	0.27				48.65			16.9	0.03	0.104
	Drying	1	0.02				0.72			0.7	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	Oil mill	4	0.59				-13.58			-6.4	0.00	-0.024
	Esterification	4	0.22				9.86			9.6	0.03	-0.002
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**47.2**	37.8	59.7	22.4	0.07	0.078
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.14**	1.04	1.25	**0.41**	**-29.0**	-38.4	-16.5			
ROFA3	**RME, glycerine to biogas, meal as animal feed**											
	Cultivation	1	0.27				48.65			16.9	0.03	0.104
	Drying	1	0.02				0.72			0.7	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	Oil mill	4	0.59				-13.58			-6.4	0.00	-0.024
	Esterification	4	0.19				8.30			7.7	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**45.7**	35.8	59.0	20.5	0.06	0.080
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.10**	1.01	1.21	**0.37**	**-30.5**	-40.4	-17.2			
ROFA4	**RME, glycerine and cake to biogas**											
	Cultivation	1	0.27				48.65			16.9	0.03	0.104
	Drying	1	0.02				0.72			0.7	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	Oil mill	4	0.19				-30.73			-21.7	-0.06	-0.025
	Esterification	4	0.17				8.01			7.4	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**28.2**	20.7	40.9	4.8	0.00	0.079
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.70**	0.60	0.80	**-0.02**	**-48.0**	-55.5	-35.3			
ROFE1	**REE, glycerine as chemical, meal as animal feed**											
	Cultivation	1	0.26				46.54			16.2	0.03	0.099
	Drying	1	0.02				0.69			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.56				-12.99			-6.1	0.00	-0.023
	Esterification	4	0.30				4.21			2.4	0.02	0.005
	Distribution & retail	5	0.02				1.25			1.2	0.00	0.000
	Total WTT GHG emitted						**40.0**	33.7	54.2	14.7	0.05	0.081
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.17**	1.09	1.29	**0.31**	**-36.2**	-42.5	-22.0			
ROFE2	**REE, glycerine and meal as animal feed**											
	Cultivation	1	0.26				46.54			16.2	0.03	0.099
	Drying	1	0.02				0.69			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.56				-12.99			-6.1	0.00	-0.023
	Esterification	4	0.34				8.97			7.5	0.02	0.003
	Distribution & retail	5	0.02				1.25			1.2	0.00	0.000
	Total WTT GHG emitted						**44.7**	37.4	58.1	19.8	0.06	0.079
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.22**	1.12	1.33	**0.36**	**-31.4**	-38.8	-18.1			
ROFE3	**REE, glycerine to biogas, meal as animal feed**											
	Cultivation	1	0.26				46.54			16.2	0.03	0.099
	Drying	1	0.02				0.69			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.56				-12.99			-6.1	0.00	-0.023
	Esterification	4	0.31				7.56			5.7	0.02	0.005
	Distribution & retail	5	0.02				1.25			1.2	0.00	0.000
	Total WTT GHG emitted						**43.3**	35.7	56.2	18.0	0.05	0.081
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.19**	1.10	1.29	**0.32**	**-32.9**	-40.5	-20.0			
ROFE4	**REE, glycerine and cake to biogas**											
	Cultivation	1	0.26				46.54			16.2	0.03	0.099
	Drying	1	0.02				0.69			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill + esterification	4	0.18				46.80			55.4	-0.06	-0.024
	Distribution & retail	5	0.29				-69.00			-70.8	0.02	0.005
	Total WTT GHG emitted						**25.3**	76.2	76.2	1.7	-0.01	0.080
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.77**	0.00	0.00	**-0.07**	**-50.9**	0.0	0.0			

SOFA1/2/3/4 Sunflower seed to FAME

The same pathways as ROFA above, now with sunflower seeds as feedstock.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
SOFA1	**SME, glycerine as chemical, meal as animal feed**											
	Cultivation	1	0.18				27.37			12.0	0.01	0.051
	Drying	1	0.01				0.67			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.52				-8.17			-2.8	0.00	-0.018
	FAME manufacture	4	0.17				4.75			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**26.2**	21.6	30.3	15.4	0.04	0.032
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.93**	0.84	1.03	**0.32**	**-50.0**	-54.6	-45.9			
SOFA2	**SME, glycerine and meal as animal feed**											
	Cultivation	1	0.18				27.37			12.0	0.01	0.051
	Drying	1	0.01				0.67			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.52				-8.17			-2.8	0.00	-0.018
	FAME manufacture	4	0.22				9.86			9.6	0.03	-0.002
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**31.3**	26.2	36.2	19.7	0.05	0.031
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.98**	0.89	1.07	**0.37**	**-44.9**	-50.0	-40.0			
SOFA3	**SME, glycerine to biogas, meal as animal feed**											
	Cultivation	1	0.18				27.37			12.0	0.01	0.051
	Drying	1	0.01				0.67			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.52				-8.17			-2.8	0.00	-0.018
	FAME manufacture	4	0.19				8.30			7.7	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**29.7**	24.5	34.3	19.0	0.04	0.032
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.95**	0.85	1.04	**0.33**	**-46.5**	-51.7	-41.9			
SOFA4	**SME, glycerine and cake to biogas**											
	Cultivation	1	0.18				27.37			12.0	0.01	0.051
	Drying	1	0.01				0.67			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	Oil mill	4	0.17				-22.37			-16.8	-0.04	-0.015
	FAME manufacture	4	0.17				7.99			7.4	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**15.2**	11.7	19.5	4.7	0.00	0.036
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**0.58**	0.58	0.59	**-0.01**	**-61.0**	-64.5	-56.7			

SYFA1/3 Soy beans to FAME

These pathways are based on soy bean farming in Brazil with transport of soy beans over land, sea transport to Europe and FAME production there. However, soy meal produced in Europe as a result avoids imports of meal from Brazil so that the sea transport cost of meal cancels out, leaving only sea transport for oil. Soy meal further attracts a credit related to corn substitution in Brazil. In variant 1, glycerine is used as animal feed. In variant 3 it is used to generate biogas to supply part of the FAME plant energy requirement.

In SYFA1a soy meal substitutes European wheat while soy oil supports the full cost of transporting the meal, resulting in a rather high energy/GHG balance. This was our original pathway published in November 2008. We now believe the previous view is more realistic.

In SYFA1c we have applied market value allocation between meal and oil, still assuming sea transport of beans to Europe. Energy is much lower than for the other variants as a significant past of it (about 42%) is allocated to the meal. In terms of GHG

the outcome is similar to SYFA1 because the reductions due to allocation to the meal are compensated by the removal of the credit for meal substitution.

POFA1/2 Palm oil to FAME

The palm fruit bunches (FFB) are crushed near the plantation (typically in South-East Asia) to produce palm oil which is shipped to Europe for processing into FAME. Variants 1a and 1b cover an important aspect of palm oil production management viz. how the organic waste material is disposed of. Traditionally it is left to rot in anaerobic conditions in a lagoon, generating CH_4 (variant 1a). In variant 1b these emissions are deemed to have been avoided. In variant 1a/b a heating oil credit is given for heat generated with the crushed FFBs. In variant 1c, this credit is removed. In variant 2, glycerine from FAME production is used as biogas to generate biogas to supply part of the FAME plant energy requirement instead of chemical substitution as in variant 1; all other parameters are as per variant 1a.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
SYFA1	**Net import of soy oil, glycerine as chemical, displaced soy meal replaces corn in Brazil**											
	Cultivation	1	0.28				56.40			18.1	0.02	0.127
	Beans transport	2	0.15				8.76			8.7	0.00	0.000
	Oil shipping	2	0.04				3.10			3.1	0.00	0.000
	Oil mill	4	2.03				-20.97			-2.2	0.03	-0.065
	FAME manufacture	4	0.17				4.74			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**53.3**	-0.8	72.2	33.1	0.07	0.062
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**2.69**	2.68	2.71	**0.61**	**-22.9**	-77.0	-4.0			
SYFA1a	**Imported soy beans, glycerineas chemical, soya meal replaces EU wheat**											
	Cultivation	1	0.28				56.40			18.1	0.02	0.127
	Beans road transport	2	0.15				8.76			8.7	0.00	0.000
	Beans shipping	2	0.34				27.12			26.8	0.00	0.001
	Oil mill	4	2.04				-20.70			-1.1	0.02	-0.067
	FAME manufacture	4	0.17				4.74			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**77.6**	52.1	99.8	58.0	0.06	0.061
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**3.00**	2.98	3.01	**0.92**	**1.4**	-24.1	23.6			
SYFA1c	**Imported soy beans, allocation by economic values**											
	Cultivation	1	0.16				32.73			10.5	0.01	0.074
	Beans transport	2	0.08				5.08			5.1	0.00	0.000
	Oil shipping	2	0.04				3.10			3.1	0.00	0.000
	Oil mill	4	0.89				9.70			9.0	0.03	0.000
	FAME manufacture	4	0.17				4.75			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**56.6**	42.3	69.4	33.0	0.06	0.074
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.37**	1.36	1.38	**0.58**	**-19.6**	-33.9	-6.8			
SYFA3	**Net import of soy oil, glycerine to biogas, displaced soy meal replaces corn in Brazil**											
	Cultivation	1	0.28				56.40			18.1	0.02	0.127
	Beans transport	2	0.15				8.76			8.7	0.00	0.000
	Oil shipping	2	0.04				3.10			3.1	0.00	0.000
	Oil mill	4	2.03				-20.97			-2.2	0.03	-0.065
	FAME manufacture	4	0.19				8.30			7.7	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**56.8**	0.1	79.6	36.7	0.07	0.062
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**2.71**	2.69	2.72	**0.62**	**-19.4**	-76.1	3.4			
POFA1a	**Imported palm oil, glycerine as chemical, CH4 emissions from waste**											
	Plantation	1	0.10				15.73			5.8	0.01	0.032
	FFB transport and storage	2	0.06				1.16			1.1	0.00	0.000
	Pressing	2	0.91				21.98			-2.3	0.99	-0.002
	Oil shipping	3	0.05				3.45			3.4	0.00	0.000
	FAME manufacture	4	0.17				4.75			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**48.3**	43.8	76.9	13.5	1.03	0.031
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.31**	1.30	1.31	**0.27**	**-27.9**	-32.4	0.7			
POFA1b	**Imported palm oil, glycerine as chemical, no CH4 emissions from waste**											
	Plantation	1	0.10				15.73			5.8	0.01	0.032
	FFB transport and storage	2	0.06				1.16			1.1	0.00	0.000
	Pressing	2	0.91				-2.77			-2.3	0.00	-0.002
	Oil shipping	3	0.05				3.45			3.4	0.00	0.000
	FAME manufacture	4	0.17				4.75			4.2	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**23.6**	18.6	49.6	13.5	0.04	0.031
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.31**	1.30	1.31	**0.27**	**-52.6**	-57.6	-26.6			
POFA1c	**Imported palm oil, glycerine as chemical, CH4 emissions from waste, no heat credit for crushed FFB**											
	Plantation	1	0.10				15.73			5.8	0.01	0.032
	FFB transport and storage	2	0.06				1.16			1.1	0.00	0.000
	Pressing	2	0.94				23.86			-0.4	0.99	-0.002
	Oil shipping	3	0.05				3.45			3.4	0.00	0.000
	FAME manufacture	4	0.17				4.75			4.2	1.03	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**50.2**	44.8	74.7	15.4	2.03	0.031
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.33**	1.32	1.34	**0.30**	**-26.0**	-31.4	-1.5			
POFA2	**Imported palm oil, glycerine to biogas, CH4 emissions from waste**											
	Plantation	1	0.10				15.73			5.8	0.01	0.032
	FFB transport and storage	2	0.06				1.16			1.1	0.00	0.000
	Pressing	2	0.91				21.98			-2.3	0.99	-0.002
	Oil shipping	3	0.05				3.45			3.4	0.00	0.000
	FAME manufacture	4	0.19				8.31			7.7	0.02	0.000
	Distribution & retail	5	0.02				1.27			1.2	0.00	0.000
	Total WTT GHG emitted						**51.9**	45.8	78.8	17.1	1.03	0.031
	Credit for renewable combustion CO_2						-76.2			-76.2		
	Total pathway		**1.32**	1.32	1.33	**0.29**	**-24.3**	-30.4	2.6			

ROHY1a/b/4a, SOHY1, POHY1a/b/c Hydrotreated vegetable oil

These pathways describe the recently developed processes for deep hydrotreatment of plant oil. These processes turn plant oil (or animal fats) into a essentially straight chain paraffins and a product very similar to synthetic diesel obtained by Fischer-Tropsch conversion of syngas (see section 5).

All pathways describe the Neste Oil process (NexBTL®) except ROHY1b uses data provided by UOP for a similar process.

The pathways codes are consistent with those for the corresponding biodiesel pathways with the same process and procedures for the production of the vegetable oil.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
ROHY1a	**Hydrogenated rape oil (NExBTL process), meal to animal feed**											
	Cultivation	1	0.27				47.99			16.71	0.03	0.102
	Drying	1	0.02				0.71			0.66	0.00	0.000
	Transport, road 50 km	3	0.02				0.29			0.29	0.00	0.000
	Oil mill	4	0.58				-13.39			-6.28	0.00	-0.024
	Hydrotreating	4	0.15				6.75			6.22	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.11	0.00	0.000
	Total WTT GHG emitted						**43.5**	40.6	62.1	18.7	0.06	0.078
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.05**	0.95	1.15	**0.34**	**-27.3**	-35.6	-14.1			
ROHY1b	**Hydrogenated rape oil (UOP process), meal to animal feed**											
	Cultivation	1	0.24				42.23			14.70	0.03	0.090
	Drying	1	0.01				0.62			0.58	0.00	0.000
	Transport, road 50 km	3	0.02				0.26			0.26	0.00	0.000
	Oil mill	4	0.51				-11.79			-5.53	0.00	-0.021
	Hydrotreating	4	0.12				12.45			11.56	0.03	0.000
	Distribution & retail	5	0.02				1.15			1.11	0.00	0.000
	Total WTT GHG emitted						**44.9**	43.1	62.9	22.7	0.07	0.069
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**0.92**	0.83	1.01	**0.41**	**-25.9**	-33.1	-13.3			
ROHY4a	**Hydrogenated rape oil (NExBTL process), cake to biogas**											
	Cultivation	1	0.27				47.99			16.71	0.03	0.102
	Drying	1	0.02				0.71			0.66	0.00	0.000
	Transport, road 50 km	3	0.02				0.29			0.29	0.00	0.000
	Oil mill	4	0.19				-30.31			-21.45	-0.06	-0.025
	Hydrotreating	4	0.15				6.74			6.20	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.11	0.00	0.000
	Total WTT GHG emitted						**26.6**	23.4	45.2	3.5	0.00	0.077
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**0.66**	0.55	0.75	**-0.03**	**-44.3**	-52.8	-31.0			
SOHY1	**Hydrogenated sunflower oil (NExBTL process), meal to animal feed**											
	Cultivation	1	0.18				26.99			11.8	0.01	0.050
	Drying	1	0.01				0.66			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.27			0.3	0.00	0.000
	Oil mill	4	0.51				-8.05			-2.79	0.00	-0.018
	Hydrotreating	4	0.15				6.75			6.2	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.1	0.00	0.000
	Total WTT GHG emitted						**27.8**	28.1	37.5	17.2	0.04	0.032
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**0.89**	0.80	1.00	**0.30**	**-43.1**	-48.0	-38.7			
POHY1a	**Hydrogenated palm oil (NExBTL process), CH4 from waste**											
	Plantation	1	0.10				15.52			5.8	0.01	0.032
	FFB tansport & storage	1	0.05				1.14			1.1	0.00	0.000
	Pressing	2	0.90				21.68			-2.2	0.98	-0.002
	Oil shipping	3	0.04				3.40			3.4	0.00	0.000
	Hydrotreating	4	0.15				6.76			6.2	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.1	0.00	0.000
	Total WTT GHG emitted						**49.6**	49.3	78.9	15.4	1.01	0.030
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.26**	1.26	1.27	**0.26**	**-21.2**	-26.8	2.7			
POHY1b	**Hydrogenated palm oil (NExBTL process), no CH4 from waste**											
	Plantation	1	0.10				15.52			5.8	0.01	0.032
	FFB tansport & storage	1	0.05				1.14			1.1	0.00	0.000
	Pressing	2	0.90				-2.73			-2.2	0.00	-0.002
	Oil shipping	3	0.04				3.40			3.4	0.00	0.000
	Hydrotreating	4	0.15				6.76			6.2	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.1	0.00	0.000
	Total WTT GHG emitted						**25.2**	25.9	58.8	15.4	0.03	0.030
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.26**	1.26	1.27	**0.26**	**-45.6**	-50.3	-17.4			
POHY1c	**Hydrogenated palm oil (NExBTL process), CH4 from waste, no heat credit for crushed FFB**											
	Plantation	1	0.10				15.52			5.8	0.01	0.032
	FFB tansport & storage	1	0.05				1.14			1.1	0.00	0.000
	Pressing	2	0.92				23.53			-0.4	0.98	-0.002
	Oil shipping	3	0.04				3.40			3.4	0.00	0.000
	Hydrotreating	4	0.15				6.76			6.2	0.02	0.000
	Distribution & retail	5	0.02				1.15			1.1	0.00	0.000
	Total WTT GHG emitted						**51.5**	52.5	82.7	17.2	1.01	0.030
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.29**	1.28	1.30	**0.28**	**-19.3**	-23.7	6.5			

5 Synthetic fuels

5.1 Synthetic diesel

		Remote NG			Coal		Farmed wood	Waste wood	Black liquor
Pathway code		**GRSD**			**KOSD**		**WFSD**	**WWSD**	**BLSD**
		1	**2**	**2C**	**1**	**1C**	**1**	**1**	**1**
Code	Process								
GG1	NG Extraction & Processing	✓	✓	✓					
NG to syn diesel									
GD1	NG to syn-diesel (remote or central plant)	✓	✓						
GD1C	NG to syn-diesel (remote or central plant) with CC&S			✓					
NG common processes									
GG2	Electricity generation from NG (CCGT)	✓	✓	✓					
Coal									
KO1	Hard coal provision (EU-mix) (1)				✓	✓			
KD1	Coal to syndiesel				✓				
KD1C	Coal to syndiesel with CC&S					✓			
Wood (farmed)									
WF1	Wood farming and chipping						✓		
Wood (waste)									
WW1	Forest residuals to wood chips							✓	✓
Wood transport & processing (all sources)									
WC2a	Wood chips road transport, 50 km						✓	✓	✓
WC2b	Wood chips road transport, 12 km								
WC2c	Coastal/river shipping wood ships (200MW plant)							✓	
W3f	Wood to syn-diesel: gasification + FT						✓	✓	
Wood waste via black liquor									
BLS	Wood waste to syn diesel via black liquor								✓
Syn diesel transport & distribution									
DS1	Syn diesel handling and loading (remote)	✓	✓	✓					
DS2	Syn diesel sea transport	✓	✓	✓					
DS3	Syn diesel depot	✓	✓	✓			✓	✓	
DS4	Syn diesel distribution (blending component)	**CD2/3/4**			✓	✓			
DS5	Syn diesel distribution (neat)		✓	✓					
SDd	Bio-(synthetic diesel) distribution (blended)						✓	✓	✓
Common processes									
Z1	Diesel production	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓	✓	✓
Z3	HFO production	✓	✓	✓					
Z4	Product carrier 50 kt	✓	✓	✓					
Z5	Rail transport	✓	✓	✓	✓	✓	✓	✓	
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓

GRSD1/2/2C GTL: Remote NG to synthetic diesel (remote plant) (+CCS option)

This option of a GTL plant installed near a remote gas supply is the most likely (note that the efficiency of the GTL plant has been slightly increased to reflect state-of-the-art performance). Transport is less energy-intensive for a liquid such as synthetic diesel than for any gaseous fuel. Synthetic diesel is either blended into conventional diesel or used neat for a niche application. A substantial part of the CO_2 emitted by the GTL plant is scrubbed out of the syngas before the FT synthesis and is available in virtually pure form. Compression and re-injection in a nearby gas or oil field (CCS) could be an attractive option.

KOSD1/1C CTL: Coal to synthetic diesel (+CCS option)

The typical EU coal mix is used in a large scale Coal-to-Liquids (CTL) plant located in Europe. Synthetic diesel is blended into conventional diesel. A large amount of CO_2 is produced during the gasification process and is separated from the syngas before the Fischer-Tropsch stage. This offers an attractive opportunity for CCS, as long as a suitable geological formation is available within a reasonable distance for long-term storage.

W/F-WSD1 Waste/Farmed wood to synthetic diesel

This is the Biomass-to-Liquids (BTL) pathway: wood gasification followed by Fischer-Tropsch synthesis.

BLSD1 Waste wood via black liquor to synthetic diesel

Black liquor is the residue of extraction of cellulose fibres from wood for paper pulp manufacturing. It contains the lignin and is used as fuel for the large power plant required by a paper mill. Black liquor is also suitable for gasification, the syngas being then available for either electricity hydrogen or synthetic fuels production. The shortfall of energy available to the paper mill can be made up by burning waste wood. Compared to a reference case with a traditional black liquor boiler and all other parameters being the desired fuel can be produced with significantly higher net energy efficiency than in a more conventional scheme.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GRSD1	**Syn diesel, remote plant, diesel mix**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.9			1.7	0.13	0.000
	GTL plant	2	0.54	0.49	0.59		13.8			13.8	0.00	0.000
	GTL transport	3	0.04				2.7			2.7	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total pathway		**0.63**	0.57	0.69	**0.63**	**22.4**	19.3	25.6	19.1	0.13	0.000
GRSD2	**Syn diesel, remote plant, neat**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.9			1.7	0.13	0.000
	GTL plant	2	0.54	0.49	0.59		13.8			13.8	0.00	0.000
	GTL transport	3	0.04				2.7			2.7	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total pathway		**0.63**	0.59	0.69	**0.63**	**22.5**	20.1	26.0	19.2	0.13	0.000
GRSD2C	**Syn diesel, remote plant, neat, CCS**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.3			1.9	0.14	0.000
	GTL plant (CCS)	2	0.67	0.61	0.73		4.2			4.2	0.00	0.000
	GTL transport	3	0.04				2.7			2.7	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total pathway		**0.76**	0.71	0.82	**0.76**	**13.3**	10.5	16.6	9.7	0.14	0.000
KOSD1	**Coal EU-mix, gasifier + FT synthesis**											
	Coal provision	1	0.17				28.7			11.5	0.68	0.001
	Gasifier + FT synthesis	4	0.78				100.3			100.6	0.00	-0.001
	Syndiesel distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total pathway		**0.97**	0.89	1.05	**0.97**	**130.1**	121.9	138.5	113.2	0.68	0.000
KOSD1C	**Coal EU-mix, gasifier + FT synthesis, CCS**											
	Coal provision	1	0.17				30.0			112.8	0.68	0.000
	Gasifier + FT synthesis + CCS	4	0.86				9.3			0.4	0.00	0.000
	Syndiesel distribution & dispensing	5	0.02				1.1			-98.0	0.22	0.001
	Total pathway		**1.06**	0.98	1.13	**1.05**	**40.4**	32.6	48.4	15.2	0.90	0.001
WWSD1	**Syn diesel, wood waste**											
	Waste collection and chipping	1	0.06				0.8			0.7	0.00	0.000
	Transport (road + sea)	3	0.04				2.9			2.7	0.01	0.000
	Gasifier + FT plant	4	1.08				0.0		`	0.0	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.2			1.1	0.00	0.000
	Total WTT GHG emitted						**4.8**	4.6	5.0	4.6	0.01	0.000
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.19**	1.09	1.30	**0.07**	**-66.0**	-66.2	-65.9			
WFSD1	**Syn diesel, farmed wood**											
	Wood farming and chipping	1	0.09				5.0			2.5	0.00	0.008
	Road transport	3	0.01				0.7			0.7	0.00	0.000
	Gasifier + FT plant	4	1.08				0.0			0.0	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.2			1.1	0.00	0.000
	Total WTT GHG emitted						**6.9**	5.4	18.8	4.3	0.00	0.008
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.19**	1.09	1.29	**0.06**	**-64.0**	-65.5	-52.1			
BLSD1	**Syn diesel, black liquor**											
	Wood collection and chipping	1	0.05				0.7			0.6	0.00	0.000
	Road transport	3	0.01				0.6			0.6	0.00	0.000
	Black liquor gasifier + FT plant	4	0.83				0.0			0.0	0.00	0.000
	Diesel distribution & dispensing	5	0.02				1.2			1.1	0.00	0.000
	Total WTT GHG emitted						**2.4**	2.4	2.5	2.4	0.00	0.000
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**0.91**	0.85	0.97	**0.04**	**-68.4**	-68.4	-68.4			

5.2 DME

						Coal	Farmed wood	Waste wood	Black liquor
Pathway code		**GPDE**		**GRDE**		**KODE**	**WFDE**	**WWDE**	**BLDE**
		1a	**1b**	**1**	**1C**	**1**	**1**	**1**	**1**
Code	Process								
GG1	NG Extraction & Processing	✓	✓	✓	✓				
NG from pipeline									
GP1a	Russian quality, 7000 km	✓							
GP1b	Average quality, 4000 km		✓						
NG distribution									
GG3	NG trunk distribution	✓	✓						
NG to DME									
GT1	NG to DME (remote or central plant)	✓	✓	✓					
GT1C	NG to DME (remote or central plant) with CC&S				✓				
NG common processes									
GG2	Electricity generation from NG (CCGT)			✓	✓				
Coal									
KO1	Hard coal provision (EU-mix) (1)					✓			
KE1	Coal to DME					✓			
Wood (farmed)									
WF1	Wood farming and chipping						✓		
Wood (waste)									
WW1	Forest residuals to wood chips							✓	✓
Wood transport & processing (all sources)									
WC2a	Wood chips road transport, 50 km						✓	✓	✓
WC2b	Wood chips road transport, 12 km								
WC2c	Coastal/river shipping wood chips (200MW plant)							✓	
W3g	Wood to methanol or DME: gasification + synthesis						✓	✓	
Wood waste via black liquor									
BLD	Wood waste to DME via black liquor								✓
DME transport & distribution									
DE1	DME handling and loading (remote)			✓	✓				
DE2	DME sea transport			✓	✓				
DE3	DME depot			✓	✓	✓			
DE4a	DME distribution and dispensing	✓	✓	✓	✓				
DEd	Bio-DME distribution direct from plant						✓	✓	✓
Common processes									
Z1	Diesel production	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓	✓	✓
Z3	HFO production	✓	✓	✓	✓				
Z5	Rail transport	✓	✓	✓	✓	✓	✓	✓	
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓

GPDE1a/b Piped NG to DME (EU plant)

This pathway foresees a DME plant located in Europe and fed by gas from a major gas pipeline source (7000 or 4000 km). Similarly to the GTL case, this is an unlikely scenario. As in all other pathways DME is distributed through a dedicated network similar to that for LPG.

GRDE1/1C Remote NG to DME (remote plant) (+CCS option)

This option of a DME plant installed near a remote gas supply is the most likely. Transport is less energy-intensive for DME than for natural gas (as LNG). As for a GTL plant, CO_2 recovered from the process could relatively easily be compressed and re-injected in a nearby gas or oilfield.

W/F-WDE1 Waste/Farmed wood to DME

Wood gasification followed by DME synthesis.

BLDE1 Waste wood via black liquor to DME

Black liquor is the residue of extraction of cellulose fibres from wood for paper pulp manufacturing. It contains the lignin and is used as fuel for the large power plant required by a paper mill. Black liquor is also suitable for gasification, the syngas being then available for either electricity hydrogen or synthetic fuels production. The shortfall of energy available to the paper mill can be made up by burning waste wood. Compared to a reference case with a traditional black liquor boiler and all other parameters being the desired fuel can be produced with significantly higher net energy efficiency than in a more conventional scheme.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPDE1a	**Piped NG, 7000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.4			1.9	0.14	0.000
	NG Transport	3	0.28	0.09	0.31		21.2			14.4	0.26	0.001
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	DME plant	4	0.41	0.39	0.43		10.6			10.5	0.00	0.000
	DME distribution & dispensing	5	0.03				1.7			1.6	0.00	0.000
	Total pathway		**0.77**	0.57	0.84	**0.77**	**39.7**	28.4	43.6	29.2	0.41	0.001
GPDE1b	**Piped NG, 4000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.07		5.0			1.7	0.13	0.000
	NG Transport	3	0.13	0.04	0.15		10.6			6.8	0.15	0.000
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	DME plant	4	0.41	0.39	0.43		10.6			10.5	0.00	0.000
	DME distribution & dispensing	5	0.03				1.7			1.6	0.00	0.000
	Total pathway		**0.62**	0.54	0.66	**0.62**	**28.7**	24.0	31.1	21.4	0.28	0.000
GRDE1	**Remote plant**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.5			1.6	0.12	0.000
	DME plant	2	0.41	0.39	0.43		10.6			10.5	0.00	0.000
	DME transport	3	0.06				4.3			4.3	0.00	0.000
	DME distribution & dispensing	5	0.03				1.7			1.6	0.00	0.000
	Total pathway		**0.53**	0.51	0.56	**0.53**	**21.1**	20.1	22.9	18.0	0.12	0.000
GRDE1C	**Remote plant, CCS**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.5			1.6	0.12	0.000
	DME plant	2	0.42	0.40	0.42		0.6			0.6	0.00	0.000
	DME transport	3	0.06				4.3			4.3	0.00	0.000
	DME distribution & dispensing	5	0.03				1.7			1.6	0.00	0.000
	Total pathway		**0.54**	0.54	0.61	**0.54**	**11.1**	11.0	14.8	8.1	0.12	0.000
KODE1	**Coal EU-mix, gasifier + DME synthesis**											
	Coal provision	3	0.16				27.97			11.2	0.66	0.000
	Gasifier + DME synthesis	4	0.74				99.98			99.8	0.01	0.000
	DME distribution & dispensing	5	0.03				1.69			1.6	0.00	0.000
	Total pathway		**0.93**	0.83	1.01	**0.92**	**129.6**	119.4	137.6	112.7	0.67	0.001
WWDE1	**Wood waste**											
	Waste collection and chipping	1	0.06				0.7			0.7	0.00	0.000
	Transport (road + sea)	3	0.03				2.7			2.6	0.01	0.000
	Gasifier + DME synthesis (CCS)	4	0.96				0.1			0.1	0.00	0.000
	DME distribution & dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total WTT GHG emitted						**4.6**	4.3	4.8	4.3	0.01	0.000
	Credit for renewable combustion CO_2						-67.3			-67.3		
	Total pathway		**1.07**	0.93	1.20	**0.06**	**-62.7**	-63.0	-62.5			
WFDE1	**Farmed wood**											
	Wood farming and chipping	1	0.08				4.7			2.3	0.00	0.008
	Road transport	3	0.01				0.7			0.7	0.00	0.000
	Gasifier + MeOH synthesis	4	0.96				0.1			0.1	0.00	0.000
	DME distribution & dispensing	5	0.02				1.0			1.0	0.00	0.000
	Total WTT GHG emitted						**6.5**	5.1	18.9	4.1	0.00	0.008
	Credit for renewable combustion CO_2						-67.3			-67.3		
	Total pathway		**1.07**	0.94	1.21	**0.06**	**-60.8**	-62.18	-48.41			
BLDE1	**DME from black liquor**											
	Waste collection and chipping	1	0.04				0.5			0.5	0.0	0.000
	Transport (road)	3	0.01				0.5			0.5	0.0	0.000
	Black liquor gasification + DME synthesis	4	0.49				0.1			0.1	0.0	0.000
	DME distribution & dispensing	5	0.02				1.0			1.0	0.0	0.000
	Total WTT GHG emitted						**2.2**	2.1	2.2	2.1	0.00	0.000
	Credit for renewable combustion CO_2						-67.3			-67.3		
	Total pathway		**0.55**	0.50	0.60	**0.03**	**-65.1**	-65.17	-65.10			

5.3 Methanol

					Coal	Farmed wood	Waste wood	Waste wood	Black liquor
Pathway code		**GPME**		**GRME**	**KOME**	**WFME**	**WWME**	**WWDE**	**BLME**
		1a	**1b**	**1**	**1**	**1**	**1**	**1**	**1**
Code	Process								
GG1	NG Extraction & Processing	✓	✓	✓					
NG from pipeline									
GP1a	Russian quality, 7000 km	✓							
GP1b	Average quality, 4000 km		✓						
NG distribution									
GG3	NG trunk distribution	✓	✓						
NG to Methanol									
GA1	NG to Methanol (remote or central plant)	✓	✓	✓					
NG common processes									
GG2	Electricity generation from NG (CCGT)			✓					
Coal									
KO1	Hard coal provision (EU-mix) (1)				✓				
KA1	Coal to methanol				✓				
Wood (farmed)									
WF1	Wood farming and chipping					✓			
Wood (waste)									
WW1	Forest residuals to wood chips						✓	✓	✓
Wood transport & processing (all sources)									
WC2a	Wood chips road transport, 50 km					✓	✓	✓	✓
WC2b	Wood chips road transport, 12 km								
WC2c	Coastal/river shipping wood chips (200MW plant)						✓	✓	
W3g	Wood to methanol or DME: gasification + synthesis					✓	✓	✓	
Wood waste via black liquor									
BLM	Wood waste to methanol via black liquor								✓
Methanol transport & distribution									
ME1	Methanol handling and loading (remote)			✓					
ME2	Methanol sea transport (average of two distances)			✓					
ME3	Methanol depot			✓					
ME4	Methanol distribution and dispensing	✓	✓	✓	✓				
MEd	Biomethanol distribution direct from plant					✓	✓		✓
Common processes									
Z1	Diesel production	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓	✓	✓
Z3	HFO production	✓	✓	✓					
Z4	Product carrier 50 kt			✓					
Z5	Rail transport	✓	✓	✓	✓	✓	✓	✓	
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓

GPME1a/b Piped NG to methanol (EU plant)

This pathway foresees a methanol plant located in Europe and fed by gas from a major gas pipeline source (7000 or 4000 km). Similarly to the GTL case, this is an unlikely scenario. As in all other pathways methanol is used as a fuel for on-board reformers and distributed through a dedicated network.

GRME1 Remote NG to methanol (remote plant) (+CCS option)

This option of a methanol plant installed near a remote gas supply is the most likely. Transport is less energy-intensive for methanol than for natural gas (as LNG).

KOME1 Hard coal to methanol

In this case a full size methanol synthesis plant is assumed with a wide distribution network (500 km average distance with mixed rail/road transport).

W/F-WME1 Waste/Farmed wood to methanol

Wood gasification followed by methanol synthesis.

BLME1 Waste wood via black liquor to methanol

Black liquor is the residue of extraction of cellulose fibres from wood for paper pulp manufacturing. It contains the lignin and is used as fuel for the large power plant required by a paper mill. Black liquor is also suitable for gasification, the syngas being then available for either electricity hydrogen or synthetic fuels production. The shortfall of energy available to the paper mill can be made up by burning waste wood. Compared to a reference case with a traditional black liquor boiler and all other parameters being the desired fuel can be produced with significantly higher net energy efficiency than in a more conventional scheme.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPME1a	**Piped NG, 7000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.09		5.6			2.0	0.15	0.000
	NG Transport	3	0.29	0.10	0.32		22.0			15.0	0.27	0.001
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	Methanol plant	4	0.47	0.44	0.49		11.7			11.7	0.00	0.000
	Methanol distribution & dispensing	5	0.03				1.9			1.8	0.00	0.000
	Total pathway		**0.84**	0.66	0.92	**0.84**	**42.1**	31.8	46.4	31.3	0.42	0.001
GPME1b	**Piped NG, 4000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.2			1.8	0.13	0.000
	NG Transport	3	0.14	0.05	0.15		11.0			7.0	0.16	0.000
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	Methanol plant	4	0.47	0.44	0.49		11.7			11.7	0.00	0.000
	Methanol distribution & dispensing	5	0.03				1.9			1.8	0.00	0.000
	Total pathway		**0.69**	0.61	0.73	**0.69**	**30.6**	25.9	33.0	23.2	0.29	0.000
GRME1	**NG, Remote plant**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.7			1.6	0.12	0.000
	Methanol plant	2	0.47	0.44	0.49		11.7			11.7	0.00	0.000
	Methanol transport	3	0.08				5.9			5.9	0.00	0.000
	Methanol distribution & dispensing	5	0.03				1.9			1.8	0.00	0.000
	Total pathway		**0.61**	0.60	0.64	**0.61**	**24.2**	23.4	26.1	21.0	0.12	0.000
KOME1	**Coal EU-mix, gasifier + MeOH synthesis**											
	Coal provision	3	0.16				27.97			11.2	0.66	0.000
	Gasifier + MeOH synthesis	4	0.74				98.31			98.1	0.01	0.000
	Methanol distribution & dispensing	5	0.03				1.89			1.8	0.00	0.000
	Total pathway		**0.93**	0.84	1.02	**0.93**	**128.2**	118.8	137.1	111.2	0.67	0.001
WWME1	**Wood waste**											
	Waste collection and chipping	1	0.06				0.7			0.7	0.00	0.000
	Transport (road + sea)	3	0.03				2.7			2.6	0.01	0.000
	Gasifier + MeOH synthesis	4	0.96				0.2			0.2	0.00	0.000
	Methanol distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total WTT GHG emitted						**4.8**	4.5	5.0	4.5	0.01	0.000
	Credit for renewable combustion CO_2						-69.1			-69.1		
	Total pathway		**1.07**	0.94	1.20	**0.06**	**-64.3**	-64.6	-64.1			
WFME1	**Farmed wood**											
	Wood farming and chipping	1	0.08				4.7			2.3	0.00	0.008
	Road transport	3	0.01				0.7			0.7	0.00	0.000
	Gasifier + MeOH synthesis	4	0.96				0.2			0.2	0.00	0.000
	Methanol distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total WTT GHG emitted						**6.7**	5.2	19.4	4.3	0.00	0.008
	Credit for renewable combustion CO_2						-69.1			-69.1		
	Total pathway		**1.07**	0.94	1.20	**0.06**	**-62.4**	-63.8	-49.7			
BLME1	**Methanol from black liquor**											
	Waste collection and chipping	1	0.05				0.55			0.53	0.00	0.000
	Transport (road)	3	0.01				0.51			0.51	0.00	0.000
	Black liquor gasification + MeOH synthesis	4	0.52				0.2			0.2	0.00	0.000
	Methanol distribution & dispensing	5	0.02				1.1			1.1	0.00	0.000
	Total WTT GHG emitted						**2.4**	2.3	2.4	2.3	0.00	0.000
	Credit for renewable combustion CO_2						-69.1			-69.1		
	Total pathway		**0.59**	0.54	0.63	**0.03**	**-66.7**	-66.8	-66.7			

6 Ethers

Pathway code		GRMB	LREB
		1	1
Code	Process		
GG1	NG Extraction & Processing	✓	
NG to Methanol			
GA1	NG to Methanol (remote or central plant)	✓	
LPG			
LR1	LPG production	✓	✓
LR2	LPG sea transport		✓
Ether production			
BU1	n-butane to isobutene	✓	✓
EH1	Isobutene + ethanol to ETBE		✓
MH1	Isobutene + methanol to MTBE	✓	
Farming			
WT1	Wheat farming		✓
Crop transport and processing			
WT2a	Wheat grain road transport		✓
WT3	Wheat grain handling and drying (to dwg, 3%		✓
WT4b	Wheat grain to ethanol, NG CCGT		✓
WTDa	Credit for DDGS as animal feed		✓
Methanol transport & distribution			
ME1	Methanol handling and loading (remote)	✓	
ME2	Methanol sea transport (average of two distances)	✓	
ME3	Methanol depot	✓	
Common processes			
Z1	Diesel production	✓	✓
Z2	Road tanker	✓	✓
Z3	HFO production	✓	
Z4	Product carrier 50 kt	✓	
Z6	Marginal NG for general use (4000 km piped)	✓	✓
Z7a	Electricity (EU-mix, MV)	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓

GRMB1 Natural gas and field butane to MTBE

Methanol synthesised from remote natural gas and isobutene prepared from field butane are reacted together to form MTBE. MTBE is shipped to Europe and used in blend with gasoline.

LREB1 Bio-ethanol and field butane to ETBE

Isobutene prepared in Europe from imported field butane is reacted with bio-ethanol (from wheat according to pathway WTET2a) to form ETBE. ETBE is used in blend with gasoline.

Note: evaluating the fossil energy is a little more complex in this case as only part of the feedstock is renewable. The figure of 0.07 MJ_{xf}/MJ_f shown in the table below assumes that all combustion energy is fossil i.e. the total fossil energy for the WTW pathway is 1.07 MJ_{xf}/MJ_f. Following the same logic, only 1/3 of the CO_2 emissions is credited as renewable (2 out of 6 carbon atoms in the ETBE molecule).

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GRMB1	**MTBE from remote plant**											
	NG extraction and processing	1	0.01				0.88			0.3	0.02	0.000
	Methanol and iC4= synthesis	2	0.09				2.21			2.2	0.00	0.000
	MTBE plant	2	0.14				6.04			5.6	0.02	0.000
	MTBE transport	3	0.05				4.05			4.0	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total pathway		**0.30**	0.30	0.31	**0.30**	**13.6**	13.5	14.5	12.5	0.04	0.000
LREB1	**ETBE from imported C4 and wheat ethanol (WTET2a)**											
	Wheat cultivation	1	0.10				14.37			6.3	0.01	0.026
	Road transport	3	0.01				0.20			0.2	0.00	0.000
	Ethanol plant	4	0.40				-0.97			1.7	0.02	-0.011
	ETBE plant	4	0.22				7.98			7.4	0.02	0.000
	ETBE road transport, 150 km	5	0.01				0.67			0.7	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**22.7**	68.8	74.8	16.7	0.05	0.016
	Credit for renewable combustion CO_2						-23.8			-23.8		
	Total pathway		**0.75**	0.74	0.76	**0.01***	**-1.1**	-2.5	3.4			

7 Heat and power generation

7.1 Electricity only

		Natural gas			Coal								Farmed wood				Waste wood				Black liquor	Wind	Nuclear	EU-mix		
Pathway code		GPEL		GREL	KOEL		OWEL						WFEL				WWEL				BLEL	WDEL	NUEL	EMEL	EMEL	
		1a	1b	1	1	2	1a	1b	2a	2b	3a	3b	1	2	3	4	1	2	3	4	1	1	1	1	1	1
GG1	NG Extraction & Processing	✓	✓	✓																						
NG from pipeline																										
GP1a	Russian quality, 7000 km	✓																								
GP1b	Average quality, 4000 km		✓																							
LNG production & transport																										
GR1	NG Liquefaction			✓																						
GR2	LNG terminal (loading)			✓																						
GR3	LNG transport (average of two distances)			✓																						
GR4	LNG terminal (unloading)			✓																						
Biogas from waste																										
BG1a	Liquid manure transport, 10 km								✓	✓																
BG1b	Dry manure transport, 10 km										✓	✓														
BG2a	Municipal waste to biogas (upgraded)							✓																		
BG2b	Liquid manure to biogas (upgraded)									✓																
BG2c	Dry manure to biogas (upgraded)											✓														
BG3a	Municipal waste to electricity (small scale, local)						✓																			
BG3b	Liquid manure to electricity (small scale, local)								✓																	
BG3c	Dry manure to electricity (small scale, local)										✓															
NG distribution																										
GR5	LNG vaporisation			✓																						
GG3	NG trunk distribution			✓				✓		✓		✓														
NG common processes																										
GG2	Electricity generation from NG (CCGT)	✓	✓	✓				✓		✓		✓														
Coal																										
KO1	Hard coal provision (EU-mix) (1)				✓	✓																				
KE1	Electricity from Coal (conv. Boiler)				✓	✓																				
Wood (farmed)																										
WF1	Wood farming and chipping												✓	✓	✓	✓										
Wood (waste)																										
WW1	Forest residuals to wood chips																✓	✓	✓	✓	✓					
Wood transport & processing (all sources)																										
WC2a	Wood chips road transport, 50 km												✓		✓	✓	✓		✓	✓	✓					
WC2b	Wood chips road transport, 12 km													✓				✓								
W3b	Wood to electricity: gasification, 200MW												✓				✓									
W3c	Wood to electricity: gasification, 10MW													✓				✓								
W3a	Biomass to electricity: Conventional wood boiler with steam turbine														✓				✓							
W3h	Wood cofiring in coal power station															✓				✓						
Wood waste via black liquor																										
BLE	Electricity from waste wood via black liquor																				✓					
Wind																										
DE	Electricity from wind																					✓				
Nuclear																										
NE1	Nuclear fuel provision																						✓			
NE2	Electricity from nuclear																						✓			
Common processes																										
Z1	Diesel production												✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
Z2	Road tanker												✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
Z71	HV+MV losses	✓	✓																			✓				
Z72	LV losses	✓	✓																			✓				
Z7a	Electricity (EU-mix, MV)			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Z7b	Electricity (EU-mix, LV)			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

In this study, electricity is not used as such as automotive energy source. It is an intermediate for production of hydrogen by electrolysis. These pathways are shown separately to illustrate the amount of electrical energy that can be produced from certain sources, particularly biomass, and also to allow comparison of energy efficiency and GHG avoidance potential with other uses of the same resource.

GPEL1a/b Piped NG to electricity

Natural gas is already widely used for electricity generation and all forecasts agree that this will increase in the coming decades. The Combined Cycle Gas Turbine (CCGT) is now established as the state-of-the-art scheme.

GPEL1bC Piped NG to electricity with CCS

As above with CCGT flue gas CO_2 capture.

GPHEL1a/bC Piped NG to electricity via hydrogen CCGT and CCS

In this scheme natural gas is reformed to hydrogen, CO_2 is captured and hydrogen is use to generate electricity in an adapted CCGT.

GREL1 LNG to electricity

This pathway illustrates the use of remote gas (as LNG) for electricity generation in Europe (as a comparison with the previous pathways).

KOEL1/1C Hard coal to electricity

Coal is another standard energy source for electricity generation. This pathway represents the range of available technologies (with a fairly wide variability range).

OWEL1/2/3 Biogas to electricity

Biogas produced from municipal waste or manure is used to produce electricity in a gas engine. Upgrading is not required.

W/F-WEL1-4 Farmed or waste wood to electricity

1 and 2 represent the gasification + CCGT route at either large (200 MW biomass) or small (10 MW) scale. The former is considerably more efficient. 3 represent the conventional boiler + steam turbine route. 4 is co-firing in a coal power station.

BLEL1 Waste wood via black liquor to electricity

See *section 2-5*

EMEL1 EU-mix electricity

This is the reference that is also used for all minor electricity consumptions in all pathways. GHG emissions from EU-mix are similar than those from natural gas CCGT.

WDEL1 Wind to electricity

Wind power is one of the most promising option for renewable electricity generation.

NUEL1 Nuclear energy to electricity

Although not popular at the moment, this option cannot be ignored as it has the potential to provide large amounts of essentially carbon-free electricity.

		Standard step	Energy expended (MJx/MJelec)				Net GHG emitted (g CO_2eq/MJelec)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPEL1a	**Piped NG, 7000 km, CCGT**											
	NG Extraction & Processing	1	0.05	0.03	0.11		7.2			2.5	0.19	0.000
	NG Transport	3	0.36				28.1			19.1	0.35	0.001
	NG Distribution (HP)	3	0.02				1.1			1.0	0.00	0.000
	Power generation (CCGT)	4	0.84	0.80	0.88		104.6			102.9	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.31**	1.09	1.39	**1.31**	**141.0**	128.0	145.8	125.6	0.55	0.006
GPEL1b	**Piped NG, 4000 km, CCGT**											
	NG Extraction & Processing	1	0.05	0.02	0.10		6.6			2.3	0.17	0.000
	NG Transport	3	0.17				14.0			9.0	0.20	0.000
	NG Distribution (HP)	3	0.02				1.1			1.0	0.00	0.000
	Power generation (CCGT)	4	0.84	0.80	0.88		104.6			102.9	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.11**	0.96	1.20	**1.11**	**126.3**	117.3	131.1	115.2	0.38	0.005
GPEL1bC	**Piped NG, 4000 km, CCGT + CCS**											
	NG Extraction & Processing	1	0.06	0.03	0.12		7.7			2.7	0.20	0.000
	NG Transport	3	0.20				16.4			10.5	0.23	0.000
	NG Distribution (HP)	3	0.02				1.2			1.2	0.00	0.000
	Power generation (CCGT)	4	1.16	1.10	1.22		12.5			12.3	0.01	0.000
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.47**	1.30	1.57	**1.47**	**37.8**	27.9	43.7	26.7	0.44	0.001
GPHEL1aC	**Piped NG, 7000 km, Hydrogen CCGT + CCS**											
	NG Extraction & Processing	1	0.07	0.04	0.14		9.3			3.3	0.24	0.000
	NG Transport	3	0.47				36.5			24.8	0.46	0.001
	NG Distribution (HP)	3	0.02				1.4			1.3	0.00	0.000
	Power generation (CCGT)	4	1.40	1.33	1.47		13.4			13.4	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.00**	1.67	2.07	**2.00**	**60.7**	41.5	65.0	42.8	0.70	0.001
GPHEL1bC	**Piped NG, 4000 km, Hydrogen CCGT + CCS**											
	NG Extraction & Processing	1	0.06	0.03	0.13		8.5			3.0	0.22	0.000
	NG Transport	3	0.22				18.2			11.7	0.26	0.001
	NG Distribution (HP)	3	0.02				1.4			1.3	0.00	0.000
	Power generation (CCGT)	4	1.40	1.33	1.47		13.4			13.4	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.74**	1.55	1.86	**1.74**	**41.6**	30.1	48.6	29.4	0.48	0.001
GREL1	**LNG, CCGT**											
	NG Extraction & Processing	1	0.05	0.02	0.10		6.6			2.3	0.17	0.000
	NG Liquefaction	2	0.16				10.9			8.8	0.08	0.000
	LNG transport (shipping)	3	0.16				10.5			10.4	0.00	0.000
	LNG Receipt	3	0.08				4.5			4.4	0.00	0.000
	Power generation (CCGT)	4	0.84				104.6			102.9	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.33**	1.21	1.46	**1.33**	**137.0**	130.6	144.8	128.8	0.26	0.006
KOEL1	**Coal, state-of-the-art conventional technology**											
	Coal provision	3	0.22				38.1			15.3	0.90	0.001
	Power plant	4	1.34				230.9			227.3	0.00	0.012
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.59**	1.28	1.79	**1.58**	**269.0**	236.9	289.3	242.6	0.91	0.012
KOEL2	**Coal, IGCC**											
	Coal provision	3	0.20				34.5			13.9	0.82	0.001
	Power plant	4	1.12				207.0			206.2	0.01	0.002
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.35**	1.25	1.45	**1.34**	**241.5**	231.5	252.6	220.0	0.83	0.003

		Standard step	Energy expended (MJx/MJelec)				Net GHG emitted (g CO_2eq/MJelec)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
OWEL1a	**Electricity from municipal waste (local power plant)**											
	Biogas production	4	1.67				5.77			-4.6	0.60	-0.016
	Local power plant	4	1.52				1.97			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.20**	2.91	3.57	**-0.08**	**7.7**	7.1	8.4	-4.6	0.68	-0.016
OWEL1b	**Electricity from municipal waste (large power plant)**											
	Biogas production	4	1.52				-79.19			-97.1	0.85	-0.011
	Gas distribution	3	0.00				0.00			0.0	0.00	0.000
	Large power plant	4	0.84				107.11			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.39**	2.10	2.68	**0.21**	**27.9**	22.2	33.1	8.4	0.85	-0.006
OWEL2a	**Electricity from liquid manure (local power plant)**											
	Transport of liquid manure (10 km)	2	0.06				-197.98			4.5	-8.10	0.000
	Biogas production	4	1.47				8.82			-2.7	0.57	-0.009
	Local power plant	4	1.52				1.97			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.06**	2.74	3.40	**0.01**	**-187.2**	-243.7	-122.5	1.8	-7.45	-0.009
OWEL2b	**Electricity from liquid manure (large power plant)**											
	Transport of liquid manure (10 km)	2	0.05				-177.18			4.0	-7.25	0.000
	Biogas production	4	1.64				-91.24			-111.0	0.89	-0.008
	Gas distribution	3	0.00				0.00			0.0	0.00	0.000
	Large power plant	4	0.84				107.11			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.56**	2.24	2.88	**-0.06**	**-161.3**	-209.4	-107.5	-1.4	-6.35	-0.004
OWEL3a	**Electricity from dry manure (local power plant)**											
	Transport of dry manure (10 km)	2	0.02				-18.81			1.4	-0.81	0.000
	Biogas production	4	1.47				8.82			-2.7	0.57	-0.009
	Local power plant	4	1.52				1.97			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.02**	2.72	3.32	**-0.03**	**-8.0**	-13.6	-2.0	-1.2	-0.16	-0.009
OWEL3b	**Electricity from dry manure (large power plant)**											
	Transport of dry manure (10 km)	2	0.02				-16.84			1.3	-0.72	0.000
	Biogas production	4	1.64				-91.24			-111.0	0.89	-0.008
	Gas distribution	3	0.00				0.00			0.0	0.00	0.000
	Large power plant	4	0.84				107.11			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.53**	2.21	2.84	**-0.09**	**-1.0**	-5.9	4.8	-4.2	0.17	-0.004

		Standard step	Energy expended (MJx/MJelec)				Net GHG emitted (g CO_2eq/MJelec)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
WWEL1	**Waste wood, 200 MW gasifier + CCGT**											
	Waste collection and chipping	1	0.06				0.8			0.7	0.00	0.000
	Wood chips road transport	3	0.04				3.0			2.8	0.01	0.000
	Power generation (gasifier+CCGT)	4	1.11				1.4			0.0	0.03	0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.24**	1.16	1.34	**0.05**	**5.2**	4.9	5.6	3.5	0.03	0.003
WWEL2	**Waste wood, 10 MW gasifier + GT**											
	Waste collection and chipping	1	0.09				1.1			1.0	0.00	0.000
	Wood chips road transport	3	0.00				0.2			0.2	0.00	0.000
	Power generation (gasifier+CCGT)	4	1.88				1.9			0.0	0.04	0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.00**	1.90	2.10	**0.02**	**3.2**	3.2	3.3	1.3	0.04	0.004
WWEL3	**Waste wood, steam power plant**											
	Waste collection and chipping	1	0.09				1.1			1.0	0.00	0.000
	Wood chips road transport	3	0.01				1.0			1.0	0.00	0.000
	Power generation (boiler + steam turbine)	4	1.88				1.9			0.0	0.04	0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.01**	1.90	2.12	**0.03**	**4.0**	3.9	4.0	2.0	0.04	0.004
WWEL4	**Waste wood, co-fired with coal**											
	Waste collection and chipping	1	0.07				0.9			0.8	0.00	0.000
	Wood chips road transport	3	0.04				3.3			3.1	0.01	0.000
	Coal power station (boiler + steam turbine)	4	1.34				3.6			0.0	0.00	0.012
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.48**	1.16	1.72	**0.05**	**7.7**	7.2	8.2	3.9	0.01	0.012
WFEL1	**Farmed wood, 200 MW gasifier + CCGT**											
	Wood farming	1	0.03				4.4			1.8	0.00	0.008
	Wood chipping	1	0.06				0.8			0.7	0.00	0.000
	Wood chips road transport	3	0.01				0.7			0.7	0.00	0.000
	Power generation (gasifier+CCGT)	4	1.11				1.4			0.0	0.03	0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.24**	1.15	1.35	**0.05**	**7.3**	5.6	18.9	3.3	0.03	0.011
WFEL2	**Farmed wood, 10 MW gasifier + GT**											
	Wood farming	1	0.04				5.9			2.4	0.00	0.011
	Wood chipping	1	0.09				1.1			1.0	0.00	0.000
	Wood chips road transport	3	0.00				0.2			0.2	0.00	0.000
	Power generation (gasifier+GT)	4	1.88				1.9			0.0	0.04	0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.03**	1.92	2.15	**0.05**	**9.2**	6.8	27.1	3.7	0.04	0.015
WFEL3	**Farmed wood, steam power plant**											
	Wood farming	1	0.04				6.6			2.7	0.00	0.013
	Wood chipping	1	0.10				1.2			1.1	0.00	0.000
	Wood chips road transport	3	0.01				1.1			1.1	0.00	0.000
	Power generation (boiler + steam turbine)	4	2.19				9.7			0.0	0.09	0.025
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.37**	2.20	2.53	**0.07**	**18.5**	16.2	38.4	4.9	0.09	0.038
WFEL4	**Farmed wood, co-firing with coal**											
	Wood farming	1	0.03				4.8			2.0	0.00	0.009
	Wood chipping	1	0.07				0.9			0.8	0.00	0.000
	Wood chips road transport	3	0.01				0.8			0.8	0.00	0.000
	Coal power station (boiler + steam turbine)	4	1.34				3.6			0.0	0.00	0.012
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.48**	1.12	1.70	**0.05**	**10.1**	8.2	24.9	3.6	0.01	0.021
BLEL1	**Electricity from black liquor**											
	Waste collection and chipping	1	0.03				0.42			0.4	0.00	0.000
	Transport (road, 50 km)	3	0.01				0.39			0.0	0.00	0.000
	Paper mill power plant	4	0.11				0.00			0.0	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**0.18**	0.15	0.22	**0.01**	**0.8**	0.8	0.8	0.4	0.00	0.000
EMEL1	**EU-mix electricity**											
	EU-mix power generation	4	1.84				129.8			120.8	0.29	0.005
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.87**	1.87	1.87	**1.73**	**129.8**	129.8	129.8	120.8	0.29	0.005
	Non-nuclear fossil energy					1.27						
WDEL1	**Wind turbine (offshore)**											
	EU-mix power generation	4	0.00				0.0			0.0	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.03**	0.03	0.03	**0.00**	**0.0**	0.0	0.0	0.0	0.00	0.000
NUEL1	**Nuclear**											
	Nuclear fuel provision	1	0.62				4.07			3.8	0.01	0.000
	Nuclear power station	4	2.09				0.30			0.3	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.74**	2.66	2.82	**2.74**	**4.4**	4.2	4.6	4.1	0.01	0.000
	Non-nuclear fossil energy					0.65						

7.2 Heat and CHP

These pathways are provided for reference purposes and are not further used in the WTW analysis. They describe typical performance of small and industrial boilers and large scale CHP plants fed with various feedstocks.

		Crude oil		Natural gas									Biogas			Farmed wood			Waste wood		
Pathway code		COHT		GPHT				GPEH		GRHT		GREH	OWHT			WFHT		WFEH	WWHT		WWEH
		1	2	1a	1b	2a	2b	1a	1b	1	2	1	1	2	3	1	2	1	1	2	1
Crude oil																					
CO1	Crude oil production	✓																			
CO2	Crude oil transportation	✓																			
CD1	Crude oil refining, marginal diesel	✓																			
CD2	Diesel transport	✓																			
CD3	Diesel depot	✓																			
CD4	Diesel distribution and dispensing	✓																			
BDo	Heating oil domestic boiler	✓																			
BIo	Heating oil industrial boiler		✓																		
GG1	NG Extraction & Processing			✓	✓	✓	✓	✓	✓	✓	✓	✓									
NG from pipeline																					
GP1a	Russian quality, 7000 km			✓		✓		✓													
GP1b	Average quality, 4000 km				✓		✓		✓												
LNG production & transport																					
GR1	NG Liquefaction									✓	✓	✓									
GR2	LNG terminal (loading)									✓	✓	✓									
GR3	LNG transport (average of two distances)									✓	✓	✓									
GR4	LNG terminal (unloading)									✓	✓	✓									
Biogas from waste																					
BG1a	Liquid manure transport, 10 km													✓							
BG1b	Dry manure transport, 10 km														✓						
BG3a	Municipal waste to electricity (small scale, local)												✓								
BG3b	Liquid manure to electricity (small scale, local)													✓							
BG3c	Dry manure to electricity (small scale, local)														✓						
NG distribution																					
GR5	LNG vaporisation									✓	✓	✓									
GG3	NG trunk distribution			✓	✓			✓	✓	✓	✓	✓									
GG4	NG local distribution			✓	✓					✓											
NG common processes																					
BDg	NG domestic boiler			✓	✓					✓			✓	✓	✓						
BIg	NG industrial boiler					✓	✓				✓										
HPg	CHP plant, gas fired							✓	✓			✓									
Wood (farmed)																					
WF1	Wood farming and chipping															✓	✓	✓			
Wood (waste)																					
WW1	Forest residuals to wood chips																		✓	✓	✓
Wood transport & processing (all sources)																					
WC2a	Wood chips road transport, 50 km															✓	✓	✓	✓	✓	✓
WC2b	Wood chips road transport, 12 km																				
WC2c	Coastal/river shipping wood chips (200MW plant)																				
BDw	Wood domestic boiler															✓			✓		
BIw	Wood industrial boiler																✓			✓	
HPw	CHP plant, wood fired																	✓			✓
Common processes																					
Z1	Diesel production	✓	✓										✓	✓	✓	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓										✓	✓	✓	✓	✓	✓	✓	✓	✓
Z71	HV+MV losses											✓						✓			✓

Heat

COHT1/2 Heating oil boiler

Two variants describing either a small domestic (1) or large industrial boiler (2).

GPHT1/2 Piped natural gas boiler

Four variants describing either a small domestic (1) or large industrial boiler (2) fed with piped natural gas, with, in each case two supply distances (a: 7000 km, b: 4000 km).

GRHT1/2 Natural gas (ex LNG) boiler

Two variants describing either a small domestic (1) or large industrial boiler (2) fed with natural gas from imported LNG.

		Standard step	Energy expended (MJx/MJheat)				Net GHG emitted (g CO_2eq/MJheat)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
COHT1	**Heating oil domestic boiler**											
	Crude Extraction & Processing	1	0.07				5.9			5.9	0.00	0.000
	Crude Transport	3	0.01				1.0			-0.8	0.00	0.000
	Refining	4	0.11				9.6			9.6	0.00	0.000
	Distribution and dispensing	5	0.01				0.6			0.6	0.00	0.000
	Domestic boiler	5	1.17				84.7			83.8	0.01	0.002
	Total pathway		**1.37**	1.34	1.41	**1.37**	**101.8**	99.6	104.4	99.1	0.01	0.002
COHT2	**Heating oil industrial boiler**											
	Crude Extraction & Processing	1	0.07				4.1			4.1	0.00	0.000
	Crude Transport	3	0.01				1.0			1.0	0.00	0.000
	Refining	4	0.11				9.6			9.6	0.00	0.000
	Distribution and dispensing	5	0.01				0.6			0.6	0.00	0.000
	Industrial boiler	5	1.18				85.3			84.4	0.01	0.002
	Total pathway		**1.39**	1.36	1.43	**1.38**	**100.6**	98.5	103.6	99.7	0.01	0.002
GPHT1a	**Piped NG 7000 km domestic boiler**											
	NG Extraction & Processing	1	0.03				3.8			1.3	0.10	0.000
	NG Transport	3	0.19				15.0			10.2	0.19	0.000
	NG Distribution (LP)	5	0.01				0.6			0.6	0.00	0.000
	Domestic boiler	5	1.05				57.2			56.9	0.01	0.000
	Total pathway		**1.28**	0.18	0.29	**1.28**	**76.6**	71.0	77.4	69.0	0.29	0.001
GPHT1b	**Piped NG 4000 km domestic boiler**											
	NG Extraction & Processing	1	0.03				3.5			1.2	0.09	0.000
	NG Transport	3	0.09				7.5			4.8	0.11	0.000
	NG Distribution (LP)	5	0.01				0.6			0.5	0.00	0.000
	Domestic boiler	5	1.05				57.2			56.9	0.01	0.000
	Total pathway		**1.17**	0.13	0.19	**1.17**	**68.8**	66.4	69.5	63.5	0.20	0.001
GPHT2a	**Piped NG 7000 km industrial boiler**											
	NG Extraction & Processing	1	0.03				4.3			1.5	0.11	0.000
	NG Transport	3	0.22				16.7			11.3	0.21	0.000
	NG Distribution (HP)	5	0.01				0.6			0.6	0.00	0.000
	Industrial boiler	5	1.17				64.2			63.5	0.01	0.001
	Total pathway		**1.43**	0.32	0.43	**1.43**	**85.8**	79.5	86.1	77.0	0.33	0.002
GPHT2b	**Piped NG 4000 km industrial boiler**											
	NG Extraction & Processing	1	0.03				3.9			1.4	0.10	0.000
	NG Transport	3	0.10				8.3			5.3	0.12	0.000
	NG Distribution (HP)	5	0.01				0.6			0.6	0.00	0.000
	Industrial boiler	5	1.17				64.2			63.5	0.01	0.001
	Total pathway		**1.31**	0.26	0.32	**1.31**	**77.1**	74.2	77.6	70.8	0.23	0.001
GRHT1	**LNG domestic boiler**											
	NG Extraction & Processing	1	0.03				3.5			1.2	0.09	0.000
	NG Liquefaction	2	0.09				5.8			4.7	0.04	0.000
	LNG transport (shipping)	3	0.09				5.6			5.5	0.00	0.000
	LNG Receipt + vaporisation	5	0.03				1.8			1.8	0.00	0.000
	NG distribution (LP)	5	0.01				0.6			0.5	0.00	0.000
	Domestic boiler	5	1.05				57.0			56.8	0.01	0.000
	Total pathway		**1.29**	0.28	0.31	**1.29**	**74.4**	73.8	75.7	70.6	0.14	0.001
GRHT2	**LNG industrial boiler**											
	NG Extraction & Processing	1	0.03				3.9			1.4	0.10	0.000
	NG Liquefaction	2	0.10				6.5			5.2	0.05	0.000
	LNG transport (shipping)	3	0.10				6.2			6.2	0.00	0.000
	LNG Receipt + vaporisation	5	0.04				2.1			2.0	0.00	0.000
	NG distribution (HP)	5	0.01				0.6			0.6	0.00	0.000
	Industrial boiler	5	1.17				63.9			63.2	0.01	0.001
	Total pathway		**1.44**	0.42	0.46	**1.44**	**83.2**	82.4	84.4	78.6	0.16	0.002

OWHT1/2/3 Gas (ex biogas) boiler

Three variants corresponding to three biogas sources: municipal waste, liquid or dry manure.

W/F-W1/2 Wood boiler

Four variants corresponding to either farmed or waste wood feeding either a small or industrial scale boiler.

		Standard step	Energy expended (MJx/MJheat)				Net GHG emitted (g CO_2eq/MJheat)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
OWHT1	**Municipal waste to biogas to heat**											
	Biogas production	4	0.81				-42.3			-51.9	0.45	-0.006
	Gas distribution	5	0.00				0.0			0.0	0.00	0.000
	Gas boiler	5	0.05				58.6			58.3	0.01	0.000
	Total pathway		**0.86**	0.71	0.99	**0.15**	**16.2**	13.3	18.9	6.4	0.46	-0.006
OWHT2	**Liquid manure to biogas to heat**											
	Transport of liquid manure (10 km)	4	0.03				-94.7			2.1	-3.87	0.000
	Biogas production, treating and upgrading	4	0.88				-48.7			-59.3	0.47	-0.004
	Local gas distribution	5	0.00				0.0			0.0	0.00	0.000
	Gas boiler	5	0.05				58.6			58.3	0.01	0.000
	Total pathway		**0.95**	0.78	1.12	**0.01**	**-84.9**	-111.9	-54.8	1.2	-3.39	-0.004
OWHT3	**Dry manure to biogas to heat**											
	Transport of dry manure (10 km)	4	0.01				-9.0			0.7	-0.39	0.000
	Biogas production, treating and upgrading	4	0.88				-48.7			-59.3	0.47	-0.004
	Local gas distribution	5	0.00				0.0			0.0	0.00	0.000
	Gas boiler	5	0.05				58.6			58.3	0.01	0.000
	Total pathway		**0.93**	0.76	1.08	**-0.01**	**0.8**	-2.2	3.6	-0.3	0.09	-0.004
WWHT1	**Waste wood domestic boiler**											
	Waste collection and chipping	1	0.04				0.4			0.4	0.00	0.000
	Wood chip transport	3	0.01				0.4			0.4	0.00	0.000
	Wood pellets manufacture	4	0.09				0.0			0.0	0.00	0.000
	Wood pellets distribution	5	0.00				0.3			0.3	0.00	0.000
	Domestic boiler	5	0.20				4.4			3.6	0.01	0.002
	Total pathway		**0.33**	0.29	0.37	**0.10**	**5.5**	5.5	5.5	4.7	0.01	0.002
WFHT1	**Farmed wood domestic boiler**											
	Wood plantation	1	0.02				2.5			1.0	0.00	0.005
	Wood chipping	1	0.04				0.4			0.4	0.00	0.000
	Wood chip transport	3	0.01				0.4			0.4	0.00	0.000
	Wood pellets manufacture	4	0.09				0.0			0.0	0.00	0.000
	Wood pellets distribution	5	0.00				0.3			0.3	0.00	0.000
	Domestic boiler	5	0.20				4.4			3.6	0.01	0.002
	Total pathway		**0.35**	0.31	0.39	**0.11**	**7.9**	7.1	14.7	5.7	0.01	0.006
WWHT2	**Waste wood industrial boiler**											
	Waste collection and chipping	1	0.03				0.4			0.4	0.00	0.000
	Wood chip transport	3	0.01				0.4			0.4	0.00	0.000
	Industrial boiler	5	0.23				2.8			2.4	0.01	0.001
	Total pathway		**0.27**	0.24	0.31	**0.07**	**3.7**	3.6	3.7	3.2	0.01	0.001
WFHT2	**Farmed wood industrial boiler**											
	Wood plantation	1	0.02				2.4			1.0	0.00	0.005
	Waste collection and chipping	1	0.03				0.4			0.4	0.00	0.000
	Wood chip transport	3	0.01				0.4			0.4	0.00	0.000
	Industrial boiler	5	0.23				2.8			2.4	0.01	0.001
	Total pathway		**0.29**	0.25	0.33	**0.08**	**6.1**	5.3	13.0	4.2	0.01	0.005

CHP (with heat credit)

GPEH1a/b Natural gas CHP plant

Two variants corresponding to a large scale CCGT-based CHP plant fed with piped gas with a supply distance of either 7000 km (a) or 4000 km (b).

GREH1 Natural gas (ex LNG) CHP plant

As above but now with gas from imported LNG.

W/F-WEH1 Wood CHP plant

Wood CHP plant fed with either farmed or waste wood.

		Standard step	Energy expended (MJx/MJelec)				Net GHG emitted (g CO_2eq/MJelec)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPEH1a	**Piped NG 7000 km, CCGT CHP**											
	NG Extraction & Processing	1	0.07				9.2			3.2	0.24	0.000
	NG Transport	3	0.47				36.0			24.4	0.45	0.001
	NG Distribution (HP)	3	0.02				1.4			1.3	0.00	0.000
	CHP plant (CCGT)	4	1.37				133.8			131.8	0.01	0.006
	Heat export credit	4	-1.60				-96.8			-86.8	-0.38	-0.002
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.36**	0.05	0.56	**0.36**	**83.5**	65.7	95.0	74.0	0.32	0.005
	Heat/power production ratio		*1.10*									
GPEH1b	**Piped NG 4000 km, CCGT CHP**											
	NG Extraction & Processing	1	0.06				8.4			2.9	0.22	0.000
	NG Transport	3	0.22				18.0			11.5	0.25	0.000
	NG Distribution (HP)	3	0.02				1.4			1.3	0.00	0.000
	CHP plant (CCGT)	4	1.37				133.8			131.8	0.01	0.006
	Heat export credit	4	-1.46				-86.7			-79.6	-0.26	-0.002
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.24**	0.11	0.37	**0.24**	**74.9**	67.2	82.3	67.9	0.22	0.005
	Heat/power production ratio		*1.10*									
GREH1	**LNG, CCGT CHP**											
	NG Extraction & Processing	1	0.06				8.5			2.9	0.22	0.000
	NG Liquefaction	2	0.21				13.9			11.2	0.10	0.000
	LNG transport (shipping)	3	0.21				13.4			13.3	0.00	0.000
	LNG Receipt + vaporisation	3	0.08				4.4			4.4	0.00	0.000
	NG distribution (HP)	3	0.03				1.3			1.3	0.00	0.000
	CHP plant (CCGT)	4	1.37				133.5			131.5	0.01	0.006
	Heat export credit	4	-1.61				-93.8			-88.7	-0.18	-0.002
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.37**	0.33	0.42	**0.37**	**81.2**	79.0	84.0	76.0	0.15	0.005
	Heat/power production ratio		*1.10*									
WWEH1	**Waste wood boiler + steam turbine CHP**											
	Waste collection and chipping	1	0.14				1.7			1.6	0.00	0.000
	Wood chips road transport	3	0.02				1.5			1.5	0.00	0.000
	CHP plant (boiler + steam turbine)	4	3.55				3.2			0.0	0.09	0.003
	Heat export credit	4	-3.30				-3.4			-2.2	-0.01	-0.003
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.44**	0.19	0.67	**0.01**	**3.1**	2.9	3.2	1.0	0.08	0.000
	Heat/power production ratio		*2.50*									
WFEH1	**Farmed wood boiler + steam turbine CHP**											
	Wood farming	1	0.06				9.4			3.8	0.01	0.018
	Wood chipping	1	0.14				1.7			1.6	0.00	0.000
	Wood chips road transport	3	0.02				1.5			1.5	0.00	0.000
	CHP plant (boiler + steam turbine)	4	3.55				3.2			0.0	0.09	0.003
	Heat export credit	4	-3.34				-9.9			-4.9	-0.02	-0.015
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**0.46**	0.21	0.72	**0.03**	**5.9**	-7.7	27.4	2.1	0.09	0.006
	Heat/power production ratio		*2.50*									

CHP (with electricity credit)

GPHT3b

Gas fired GT with heat recovery

WFHT3

Wood fired CHP

		Standard step	Energy expended (MJx/MJheat)				Net GHG emitted (g CO_2eq/MJheat)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPHT3b	**Piped NG 4000 km, Heat CHP**											
	NG Extraction & Processing	1	0.06				8.3			2.9	0.22	0.000
	NG Transport	3	0.22				17.7			11.3	0.25	0.000
	NG Distribution (HP)	3	0.02				1.3			1.3	0.00	0.000
	CHP plant (CCGT) inc. elec credit	4	-0.83				7.3			16.4	-0.36	0.000
	Heat distribution	5	0.11				0.0			0.0	0.00	0.000
	Total pathway		**-0.42**	0.00	0.00	**-0.42**	**34.7**	0.0	0.0	31.9	0.10	0.001
WFHT3	**Farmed wood, Heat CHP**											
	Wood farming	1	0.03				4.0			1.7	0.00	0.008
	Wood chipping	1	0.06				0.7			0.7	0.00	0.000
	Wood chips road transport	3	0.01				0.7			0.7	0.00	0.000
	CHP plant (boiler + steam turbine), inc. elec credit	4	-0.59				-6.6			-2.1	0.00	-0.015
	Electricity distribution (LV)	5	0.11				0.0			0.0	0.00	0.000
	Total pathway		**-0.38**	0.00	0.00	**0.62**	**-1.2**	0.0	0.0	0.9	0.01	-0.007

8 Hydrogen

8.1 Natural gas to hydrogen

Pathway code		GMCH	GPCH						GPLCH	GRCH			GPLH		GRLH	
		1	1a	1b	2a	2b	2bC	3b	b	1	2	3	1a	1b	1	2
Code	Process															
GG1	NG Extraction & Processing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
NG from pipeline																
GP1a	Russian quality, 7000 km		✓		✓								✓			
GP1b	Average quality, 4000 km			✓		✓	✓	✓	✓					✓		
LNG production & transport																
GR1	NG Liquefaction									✓	✓	✓				✓
GR1C	NG Liquefaction with CC&S															
GR2	LNG terminal (loading)									✓	✓	✓				✓
GR3	LNG transport (average of two distances)									✓	✓	✓				✓
GR4	LNG terminal (unloading)									✓	✓	✓				✓
NG distribution																
GR5	LNG vaporisation									✓	✓	✓				✓
GG3	NG trunk distribution	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓
NG common processes																
GG2	Electricity generation from NG (CCGT)								✓	✓	✓	✓	✓	✓	✓	✓
Hydrogen transport & distribution																
CH1a	Gasous Hyd distribution (pipeline from central plant)				✓	✓	✓				✓	✓				
CH1b	Gasous Hyd distribution (trucking from central plant)							✓								
CH2	Liquid Hyd compression/vaporisation								✓							
CH3	Gasous Hyd dispensing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
LH1	Hyd liquefaction												✓	✓	✓	✓
LH2	Liquid Hyd long-distance transport														✓	
LH3	Liquid Hyd distribution and dispensing												✓	✓	✓	✓
Common processes																
Z1	Diesel production								✓				✓	✓	✓	✓
Z2	Road tanker								✓				✓	✓	✓	✓
Z71	HV+MV losses															
Z72	LV losses															
Z7a	Electricity (EU-mix, MV)															
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓

GMCH1 EU-mix NG supply to on-site hydrogen production and compression

GPCH1a/b Piped NG to on-site hydrogen production and compression

These three pathways describe the local production of hydrogen with a small steam reformer installed at the refuelling station followed by compression (88 MPa). The only difference is in the origin of the gas. Such schemes may be attractive as it avoids transporting hydrogen but they do require up front investment in a large number of locations.

GPCH2 a/b/bC Piped NG to central hydrogen production, pipeline distribution and on-site compression (+CCS option)

Here hydrogen is produced by steam reforming of natural gas (pipeline 7 or 4000 km) in a central plant from where it is distributed through a local pipeline network (50 km average distance) before compression to 88 MPa at the refuelling station. The principal advantage of such a scheme is to allow large plants that can be made more efficient than small ones through heat integration and recovery and that can be build gradually as demand grows. As full decarbonisation occurs at the production stage CO_2 capture and storage could be an attractive option where suitable geological formations are available within a reasonable distance.

GPCH3b Piped NG to central hydrogen production, road distribution and on-site compression

This pathway is essentially the same as above except that hydrogen is now distributed by road in high pressure cylinders. This distribution mode may be more appropriate for limited markets where a pipeline network would not be justifiable.

GPLCHb Piped NG to central production of liquid hydrogen, road distribution and on-site vaporisation/compression

This is the same pathway as above but it is now assumed that the vehicle requires compressed hydrogen. The liquid hydrogen delivered to the refuelling station is compressed and vaporised on-site. Note that this operation is less energy-intensive than gaseous hydrogen compression.

GRCH1/2 Remote NG to hydrogen production and compression

LNG for remote location can offer an alternative to pipeline supplies. In these two pathways it is assumed that LNG is vaporised on receipt at the EU terminal and introduced into the grid. Hydrogen can then be produced either on-site or centrally as explained above.

GRCH3 Remote NG to methanol to hydrogen production and compression

Methanol can be used as a energy vector instead of NG. In this pathway methanol is produced from remote NG, transported to Europe, distributed within Europe and converted into hydrogen in an on-site reformer.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GMCH1	**NG EU-mix, 1000 km, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.9			1.7	0.1	0.0
	NG Transport	3	0.03	0.01	0.03		2.8			1.6	0.0	0.0
	NG Distribution	3	0.01				0.9			0.8	0.0	0.0
	On-site reforming	4	0.52	0.49	0.55		86.6			85.8	0.0	0.0
	Compression	5	0.24	0.22	0.26		10.0			9.3	0.0	0.0
	Total pathway		**0.84**	0.81	0.89	**0.83**	**105.2**	103.3	108.0	99.3	0.23	0.001
GPCH1a	**Piped NG, 7000 km, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.09		5.7			2.0	0.15	0.000
	NG Transport	3	0.29	0.10	0.32		22.1			15.0	0.28	0.001
	NG Distribution	3	0.01				0.8			0.8	0.00	0.000
	On-site reforming	4	0.52	0.49	0.55		84.7			83.9	0.03	0.000
	Compression	5	0.24	0.22	0.26		10.0			9.3	0.02	0.000
	Total pathway		**1.11**	0.94	1.18	**1.09**	**123.2**	113.5	127.7	111.0	0.48	0.001
GPCH1b	**Piped NG, 4000 km, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.2			1.8	0.13	0.000
	NG Transport	3	0.14	0.05	0.15		11.0			7.1	0.16	0.000
	NG Distribution	3	0.01				0.8			0.8	0.00	0.000
	On-site reforming	4	0.52	0.49	0.55		84.7			83.9	0.03	0.000
	Compression	5	0.24	0.22	0.26		10.0			9.3	0.02	0.000
	Total pathway		**0.95**	0.86	1.00	**0.94**	**111.7**	106.7	114.7	102.9	0.34	0.001
GPCH2a	**Piped NG, 7000 km, central reforming, pipeline**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.2			1.8	0.13	0.000
	NG Transport	3	0.26	0.09	0.29		20.1			13.7	0.25	0.001
	NG Distribution (HP)	3	0.01				0.8			0.7	0.00	0.000
	Central reforming	4	0.32	0.29	0.34		74.1			73.7	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**0.86**	0.71	0.93	**0.85**	**109.3**	100.9	113.6	98.4	0.42	0.001
GPCH2b	**Piped NG, 4000 km, central reforming, pipeline**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.7			1.6	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		10.1			6.4	0.14	0.000
	NG Distribution (HP)	3	0.01				0.8			0.7	0.00	0.000
	Central reforming	4	0.32	0.29	0.34		74.1			73.7	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**0.72**	0.63	0.76	**0.71**	**98.8**	94.0	101.3	91.0	0.30	0.001
GPCH2bC	**Piped NG, 4000 km, central reforming, pipeline, CC&S**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.9			1.7	0.13	0.000
	NG Transport	3	0.13	0.04	0.14		10.5			6.7	0.15	0.000
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	Central reforming (CCS)	4	0.37	0.34	0.39		12.5			12.1	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**0.77**	0.69	0.82	**0.76**	**37.8**	33.1	40.4	29.8	0.31	0.001
GPCH3b	**Piped NG, 4000 km, central reforming, trucking**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.7			1.64	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		10.1			6.44	0.14	0.000
	NG Distribution (HP)	3	0.01				0.8			0.74	0.00	0.000
	Central reforming	4	0.32	0.29	0.34		74.1			73.67	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		10.1			9.50	0.02	0.000
	Total pathway		**0.72**	0.63	0.77	**0.71**	**99.7**	94.7	102.4	92.0	0.30	0.001

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPLCHb	**Piped NG, 4000 km, central reforming + liquefaction, vaporisation/compression**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.7			1.6	0.12	0.000
	NG Transport	3	0.12	0.11	0.13		9.9			6.3	0.14	0.000
	NG Distribution (HP)	3	0.01				0.8			0.7	0.00	0.000
	Central reforming	4	0.32	0.28	0.34		73.0			72.6	0.02	0.000
	Hyd liquefaction	4	0.62	0.43	0.80		37.0			33.8	0.11	0.002
	Liquid hyd distribution & vap/comp	5	0.17				8.3			7.8	0.02	0.000
	Total pathway		**1.28**	1.13	1.36	**1.27**	**133.6**	125.0	138.8	122.8	0.40	0.002
GRCH1	**LNG, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.2			1.8	0.14	0.000
	NG Liquefaction	2	0.13				8.6			6.9	0.06	0.000
	Long-distance transport	3	0.13				8.2			8.2	0.00	0.000
	LNG Vaporisation + Distribution	3	0.06				3.5			3.5	0.00	0.000
	On-site reforming	4	0.52	0.49	0.55		84.5			83.8	0.02	0.000
	Compression	5	0.24	0.22	0.26		10.0			9.3	0.02	0.000
	Total pathway		**1.12**	1.08	1.16	**1.10**	**119.9**	117.6	122.6	113.4	0.25	0.001
GRCH2	**LNG, central reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.7			1.6	0.12	0.000
	NG Liquefaction	2	0.12				7.8			6.3	0.06	0.000
	Long-distance transport	3	0.11				7.5			7.4	0.00	0.000
	LNG Vaporisation + Distribution	3	0.06				3.2			3.2	0.00	0.000
	Central reforming	4	0.32	0.29	0.34		74.1			73.7	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**0.87**	0.83	0.91	**0.86**	**106.5**	104.5	109.0	100.7	0.22	0.001
GRCH3	**Remote NG, methanol, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.09		5.7			2.0	0.15	0.000
	Methanol synthesis	2	0.57				14.2			14.2	0.00	0.000
	Methanol shipping and distribution	3	0.08				5.3			5.3	0.00	0.000
	On-site reforming	4	0.21	0.20	0.22		84.4			84.4	0.00	0.000
	Hydrogen compression	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**1.12**	1.10	1.16	**1.11**	**118.8**	117.6	121.0	114.3	0.17	0.000

GPLH1a/b Piped NG to central production of liquid hydrogen and road distribution

Here hydrogen is produced by steam reforming of natural gas (pipeline 7 or 4000 km) in a central plant and subsequently liquefied. Liquid hydrogen is transported to the refuelling station by road tanker. Note that this pathway assumes that liquid hydrogen is used as such in the vehicle.

GRLH1 Remote NG to liquid hydrogen transported by sea and distributed by road

Producing hydrogen at the "wellhead" is another option. It does require liquefaction and long-distance transportation of hydrogen which tends to be energy-intensive and would require complex dedicated ships. One attraction might be the possibility to capture all CO_2 at source for e.g. re-injection into the local gas/oil fields. In this case, it is also assumed that liquid hydrogen is used as such in the vehicle.

GRLH2 LNG to central production of liquid hydrogen and road distribution

This is the same as GPLH1 now based on LNG.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPLH1a	**Piped NG, 7000 km, central reforming + liquefaction**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.1			1.8	0.13	0.000
	NG Transport	3	0.26	0.09	0.29		19.8			13.5	0.25	0.001
	NG Distribution (HP)	3	0.01				0.8			0.7	0.00	0.000
	Central reforming	4	0.32	0.28	0.34		73.0			72.6	0.02	0.000
	Hyd liquefaction	4	0.68	0.47	0.88		41.3			36.8	0.16	0.002
	Liquid hyd distribution & delivery	5	0.03				1.7			1.7	0.00	0.000
	Total pathway		**1.33**	1.11	1.44	**1.33**	**141.7**	128.6	148.4	127.1	0.56	0.002
GPLH1b	**Piped NG, 4000 km, central reforming + liquefaction**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.7			1.6	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		9.9			6.3	0.14	0.000
	NG Distribution (HP)	3	0.01				0.8			0.7	0.00	0.000
	Central reforming	4	0.32	0.28	0.34		73.0			72.6	0.02	0.000
	Hyd liquefaction	4	0.62	0.43	0.80		37.0			33.8	0.11	0.002
	Liquid hyd distribution & delivery	5	0.03				1.7			1.7	0.00	0.000
	Total pathway		**1.13**	0.99	1.22	**1.13**	**127.0**	118.5	132.2	116.8	0.39	0.002
GRLH1	**Remote NG reforming + hyd liquefaction + liquid hyd shipping**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.2			1.8	0.14	0.000
	Remote reforming	2	0.39	0.35	0.41		89.8			89.4	0.02	0.000
	Remote hyd liquefaction	2	0.69	0.48	0.90		39.9			37.9	0.06	0.002
	Liquid hyd transport (shipping)	3	0.26	0.23	0.29		1.4			1.3	0.00	0.000
	Liquid hyd distribution & delivery	5	0.04				2.8			2.8	0.00	0.000
	Total pathway		**1.42**	1.31	1.55	**1.42**	**139.1**	132.4	146.7	133.2	0.22	0.002
GRLH2	**LNG, central reforming + liquefaction**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.6			1.6	0.12	0.000
	NG Liquefaction	2	0.11	0.00	0.00		7.6			6.1	0.06	0.000
	LNG Transport (shipping)	3	0.11	0.10	0.12		7.3			7.3	0.00	0.000
	LNG Receipt + Vaporisation	4	0.04				2.4			2.4	0.00	0.000
	Central reforming	4	0.32	0.29	0.34		73.0			72.6	0.02	0.000
	Hyd liquefaction	4	0.67	0.47	0.88		39.7			37.4	0.08	0.002
	Liquid hyd distribution & delivery	5	0.04				2.8			2.8	0.00	0.000
	Total pathway		**1.34**	1.22	1.49	**1.34**	**137.5**	130.6	146.2	130.1	0.27	0.002

8.2 Coal to hydrogen

The pathways described here assume gasification of hard coal (EU-mix origin) followed by processing to a final fuel (see also section 2-6 for electricity pathways).

Pathway code		**KOCH**	
		1	**1C**
Code	Process		
Coal			
KO1	Hard coal provision (EU-mix) (1)	✓	✓
KE1	Electricity from Coal (conv. Boiler)		
KH1	Coal to hydrogen	✓	
KH1C	Coal to hydrogen with CC&S		✓
Hydrogen transport & distribution			
CH1a	Gasous Hyd distribution (pipeline from central plant)	✓	✓
CH3	Gasous Hyd dispensing	✓	✓
Common processes			
Z7a	Electricity (EU-mix, MV)	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓

KOCH1/1C Hard coal to compressed hydrogen (+CCS option)

Gasification is followed by CO shift for hydrogen production. Distribution is through a local pipeline network (50 km average distance). Although coal gasification plants are likely to be very large, the assumption of hydrogen production for only relatively local needs is justified inasmuch as such plants can easily be designed to produce both

hydrogen and e.g. electricity. This is often the case in industrial IGCC projects where there is a need for hydrogen for processing purposes. As full decarbonisation occurs at the production stage CO_2 capture and storage could be an attractive option where suitable geological formations are available within a reasonable distance.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
KOCH1	**Coal EU-mix, gasifier + CO shift**											
	Coal provision	3	0.19				32.3			12.99	0.77	0.001
	Gasifier + CO shift	4	0.99				193.0			193.0	0.00	0.000
	Gaseous Hyd distribution & compression	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**1.40**	1.40	1.40	**1.38**	**234.4**	234.4	234.4	214.4	0.79	0.001
KOCH1C	**Coal EU-mix, gasifier + CO shift, CCS**											
	Coal provision	3	0.22				37.8			15.2	0.90	0.001
	Gasifier + CO shift + CCS	4	1.33				5.8			5.8	0.00	0.000
	Gaseous Hyd distribution & compression	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**1.77**	1.77	1.77	**1.76**	**52.7**	52.7	52.7	29.5	0.92	0.001

8.3 Wood to hydrogen

Pathway code		**WFCH**		**WFLH**	**WWCH**		**BLCH**
		1	**2**	**1**	**1**	**2**	**1**
Code	Process						
Coal							
KO1	Hard coal provision (EU-mix) (1)						
KE1	Electricity from Coal (conv. Boiler)						
KH1	Coal to hydrogen						
KH1C	Coal to hydrogen with CC&S						
Wood (farmed)							
WF1	Wood farming and chipping	✓	✓	✓			
Wood (waste)							
WW1	Forest residuals to wood chips				✓	✓	✓
Wood transport & processing (all sources)							
WC2a	Wood chips road transport, 50 km		✓	✓		✓	✓
WC2b	Wood chips road transport, 12 km	✓			✓		
WC2c	Coastal/river shipping wood chips (200MW plant)					✓	
W3d	Wood to hydrogen: gasification, 200MW		✓	✓		✓	
W3e	Wood to hydrogen: gasification, 10MW	✓			✓		
Wood waste via black liquor							
BLH	Wood waste to hydrogen via black liquor						✓
Hydrogen transport & distribution							
CH1a	Gasous Hyd distribution (pipeline from central plant)		✓			✓	
CH1b	Gasous Hyd distribution (trucking from central plant)						
CH2	Liquid Hyd compression/vaporisation			✓			
CH3	Gasous Hyd dispensing	✓	✓		✓	✓	
Common processes							
Z71	HV+MV losses	✓	✓				
Z72	LV losses	✓					
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓

WWCH1/2 Wood waste (200/10 MW) to compressed hydrogen

These pathways use the wood gasification route to hydrogen either small or large scale. The latter is notably more efficient. In the large scale case distribution is assumed to be by pipeline.

WFCH1//2 Farmed wood (200/10 MW) to compressed hydrogen

The same as above, with farmed wood (which requires slightly more energy).

WFLH1 Farmed wood (200 MW) to liquid hydrogen

Hydrogen from the large scale plant is liquefied and transported by road tanker.

BLCH1 Waste wood to compressed hydrogen via black liquor route

The black liquor gasification route described in *section 2-5* can be equally applied to hydrogen production.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
WFCH1	**Farmed wood , on-site gasification, 10 MW (biomass)**											
	Wood farming and chipping	1	0.08				4.7			2.3	0.00	0.01
	Road transport	2	0.00				0.2			0.2	0.00	0.00
	On-site gasifier (10 MW) + CO shift	4	0.94				0.7			-0.6	0.01	0.00
	On-site delivery	5	0.22				9.1			8.5	0.02	0.00
	Total pathway		**1.24**	1.15	1.35	**0.22**	**14.8**	13.1	27.2	10.4	0.03	0.012
WFCH2	**Farmed wood, large scale gasification, 200 MW (biomass)**											
	Wood farming	1	0.06				3.6			1.8	0.00	0.006
	Road transport	3	0.01				0.5			0.5	0.00	0.000
	Med scale gasifier (200 MW) + CO shift	4	0.68				0.5			0.3	0.00	0.001
	Gaseous Hyd distribution & delivery	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**0.97**	0.89	1.05	**0.23**	**13.8**	13.1	25.2	11.1	0.02	0.007
WFLH1	**Farmed wood, large scale gasification, 200 MW (biomass), liquefaction**											
	Wood farming	1	0.06				3.5			1.7	0.00	0.006
	Road transport	3	0.01				1.0			0.8	0.00	0.001
	Med scale gasifier (200 MW) + CO shift	4	0.67				1.9			1.1	0.00	0.003
	Hyd liquefaction	4	0.74				0.8			0.8	0.00	0.000
	Liquid hyd distribution & delivery	5	0.02				0.1			0.1	0.00	0.000
	Total pathway		**1.50**	1.37	1.67	**0.07**	**7.5**	6.6	21.2	4.6	0.00	0.009
WWCH1	**Wood waste, on-site gasification, 10 MW (biomass)**											
	Waste collection and chipping	1	0.06				0.7			0.7	0.00	0.000
	Transport (road + sea)	3	0.00				0.2			0.2	0.00	0.000
	On-site gasifier (10 MW) + CO shift	4	0.94				0.7			-0.6	0.01	0.003
	On-site delivery	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**1.22**	1.11	1.31	**0.19**	**10.7**	10.7	10.8	8.8	0.03	0.004
WWCH2	**Wood waste, large scale gasification, 200 MW (biomass)**											
	Waste collection and chipping	1	0.04				0.5			0.5	0.00	0.000
	Transport (road + sea)	3	0.03				2.1			2.0	0.00	0.000
	Med scale gasifier (200 MW) + CO shift	4	0.68				0.3			0.3	0.00	0.000
	Gaseous Hyd distribution & delivery	5	0.22				9.1			8.5	0.0	0.0
	Total pathway		**0.97**	0.89	1.05	**0.23**	**12.1**	12.0	12.2	11.3	0.03	0.000
BLCH1	**Waste wood via black liquor**											
	Waste collection and chipping	1	0.04				0.5			0.4	0.00	0.000
	Transport (road)	3	0.01				0.4			0.4	0.00	0.000
	Black liquor gasification + CO shift	4	0.25				0.0			0.0	0.00	0.000
	Gaseous Hyd distribution & delivery	5	0.22				9.1			8.5	0.0	0.0
	Total pathway		**0.51**	0.47	0.55	**0.20**	**10.0**	10.0	10.1	9.4	0.02	0.000

8.4 Electricity to hydrogen (electrolysis)

An electrolyser can obviously make use of any electricity source. It can be a large central plant or a small on-site installation. From a central plant hydrogen can be piped to the refuelling station and compressed or liquefied and transported by road. From an on-site plant hydrogen must be compressed. This potentially makes for a very large number of combinations out of which we have only selected a few for illustration.

Pathway code		GPEL				GREL	KOEL			WFEL		WDEL	NUEL	EMEL	
		1a	1b	1b	1b	1	1	1	1	2	3	1	1	1	1
Code	Process	CH1	CH1	CH2	LH1	CH1	CH1	CH2	LH1	CH1	CH1	CH1	CH1	CH1	LH1
GG1	NG Extraction & Processing	✓	✓	✓	✓	✓									
NG from pipeline															
GP1a	Russian quality, 7000 km	✓													
GP1b	Average quality, 4000 km		✓	✓	✓										
LNG production & transport															
GR1	NG Liquefaction					✓									
GR2	LNG terminal (loading)					✓									
GR3	LNG transport (average of two distances)					✓									
GR4	LNG terminal (unloading)					✓									
NG distribution															
GR5	LNG vaporisation					✓									
GG3	NG trunk distribution					✓									
NG common processes															
GG2	Electricity generation from NG (CCGT)	✓	✓	✓	✓	✓									
Coal															
KO1	Hard coal provision (EU-mix) (1)						✓	✓	✓						
KE1	Electricity from Coal (conv. Boiler)						✓	✓	✓						
Wood (farmed)															
WF1	Wood farming and chipping									✓	✓				
Wood transport & processing (all sources)															
WC2a	Wood chips road transport, 50 km										✓				
WC2b	Wood chips road transport, 12 km									✓					
W3c	Wood to electricity: gasification, 10MW									✓					
W3h	Wood cofiring in coal power station										✓				
Wind															
DE	Electricity from wind											✓			
Nuclear															
NE1	Nuclear fuel provision												✓		
NE2	Electricity from nuclear												✓		
Electrolysis															
EK1	On-site electrolyser	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓
EK2	Central electrolyser			✓				✓	✓						
Hydrogen transport & distribution															
CH1a	Gasous Hyd distribution (pipeline from central plant)			✓				✓							
CH3	Gasous Hyd dispensing	✓	✓			✓	✓			✓	✓	✓	✓	✓	
LH1	Hyd liquefaction				✓				✓						✓
LH2	Liquid Hyd long-distance transport								✓						
LH3	Liquid Hyd distribution and dispensing				✓				✓						✓
Common processes															
Z1	Diesel production				✓										✓
Z2	Road tanker				✓										✓
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

GPEL1a/b CH1 Piped NG to compressed hydrogen via on-site electrolysis

These two pathways illustrate the use of natural gas as a source of electricity and the impact of the gas origin.

GPEL1b CH1/CH2/LH1 Piped NG to compressed or liquid hydrogen via electrolysis

These three pathways illustrate the relative impacts of the plant location and scale and of the hydrogen delivery mode.

GREL1 CH1 LNG to compressed hydrogen via on-site electrolysis

This pathway further illustrates the impact of the gas origin, to be compared to GPEL1 above.

WFEL2/3 CH1 Farmed wood to compressed hydrogen via on-site electrolysis

Pathway 2 uses the large scale gasifier (200 MW) followed by a CCGT for electricity generation and on-site electrolysis. Pathway 3 is the same with the electricity generated by a conventional boiler + steam turbine plant.

WDEL1 CH1 Wind to compressed hydrogen via central electrolysis

This pathway assumes central electrolysis and hydrogen distribution as it is mostly applicable to "stranded electricity" that cannot be fed into the grid.

EMEL1 CH1/LH1 EU-mix electricity to compressed/liquid hydrogen via on-site electrolysis

NUEL1 CH1 Nuclear to compressed hydrogen via on-site electrolysis

KOEL1 CH1/CH2/LH1 Hard coal to compressed/liquid hydrogen via on-site/central electrolysis

This is an indirect route to hydrogen to be compared to KOCH1 in section 2-5.

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
GPEL1a/CH1	**Piped NG 7000 km, CCGT, on-site electrolysis**											
	NG Extraction & Processing	1	0.08	0.04	0.17		11.2			3.9	0.29	0.000
	NG Transport	3	0.57	0.19	0.63		43.6			29.6	0.54	0.001
	NG Distribution (HP)	3	0.03				1.7			1.6	0.00	0.000
	Power generation (CCGT)	4	1.31	1.24	1.37		162.1			159.6	0.01	0.008
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)	4	0.55	0.53	0.55		0.0			0.0	0.00	0.000
	Compression	5	0.16				8.6			7.7	0.03	0.000
	Total pathway		**2.72**	2.30	2.87	**2.72**	**227.1**	202.1	236.1	202.3	0.88	0.009
GPEL1b/CH1	**Piped NG 4000 km, CCGT, on-site electrolysis**											
	NG Extraction & Processing	1	0.08	0.04	0.15		10.2			3.6	0.27	0.000
	NG Transport	3	0.27	0.09	0.30		21.8			13.9	0.31	0.001
	NG Distribution (HP)	3	0.03				1.7			1.6	0.00	0.000
	Power generation (CCGT)	4	1.31	1.24	1.37		162.1			159.6	0.01	0.008
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Compression	5	0.15				7.7			7.0	0.02	0.000
	Total pathway		**2.40**	2.15	2.58	**2.40**	**203.5**	188.7	214.0	185.7	0.61	0.009
GPEL1b/CH2	**Piped NG, 4000 km, CCGT, central electrolysis, pipe**											
	NG Extraction & Processing	1	0.08	0.04	0.15		10.1			3.5	0.26	0.000
	NG Transport	3	0.27	0.09	0.30		21.6			13.8	0.30	0.001
	NG Distribution (HP)	3	0.03				1.6			1.6	0.00	0.000
	Power generation (CCGT)	4	1.30	1.23	1.36		161.0			158.5	0.01	0.007
	Electricity distribution (HV)	4	0.02				0.0			0.0	0.00	0.000
	Electrolysis (central)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Gaseous hyd distribution & comp.	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**2.45**	2.19	2.65	**2.44**	**203.5**	188.0	215.3	185.9	0.60	0.009
GPEL1b/LH1	**Piped NG 4000 km, CCGT, central electrolysis, liquefaction**											
	NG Extraction & Processing	1	0.08	0.04	0.15		10.0			3.5	0.26	0.000
	NG Transport	3	0.26	0.09	0.29		21.3			13.6	0.30	0.001
	NG Distribution (HP)	3	0.03				1.6			1.6	0.00	0.000
	Power generation (CCGT)	4	1.28	1.21	1.33		158.6			156.1	0.01	0.007
	Electricity distribution (HV)	4	0.02				0.0			0.0	0.00	0.000
	Electrolysis (central)	4	0.54	0.52	0.56		0.0			0.0	0.00	0.000
	Hyd liquefaction	4	0.62	0.55	0.69		37.2			33.9	0.11	0.002
	Liquid hyd distribution & delivery	1	0.04				2.8			2.8	0.00	0.000
	Total pathway		**2.86**	2.59	3.05	**2.86**	**231.5**	215.8	242.4	211.5	0.69	0.010
GREL1/CH1	**LNG, CCGT, on-site electrolysis**											
	NG Extraction & Processing	1	0.08	0.04	0.15		10.2			3.6	0.27	0.000
	NG Liquefaction	2	0.25				16.9			13.6	0.13	0.001
	Long-distance transport	3	0.25				16.2			16.1	0.00	0.000
	LNG Vaporisation + Distribution (HP)	3	0.13	0.12	0.13		7.0			6.9	0.00	0.000
	Power generation (CCGT)	4	1.31				162.1			159.6	0.01	0.008
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Compression	5	0.16				8.3			7.8	0.02	0.000
	Total pathway		**2.75**	2.49	2.97	**2.75**	**220.8**	205.9	234.0	207.5	0.42	0.009

		Standard step	Energy expended (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			CO_2	CH4	N_2O
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g/MJ	g/MJ	g/MJ
KOEL1/CH1	**Coal electricity, on-site electrolysis**											
	Coal provision (EU-mix)	3	0.34				59.1			23.7	1.40	0.001
	Coal power station	4	2.07				357.9			352.4	0.01	0.018
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.0	0.0
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.0	0.0
	Compression	5	0.18				16.4			14.8	0.1	0.0
	Total pathway		**3.17**	2.62	3.54	**3.16**	**433.4**	376.6	471.8	390.9	1.46	0.020
KOEL1/CH2	**Coal electricity, central electrolysis**											
	Coal provision (EU-mix)	3	0.34				58.6			23.6	1.39	0.001
	Coal power station	4	2.06				355.5			349.9	0.01	0.018
	Electricity distribution (MV)	4	0.02				0.0			0.0	0.0	0.0
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.0	0.0
	Compression	5	0.22				9.1			8.5	0.0	0.0
	Total pathway		**3.19**	2.70	3.60	**3.17**	**423.2**	372.9	466.0	382.0	1.42	0.019
KOEL1/LH1	**Coal electricity, central electrolysis, liquefaction**											
	Coal provision (EU-mix)	3	0.34				57.8			23.2	1.37	0.001
	Coal power station	4	2.03				350.2			344.8	0.01	0.018
	Electricity distribution (MV)	4	0.02				0.0			0.0	0.0	0.0
	Electrolysis (central)	4	0.54	0.52	0.56		0.0			0.0	0.0	0.0
	Hyd liquefaction	4	0.77	0.68	0.85		79.6			71.8	0.3	0.0
	Liquid hyd distribution & delivery	5	0.04				2.7			2.7	0.0	0.0
	Total pathway		**3.73**	3.20	4.08	**3.72**	**490.3**	436.6	526.1	442.5	1.65	0.022
WFEL2/CH1	**Farmed wood, CCGT, on-site electrolysis**											
	Wood harvesting and chipping	1	0.14				8.0			3.9	0.00	0.013
	Mixed transport	3	0.01				1.1			1.1	0.00	0.000
	Gasification (200 MW)+ CCGT	4	1.71				2.2			0.0	0.04	0.004
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)		0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Compression	5	0.16				0.4			0.2	0.00	0.001
	Total pathway		**2.60**	2.41	2.82	**0.08**	**11.8**	9.7	32.6	5.3	0.05	0.018
WFEL3/CH1	**Farmed wood, conv. power plant, on-site electrolysis**											
	Wood harvesting and chipping	1	0.21				12.0			5.9	0.01	0.020
	Mixed transport	3	0.02				1.7			1.7	0.00	0.000
	Conv power plant (200 MW), cond. turbine	4	3.39				15.1			0.0	0.13	0.039
	Electricity distribution (MV)	4	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Compression	5	0.23				1.1			0.3	0.01	0.002
	Total pathway		**4.43**	4.08	4.74	**0.11**	**29.9**	26.1	58.9	7.9	0.14	0.062
WDEL1/CH2	**Wind offshore, central electrolysis**											
	Wind offshore	1	0.00				0.0			0.0	0.00	0.000
	Electricity distribution (MV)	3	0.02				0.0			0.0	0.00	0.000
	Electrolysis (central)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Gaseous hyd distribution & comp.	5	0.22				9.1			8.5	0.02	0.000
	Total pathway		**0.79**	0.74	0.86	**0.19**	**9.1**	9.1	9.1	8.5	0.02	0.000
NUEL1/CH1	**Nuclear electricity, on-site electrolysis**											
	Nuclear fuel provision	3	0.96				6.3			5.9	0.01	0.000
	Nuclear power station	4	3.26				0.5			0.5	0.00	0.000
	Electricity distribution (MV)	4	0.01				0.0			0.0	0.0	0.0
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.0	0.0
	Compression	5	0.25				0.3			0.2	0.0	0.0
	Total pathway		**5.03**	4.75	5.27	**5.02**	**7.0**	6.7	7.4	6.6	0.01	0.000
EMEL1/CH1	**EU-mix electricity, on-site electrolysis**											
	EU-mix power generation	1	2.85				201.2			187.3	0.46	0.008
	Electricity distribution (MV)	3	0.03				0.0			0.0	0.00	0.000
	Electrolysis (on-site)	4	0.55	0.53	0.57		0.0			0.0	0.00	0.000
	Compression	5	0.19				7.9			7.4	0.02	0.000
	Total pathway		**3.62**	3.43	3.81	**3.39**	**209.1**	200.4	217.5	194.6	0.47	0.009
EMEL1/LH1	**EU-mix electricity, central electrolysis, liquefaction**											
	EU-mix power generation	1	2.79				196.9			183.2	0.45	0.008
	Electricity distribution (MV)	3	0.02				0.0			0.0	0.0	0.0
	Electrolysis (central)	4	0.54	0.52	0.56		0.0			0.0	0.0	0.0
	Hyd liquefaction	4	0.85	0.76	0.95		38.4			35.7	0.1	0.0
	Liquid hyd distribution & delivery	5	0.03				1.7			1.7	0.0	0.0
	Total pathway		**4.22**	3.98	4.43	**3.97**	**237.0**	225.9	246.4	220.7	0.53	0.010

9 Summary of energy and GHG balances

9.1 Oil-based fuels, CBG/CBG

Pathway		Energy expended (MJex/MJ final fuel)											Net GHG emitted (g CO_2eq/MJ final fuel)											
Code	Description	**Total energy**	Fossil energy	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Range				**Total GHG inc. renew comb. CO2 credit**	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Total WTT GHG emitted	Credit for renewable combustion CO_2	Range			
COG1	Conventional gasoline	**0.17**	0.17	0.06		0.01	0.08	0.02	0.15	0.20	0.02	0.03	**14.2**	5.2		0.9	7.0	1.0	14.2		12	16	2	2
COD1	Conventional diesel	**0.20**	0.19	0.06		0.01	0.10	0.02	0.17	0.22	0.03	0.02	**15.9**	5.3		0.9	8.6	1.0	15.9		12	16	4	0
CON1	Conventional naphtha	**0.28**	0.28	0.06		0.05	0.09	0.09	0.12	0.16	0.16	-0.13	**11.4**	5.1		0.9	4.4	1.0	11.4		5	6	6	-5
LRLP1	LPG: imports from remote gas field	**0.12**	0.12	0.05	0.01	0.03		0.03	0.12	0.13	0.00	0.01	**8.0**	3.5	0.3	2.5		1.7	8.0		8	8	0	0
GMCG1	CNG: EU-mix	**0.12**	0.12	0.02		0.02		0.07	0.10	0.15	0.02	0.03	**8.7**	3.3		1.9		3.4	8.7		8	10	1	1
GPCG1a	CNG: Pipeline 7000 km	**0.30**	0.29	0.03		0.19		0.07	0.18	0.34	0.12	0.05	**22.3**	3.8		15.0		3.4	22.3		15	25	7	3
GPCG1b	CNG: Pipeline 4000 km	**0.19**	0.19	0.03		0.09		0.07	0.14	0.22	0.06	0.03	**14.5**	3.5		7.5		3.4	14.5		11	16	3	2
GRCG1	CNG: LNG - Vap - Pipe	**0.31**	0.30	0.03	0.09	0.12		0.07	0.29	0.33	0.02	0.03	**20.2**	3.5	5.8	7.4		3.4	20.2		19	22	1	1
GRCG1C	CNG: LNG, Vap - Pipe - CCS	**0.32**	0.32	0.03	0.10	0.12		0.07	0.29	0.35	0.02	0.03	**16.7**	3.5	2.3	7.4		3.4	16.7		16	18	1	1
GRCG2	CNG: LNG - Road - Vap	**0.26**	0.26	0.03	0.09	0.10		0.05	0.25	0.29	0.01	0.02	**20.8**	3.5	5.8	6.2		5.3	20.8		20	22	1	1
OWCG1	CBG: municipal waste	**0.87**	0.17				0.81	0.06	0.72	1.00	0.15	0.13	**-39.5**				12.7	2.9	15.5	-55.0	-42	-37	3	3
OWCG2	CBG: liquid manure	**0.97**	0.03		0.03		0.88	0.06	0.79	1.14	0.18	0.17	**-140.6**		-94.7		6.3	2.9	-85.6	-55.0	-166	-110	26	30
OWCG3	CBG: dry manure	**0.95**	0.01		0.01		0.88	0.06	0.78	1.11	0.17	0.16	**-54.9**		-9.0		6.3	2.9	0.1	-55.0	-58	-52	3	3
OWCG4	CBG: wheat (whole plant)	**1.20**	0.01	0.17	0.00		0.97	0.06	1.17	1.23	0.03	0.03	**-34.8**	23.4	0.3		-6.4	2.9	20.2	-55.0	-38	-32	4	3
OWCG5	CBG: corn and barley, double cropping	**1.34**	0.03	0.10	0.00		1.17	0.06	1.30	1.36	0.04	0.03	**-31.5**	17.4	0.3		2.9	2.9	23.5	-55.0	-34	-16	3	15

9.2 Ethanol, Ethers, Bio-diesel

Pathway		Energy expended (MJex/MJ final fuel)											Net GHG emitted (g CO_2eq/MJ final fuel)											
Code	Description	**Total energy**	Fossil energy	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Range				**Total GHG inc. renew comb. CO2 credit**	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Total WTT GHG emitted	Credit for renewable combustion CO_2	Range			
SBET1a	EtOH: Sugar beet, pulp to fodder, slops not used	**1.40**	0.55	0.11		0.01	1.25	0.03	1.30	1.50	0.10	0.10	**-33.8**	16.2		1.1	18.7	1.5	37.6	-71.4	-37	-28	3	5
SBET1b	EtOH: Sugar beet, pulp to fodder, slops to biogas	**1.18**	0.34	0.11		0.01	1.03	0.03	1.08	1.28	0.10	0.10	**-47.0**	16.2		1.1	5.5	1.5	24.4	-71.4	-50	-42	3	5
SBET3	EtOH: Sugar beet, pulp to heat /slops to biogas	**0.88**	0.04	0.11		0.01	0.73	0.03	0.79	0.98	0.09	0.11	**-57.6**	16.2		1.1	-5.0	1.5	13.8	-71.4	-60	-52	2	6
WTET1a	EtOH: Wheat, conv NG boiler, DDGS as AF	**1.66**	0.77	0.27		0.03	1.34	0.03	1.64	1.69	0.02	0.02	**-13.0**	39.5		0.6	16.8	1.5	58.4	-71.4	-20	-2	7	11
WTET1b	EtOH: Wheat, conv NG boiler, DDGS as fuel	**1.24**	0.38	0.27		0.03	0.92	0.03	1.22	1.27	0.02	0.03	**-20.3**	39.5		0.6	9.5	1.5	51.1	-71.4	-26	-9	6	11
WTET2a	EtOH: Wheat, NG GT+CHP, DDGS as AF	**1.42**	0.53	0.27		0.03	1.09	0.03	1.40	1.44	0.02	0.02	**-25.0**	39.5		0.6	4.8	1.5	46.4	-71.4	-33	-14	8	11
WTET2b	EtOH: Wheat, NG GT+CHP, DDGS as fuel	**1.00**	0.14	0.27		0.03	0.67	0.03	0.97	1.01	0.02	0.02	**-32.3**	39.5		0.6	-2.6	1.5	39.1	-71.4	-38	-22	6	11
WTET3a	EtOH: Wheat, Lignite CHP, DDGS as AF	**1.49**	0.60	0.27		0.03	1.16	0.03	1.48	1.49	0.00	0.00	**5.0**	39.5		0.6	34.8	1.5	76.4	-71.4	-1	15	6	10
WTET3b	EtOH: Wheat, Lignite CHP, DDGS as fuel	**1.06**	0.21	0.27		0.03	0.74	0.03	1.06	1.07	0.01	0.00	**-2.3**	39.5		0.6	27.5	1.5	69.1	-71.4	-9	10	6	12
WTET4a	EtOH: Wheat, Straw CHP, DDGS as AF	**1.58**	0.16	0.27		0.03	1.25	0.03	1.57	1.58	0.00	0.00	**-47.5**	39.5		0.6	-17.7	1.5	23.9	-71.4	-55	-36	8	11
WTET4b	EtOH: Wheat, Straw CHP, DDGS as fuel	**1.15**	-0.23	0.27		0.03	0.83	0.03	1.15	1.16	0.00	0.01	**-54.8**	39.5		0.6	-25.0	1.5	16.6	-71.4	-61	-43	6	11
WTET5	EtOH: Wheat, DDGS to biogas	**1.10**	0.21	0.27		0.03	0.77	0.03	1.10	1.10	0.00	0.00	**-42.7**	39.5		0.6	-13.0	1.5	28.6	-71.4	-49	-33	6	10
WWET1	EtOH: W Wood	**1.95**	0.28	0.08		0.04	1.81	0.03	1.85	2.05	0.10	0.10	**-52.4**	0.9		3.2	13.3	1.5	19.0	-71.4	-53	-52	0	0
WFET1	EtOH: F wood	**1.96**	0.28	0.11		0.01	1.81	0.03	1.86	2.07	0.09	0.11	**-49.4**	6.3		0.9	13.3	1.5	22.0	-71.4	-52	-32	2	17
STET1	EtOH: Wheat straw	**1.32**	0.10	0.04		0.01	1.24	0.03	1.32	1.32	0.00	0.00	**-62.4**	3.1		0.6	3.7	1.5	9.0	-71.4	-62	-62	0	0
SCET1a	EtOH: Sugar cane (Brazil), HFO credit for excess bagasse	**1.81**	0.04	0.06		0.01	1.63	0.11	1.81	1.82	0.00	0.00	**-57.8**	14.5		0.8	-9.8	8.1	13.6	-71.4	-61	-41	4	17
SCET1b	EtOH: Sugar cane (Brazil), no credit for excess bagasse	**1.96**	0.18	0.06		0.01	1.78	0.11	1.95	1.96	0.00	0.00	**-46.8**	14.5		0.8	1.2	8.1	24.6	-71.4	-50	-30	3	16
GRMB1	MTBE: remote plant	**0.30**	0.30	0.01	0.23	0.05		0.01	0.30	0.31	0.00	0.02	**13.6**	0.9	8.2	4.0		0.4	13.6		13	15	0	1
LREB1	ETBE: imported C4 and wheat ethanol	**0.75**	0.01	0.10		0.01	0.62	0.02	0.74	0.76	0.01	0.01	**-0.9**	14.4		0.2	7.3	1.1	22.9	-23.8	-3	3	2	4
ROFA1	RME: Glycerine as chem, meal as AF	**1.09**	0.36	0.29		0.02	0.76	0.02	0.98	1.18	0.11	0.09	**-34.1**	49.4		0.3	-8.8	1.3	42.1	-76.2	-44	-21	10	13
ROFA2	RME: Glycerine and meal as AF	**1.14**	0.41	0.29		0.02	0.81	0.02	1.04	1.25	0.11	0.11	**-29.0**	49.4		0.3	-3.7	1.3	47.2	-76.2	-38	-15	9	14
ROFA3	RME: Glycerine to biogas, meal as AF	**1.11**	0.37	0.29		0.02	0.78	0.02	1.02	1.20	0.08	0.10	**-30.5**	49.4		0.3	-5.3	1.3	45.7	-76.2	-40	-17	10	14
ROFA4	RME: Glycerine and cake to biogas	**0.70**	-0.02	0.29		0.02	0.36	0.02	0.58	0.80	0.11	0.11	**-48.0**	49.4		0.3	-22.7	1.3	28.2	-76.2	-56	-35	8	13
ROFE1	REE: Glycerine as chem, meal as AF	**1.17**	0.31	0.27		0.02	0.86	0.02	1.07	1.28	0.10	0.11	**-36.1**	47.2		0.3	-8.7	1.3	40.1	-76.2	-45	-24	9	12
ROFE2	REE: Glycerine and meal as AF	**1.22**	0.36	0.27		0.02	0.91	0.02	1.13	1.33	0.10	0.10	**-31.4**	47.2		0.3	-3.9	1.3	44.8	-76.2	-39	-19	8	12
ROFE3	REE: Glycerine to biogas, meal as AF	**1.19**	0.33	0.27		0.02	0.87	0.02	1.10	1.28	0.09	0.09	**-32.8**	47.2		0.3	-5.3	1.3	43.4	-76.2	-41	-21	8	12
ROFE4	REE: Glycerine and cake to biogas	**0.77**	-0.07	0.27		0.02	0.18	0.29			0.77	-0.77	**-50.8**	47.2		0.3	46.8	-68.9	25.4	-76.2			-51	51
SOFA1	SME: Glycerine as chem, meal as AF	**0.93**	0.32	0.20		0.02	0.69	0.02	0.83	1.02	0.10	0.09	**-50.0**	28.0		0.3	-3.4	1.3	26.2	-76.2	-55	-46	5	4
SOFA2	SME: Glycerine and meal as AF	**0.98**	0.37	0.20		0.02	0.74	0.02	0.89	1.07	0.09	0.09	**-44.9**	28.0		0.3	1.7	1.3	31.3	-76.2	-50	-40	5	5
SOFA3	SME: Glycerine to biogas, meal as AF	**0.95**	0.33	0.20		0.02	0.71	0.02	0.87	1.03	0.08	0.08	**-46.5**	28.0		0.3	0.2	1.3	29.7	-76.2	-51	-42	5	5
SOFA4	SME: Glycerine and cake to biogas	**0.58**	-0.01	0.20		0.02	0.34	0.02	0.58	0.59	0.01	0.01	**-61.0**	28.0		0.3	-14.4	1.3	15.2	-76.2	-65	-56	4	5
SYFA1	SYME: Glycerine as chem, mill in EU, meal as AF in Brazil	**2.69**	0.61	0.28		0.19	2.21	0.02	2.67	2.71	0.02	0.02	**-22.9**	56.4		11.9	-16.2	1.3	53.3	-76.2	-72	0	49	22
SYFA1a	SYME: Glycerine as chem, mill in EU, meal as AF in EU	**3.00**	0.92	0.28		0.49	2.21	0.02	2.98	3.02	0.02	0.02	**1.4**	56.4		35.9	-15.9	1.3	77.6	-76.2	-24	24	26	23
SYFA1c	SYME: Glycerine as chem, mill in EU, economic values	**1.37**	0.58	0.16		0.12	1.07	0.02	1.36	1.38	0.01	0.01	**-19.5**	32.7		8.2	14.5	1.3	56.6	-76.2	-33	-6	13	14
SYFA2	SYME: Glycerine as AF, mill in Brazil, meal as AF	**2.74**	0.66	0.28		0.19	2.26	0.02	2.73	2.76	0.01	0.02	**-17.8**	56.4		11.9	-11.1	1.3	58.4	-76.2	-73	3	55	21
SYFA3	SYME: Glycerine to biogas, mill in Brazil, meal as AF	**2.71**	0.62	0.28		0.19	2.22	0.02	2.69	2.72	0.01	0.01	**-19.3**	56.4		11.9	-12.7	1.3	56.9	-76.2	-78	-4	58	15
POFA1a	PME: Glycerine as chem, CH4 emissions from waste	**1.31**	0.27	0.15	0.91	0.05	0.17	0.02	1.30	1.31	0.01	0.01	**-27.8**	16.9	22.0	3.5	4.8	1.3	48.4	-76.2	-33	2	5	30
POFA1b	PME: Glycerine as chem, no CH4 from waste	**1.31**	0.27	0.15	0.91	0.05	0.17	0.02	1.30	1.31	0.01	0.01	**-52.6**	16.9	-2.8	3.5	4.8	1.3	23.6	-76.2	-58	-23	5	29
POFA1c	PME: Glycerine as chem, no CH4 from waste, no heat credit	**1.33**	0.30	0.15	0.94	0.05	0.17	0.02	1.32	1.34	0.01	0.01	**-26.0**	16.9	23.9	3.5	4.8	1.3	50.2	-76.2	-32	0	6	26
POFA2	PME: Glycerine to biogas, CH4 emissions from waste	**1.32**	0.29	0.15	0.91	0.05	0.19	0.02	1.32	1.33	0.01	0.01	**-24.3**	16.9	22.0	3.5	8.3	1.3	51.9	-76.2	-29	2	5	26
ROHY1a	HRO (NExBTL), meal as AF	**1.05**	0.34	0.28		0.02	0.73	0.02	0.95	1.15	0.10	0.10	**-27.3**	48.7		0.3	-6.6	1.2	43.5	-70.8	-36	-14	8	13
ROHY1b	HRO (UOP), meal as AF	**0.92**	0.41	0.25		0.02	0.63	0.02	0.83	1.01	0.09	0.09	**-25.9**	42.9		0.3	0.7	1.2	44.9	-70.8	-33	-13	7	13
ROHY4a	HRO (NExBTL), cake to biogas	**0.66**	-0.03	0.28		0.02	0.33	0.02	0.55	0.75	0.10	0.10	**-44.3**	48.7		0.3	-23.6	1.2	26.6	-70.8	-53	-31	9	13
SOHY1	HSO (NExBTL), meal as AF	**0.89**	0.30	0.19		0.02	0.66	0.02	0.80	1.00	0.09	0.10	**-43.1**	27.7		0.3	-1.3	1.2	27.8	-70.8	-48	-39	5	4
POHY1a	HPO (NExBTL), CH4 from waste	**1.26**	0.26	0.15	0.90	0.04	0.15	0.02	1.26	1.27	0.01	0.01	**-21.2**	16.7	21.7	3.4	6.8	1.2	49.6	-70.8	-27	3	6	24
POHY1b	HPO (NExBTL), no CH4 from waste	**1.26**	0.26	0.15	0.90	0.04	0.15	0.02	1.26	1.27	0.01	0.01	**-45.6**	16.7	-2.7	3.4	6.8	1.2	25.2	-70.8	-50	-17	5	28
POHY1c	HPO (NExBTL), CH4 from waste, no heat credit	**1.29**	0.28	0.15	0.92	0.04	0.15	0.02	1.28	1.30	0.01	0.01	**-19.3**	16.7	23.5	3.4	6.8	1.2	51.5	-70.8	-24	6	4	26

9.3 Synthetic diesel, Methanol, DME

Pathway		Energy expended (MJex/MJ final fuel)											Net GHG emitted (g CO_2eq/MJ final fuel)										
Code	Description	**Total energy**	Fossil energy	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Range				**Total GHG inc. renew comb. CO2 credit**	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Total WTT GHG emitted Credit for renewable combustion CO_2	Range			
GRSD1	Syn-diesel: Rem GTL, Sea, Diesel mix	**0.63**	0.63	0.04	0.54	0.04		0.02	0.57	0.69	0.06	0.06	**22.4**	4.9	13.8	2.7		1.0	22.4		19	26	3	3
GRSD2	Syn-diesel: Rem GTL, Sea, Rail/Road	**0.63**	0.63	0.04	0.54	0.04		0.02	0.59	0.69	0.04	0.06	**22.5**	4.9	13.8	2.7		1.1	22.5		20	26	2	4
GRSD2C	Syn-diesel: Rem GTL, Sea, Rail/Road, CCS	**0.76**	0.76	0.04	0.67	0.04		0.02	0.71	0.82	0.05	0.06	**13.3**	5.3	4.2	2.7		1.1	13.3		10	17	3	3
KOSD1	Syn-diesel: CTL, Diesel mix	**0.97**	0.97	0.17			0.78	0.02	0.89	1.05	0.08	0.08	**130.1**	28.7			100.3	1.1	130.1		122	139	8	8
KOSD1C	Syn-diesel: CTL, CCS, Diesel mix	**1.06**	1.05	0.17			0.86	0.02	0.98	1.13	0.08	0.08	**40.4**	30.0			9.3	1.1	40.4		33	48	8	8
WWSD1	Syn-diesel: W Wood, diesel mix	**1.19**	0.07	0.06		0.04	1.08	0.02	1.08	1.29	0.11	0.10	**-66.0**	0.8		2.9		1.2	4.8	-70.8	-66	-66	0	0
WFSD1	Syn-diesel: F wood, diesel mix	**1.19**	0.06	0.09		0.01	1.08	0.02	1.08	1.29	0.11	0.10	**-64.0**	5.0		0.7		1.2	6.9	-70.8	-65	-51	1	13
BLSD1	Syn-diesel: W Wood, Black liquor	**0.91**	0.04	0.05		0.01	0.83	0.02	0.85	0.96	0.06	0.05	**-68.4**	0.7		0.6		1.2	2.4	-70.8	-68	-68	0	0
GPME1a	MeOH: NG 7000 km, Syn, Rail/Road	**0.84**	0.84	0.04		0.30	0.47	0.03	0.66	0.92	0.18	0.08	**42.1**	5.6		22.9	11.7	1.9	42.1		32	46	10	4
GPME1b	MeOH: NG 4000 km, Syn, Rail/Road	**0.69**	0.69	0.04		0.15	0.47	0.03	0.61	0.73	0.08	0.04	**30.6**	5.2		11.8	11.7	1.9	30.6		26	33	5	2
GRME1	MeOH: Rem Syn, Sea, Rail/Road	**0.61**	0.61	0.04	0.47	0.08		0.03	0.60	0.64	0.01	0.03	**24.2**	4.7	11.7	5.9		1.9	24.2		23	26	1	2
KOME1	MeOH: Coal EU-mix, Cen, Rail/Road	**0.93**	0.93			0.16	0.74	0.03	0.84	1.02	0.09	0.09	**128.2**			28.0	98.3	1.9	128.2		119	137	9	9
WWME1	MeOH: W Wood, Road	**1.07**	0.06	0.06		0.03	0.96	0.02	0.95	1.22	0.12	0.15	**-64.3**	0.7		2.7	0.2	1.1	4.8	-69.1	-65	-64	0	0
WFME1	MeOH: F Wood, Road	**1.07**	0.06	0.08		0.01	0.96	0.02	0.94	1.21	0.13	0.14	**-62.4**	4.7		0.7	0.2	1.1	6.7	-69.1	-64	-50	2	13
BLME1	MeOH: W Wood, Black liquor	**0.59**	0.03	0.05		0.01	0.52	0.02	0.54	0.63	0.05	0.04	**-66.7**	0.6		0.5	0.2	1.1	2.4	-69.1	-67	-67	0	0
GPDE1a	DME: NG 7000 km, Syn, Rail/Road	**0.77**	0.77	0.04		0.29	0.41	0.03	0.57	0.84	0.20	0.07	**39.7**	5.4		22.0	10.6	1.7	39.7		28	44	11	4
GPDE1b	DME: NG 4000 km, Syn, Rail/Road	**0.62**	0.62	0.04		0.14	0.41	0.03	0.54	0.66	0.08	0.04	**28.7**	5.0		11.4	10.6	1.7	28.7		24	31	5	2
GRDE1	DME: Rem Syn, Sea, Rail/Road	**0.53**	0.53	0.03	0.41	0.06		0.03	0.51	0.56	0.02	0.03	**21.1**	4.5	10.6	4.3		1.7	21.1		20	23	1	2
KODE1	DME: Coal EU-mix, Cen, Rail/Road	**0.93**	0.92			0.16	0.74	0.03	0.83	1.01	0.10	0.08	**129.6**			28.0	100.0	1.7	129.6		119	138	10	8
GRDE1C	DME: Rem Syn, Sea, Rail/Road, CCS	**0.54**	0.54	0.03	0.42	0.06		0.03	0.54	0.61	0.00	0.07	**11.1**	4.5	0.6	4.3		1.7	11.1		11	15	0	4
WWDE1	DME: W Wood, Road	**1.07**	0.06	0.06		0.03	0.96	0.02	0.94	1.20	0.13	0.13	**-62.7**	0.7		2.7	0.1	1.0	4.6	-67.3	-63	-63	0	0
WFDE1	DME: F Wood, Road	**1.07**	0.06	0.08		0.01	0.96	0.02	0.93	1.20	0.14	0.13	**-60.8**	4.7		0.7	0.1	1.0	6.5	-67.3	-62	-47	2	13
BLDE1	DME: W Wood, Black liquor	**0.55**	0.03	0.04		0.01	0.49	0.02	0.51	0.60	0.04	0.05	**-65.1**	0.5		0.5	0.1	1.0	2.2	-67.3	-65	-65	0	0

9.4 Hydrogen

Pathway		Energy expended (MJex/MJ final fuel)											Net GHG emitted (g CO_2eq/MJ final fuel)									
Code	Description	**Total energy**	Fossil energy	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Range				**Total GHG inc. renew comb. CO2 credit**	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Total WTT GHG emitted Credit for renewable combustion CO_2	Range			
GMCH1	C-H2, EU-mix, O/S Ref	**0.84**	0.83	0.04		0.05	0.52	0.24	0.81	0.89	0.03	0.05	**105.2**	4.9		3.7	86.6	10.0	105.2	103	108	2	3
GPCH1a	C-H2, NG 7000 km, O/S Ref	**1.11**	1.09	0.04		0.30	0.52	0.24	0.94	1.18	0.17	0.08	**123.2**	5.7		22.9	84.7	10.0	123.2	113	128	10	5
GPCH1b	C-H2, NG 4000 km, O/S Ref	**0.95**	0.94	0.04		0.15	0.52	0.24	0.86	1.00	0.09	0.05	**111.7**	5.2		11.9	84.7	10.0	111.7	107	115	5	3
GPCH2a	C-H2: NG 7000 km, Cen ref, Pipe	**0.86**	0.85	0.04		0.27	0.32	0.22	0.71	0.93	0.14	0.08	**109.3**	5.2		20.9	74.1	9.1	109.3	101	114	8	4
GPCH2b	C-H2: NG 4000 km, Cen Ref, Pipe	**0.72**	0.71	0.04		0.14	0.32	0.22	0.63	0.76	0.08	0.04	**98.8**	4.7		10.8	74.1	9.1	98.8	94	101	5	2
GPCH2bC	C-H2: NG 4000 km, Cen Ref, Pipe, CCS	**0.77**	0.76	0.04		0.14	0.37	0.22	0.69	0.82	0.08	0.05	**37.8**	4.9		11.2	12.5	9.1	37.8	33	40	5	3
GPCH3b	C-H2: NG 4000 km, Cen Ref, Road	**0.72**	0.71	0.04		0.14	0.32	0.22	0.63	0.77	0.09	0.05	**99.7**	4.7		10.8	74.1	10.1	99.7	95	102	5	3
GPLCHb	C-H2: NG 4000 km, Cen Ref, Liq, Road, Vap/comp.	**1.28**	0.71	0.03		0.13	0.94	0.17	1.13	1.36	0.14	0.09	**133.6**	4.7		10.7	110.0	8.3	133.6	125	139	9	5
GRCH1	C-H2: LNG, O/S Ref	**1.12**	1.10	0.04	0.13	0.19	0.52	0.24	1.08	1.16	0.04	0.05	**119.9**	5.2	8.6	11.8	84.5	10.0	119.9	118	123	2	3
GRCH2	C-H2: LNG, Cen Ref, Pipe	**0.87**	0.86	0.04	0.12	0.17	0.32	0.22	0.83	0.91	0.04	0.05	**106.5**	4.7	7.8	10.7	74.1	9.1	106.5	104	109	2	3
GRCH3	C-H2: Rem NG, methanol, O/S Ref	**1.12**	1.11	0.04	0.57	0.08	0.21	0.22	1.10	1.16	0.02	0.04	**118.8**	5.7	14.2	5.3	84.4	9.1	118.8	118	121	1	2
KOCH1	C-H2: Coal EU-mix, cen Ref, Pipe	**1.40**	1.38			0.19	0.99	0.22	1.40	1.40	0.00	0.00	**234.4**			32.3	193.0	9.1	234.4	234	234	0	0
KOCH1C	C-H2: Coal EU-mix, cen Ref, Pipe, CCS	**1.77**	1.76			0.22	1.33	0.22	1.77	1.77	0.00	0.00	**52.7**			37.8	5.8	9.1	52.7	53	53	0	0
WWCH1	C-H2: W Wood, O/S gasif	**1.22**	0.19	0.06		0.00	0.94	0.22	1.12	1.33	0.10	0.11	**10.7**	0.7		0.2	0.7	9.1	10.7	11	11	0	0
WWCH2	C-H2: W Wood, Cen gasif, Pipe	**0.97**	0.23	0.04		0.03	0.68	0.22	0.90	1.05	0.07	0.08	**12.1**	0.5		2.1	0.3	9.1	12.1	12	12	0	0
BLCH1	C-H2: W Wood, Black liquor	**0.51**	0.20	0.04		0.01	0.25	0.22	0.47	0.55	0.04	0.04	**10.0**	0.5		0.4		9.1	10.0	10	10	0	0
WFCH1	C-H2: W Wood, O/S gasif	**1.24**	0.22	0.08		0.00	0.94	0.22	1.14	1.34	0.11	0.10	**14.8**	4.7		0.2	0.7	9.1	14.8	13	28	2	13
WFCH2	C-H2: F Wood, Cen gasif, pipe	**0.97**	0.23	0.06		0.01	0.68	0.22	0.89	1.05	0.07	0.08	**13.8**	3.6		0.5	0.5	9.1	13.8	13	24	1	10
GPEL1a/CH1	C-H2: NG 7000 km, CCGT, O/S Ely	**2.72**	2.72	0.08		0.59	1.88	0.16	2.30	2.87	0.42	0.15	**227.1**	11.2		45.2	162.1	8.6	227.1	202	236	25	9
GPEL1b/CH1	C-H2: NG 4000 km, CCGT, O/S Ely	**2.40**	2.40	0.08		0.30	1.88	0.15	2.15	2.58	0.25	0.18	**203.5**	10.2		23.4	162.1	7.7	203.5	189	214	15	11
GPEL1b/CH2	C-H2: NG 4000 km, CCGT, Cen Ely, Pipe	**2.45**	2.44	0.08		0.29	1.86	0.22	2.19	2.65	0.26	0.20	**203.5**	10.1		23.3	161.0	9.1	203.5	188	215	16	12
GREL1/CH1	C-H2: LNG, O/S Ely	**2.75**	2.75	0.08		0.63	1.88	0.16	2.49	2.97	0.25	0.23	**220.8**	10.2		40.1	162.1	8.3	220.8	206	234	15	13
WFEL2/CH1	C-H2: F Wood, 200 MW gasif, CCGT, O/S Ely	**2.60**	0.08	0.14		0.01	2.29	0.16	2.41	2.82	0.19	0.22	**11.8**	8.0		1.1	2.2	0.4	11.8	10	33	2	21
WFEL3/CH1	C-H2: F Wood, Conv power, O/S Ely	**4.43**	0.11	0.21		0.02	3.97	0.23	4.08	4.74	0.34	0.32	**29.9**	12.0		1.7	15.1	1.1	29.9	26	59	4	29
EMEL1/CH1	C-H2: Elec EU-mix, O/S Ely	**3.62**	3.39				3.43	0.19	3.43	3.81	0.19	0.19	**209.1**				201.2	7.9	209.1	200	218	9	8
KOEL1/CH1	C-H2: Elec coal EU-mix, O/S Ely	**3.17**	3.16			0.34	2.65	0.18	2.62	3.54	0.55	0.37	**426.2**			59.1	352.4	14.8	426.2	377	472	50	46
KOEL1/CH2	C-H2: Elec coal EU-mix, Cen ely, Pipe	**3.19**	3.17			0.34	2.62	0.22	2.70	3.60	0.49	0.41	**417.1**			58.6	349.9	8.5	417.1	373	466	44	49
NUEL1/CH1	C-H2: Elec nuclear, O/S Ely	**5.03**	5.02			0.96	3.82	0.25	4.75	5.27	0.27	0.24	**7.0**			6.3	0.5	0.3	7.0	7	7	0	0
WDEL1/CH2	C-H2: Wind, Cen Ely, Pipe	**0.79**	0.19			0.02	0.55	0.22	0.74	0.86	0.05	0.07	**9.1**					9.1	9.1	9	9	0	0
GPLH1a	L-H2:NG 7000 km, Cen Ref, Liq, Road	**1.33**	1.33	0.04		0.27	0.32	0.71	1.11	1.44	0.22	0.11	**141.7**	5.1		20.6	73.0	43.0	141.7	129	148	13	7
GPLH1b	L-H2: NG 4000 km, Cen Ref, Liq, Road	**1.13**	1.13	0.03		0.13	0.32	0.65	0.99	1.22	0.14	0.09	**127.0**	4.7		10.7	73.0	38.7	127.0	119	132	8	5
GRLH1	L-H2: Rem Ref, Liq, Sea, Road	**1.42**	1.42	0.04	1.08	0.26		0.04	1.31	1.55	0.12	0.13	**139.1**	5.2	129.7	1.4		2.8	139.1	132	147	7	8
GRLH2	L-H2: LNG, Cen Ref, Liq, Road	**1.34**	1.34	0.03	0.11	0.16	0.32	0.72	1.22	1.49	0.12	0.15	**137.5**	4.6	7.6	9.7	73.0	42.5	137.5	131	146	7	9
WFLH1	L-H2: F Wood, Cen gasif, Liq, Road	**1.50**	0.07	0.06		0.01	1.41	0.02	1.35	1.67	0.15	0.17	**7.5**	3.5		1.0	2.8	0.1	7.5	7	19	1	12
GPEL1b/LH1	L-H2: NG 4000 km, CCGT, Cen Ely, Liq, Road	**2.86**	2.86	0.08		0.29	1.83	0.66	2.59	3.05	0.27	0.19	**231.5**	10.0		22.9	158.6	40.0	231.5	216	242	16	11
EMEL1/LH1	L-H2: Elec EU-mix, Cen Ely, Liq, Road	**4.22**	3.97				3.35	0.88	3.98	4.43	0.24	0.21	**237.0**				196.9	40.1	237.0	226	246	11	9
KOEL1/LH1	L-H2: Elec coal EU-mix, Cen Ely, Liq, Road	**3.73**	3.72			0.34	3.35	0.04	3.20	4.08	0.53	0.35	**477.0**			57.8	416.6	2.7	477.0	437	526	40	49

9.5 Heat and power

Pathway		Energy expended (MJex/MJ final fuel)											Net GHG emitted (g CO_2eq/MJ final fuel)										
Code	Description	**Total energy**	Fossil energy	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Range				**Total GHG inc. renew comb. CO_2 credit**	Production & conditioning at source	Transformation at source	Transportation to market	Transformation near market	Conditioning & distribution	Total WTT GHG emitted	Credit for renewable combustion CO_2	Range			
KOEL1	Elec:EU-mix Coal conv.	**1.59**	1.58	0.22			1.34	0.03	1.28	1.79	0.31	0.20	**269.0**	38.1			230.9		269.0		237	289	32	20
KOEL2	Elec:EU-mix Coal IGCC	**1.35**	1.34	0.20			1.12	0.03	1.25	1.45	0.10	0.11	**241.5**	34.5			207.0		241.5		232	253	10	11
GPEL1a	Elec: NG 7000 km, CCGT	**1.31**	1.31	0.05		0.38	0.84	0.03	1.09	1.39	0.22	0.08	**141.0**	7.2		29.2	104.6		141.0		128	146	13	5
GPEL1b	Elec: NG 4000 km, CCGT	**1.11**	1.11	0.05		0.19	0.84	0.03	0.96	1.20	0.15	0.09	**126.3**	6.6		15.1	104.6		126.3		117	131	9	5
GPEL1bC	Elec: NG 4000 km, CCGT + CCS	**1.47**	1.47	0.06		0.22	1.16	0.03	1.30	1.57	0.17	0.10	**37.8**	7.7		17.7	12.5		37.8		28	44	10	6
GPHEL1aC	Elec: NG 7000 km, Hydrogen CCGT + CCS	**2.00**	2.00	0.07		0.50	1.40	0.03	1.67	2.07	0.33	0.07	**60.7**	9.3		37.9	13.4		60.7		42	65	19	4
GPHEL1bC	Elec: NG 4000 km, Hydrogen CCGT + CCS	**1.74**	1.74	0.06		0.25	1.40	0.03	1.55	1.86	0.19	0.12	**41.6**	8.5		19.6	13.4		41.6		30	49	12	7
GREL1	Elec: LNG, CCGT	**1.33**	1.33	0.05	0.16	0.24	0.84	0.03	1.21	1.46	0.11	0.13	**137.0**	6.6	10.9	15.0	104.6		137.0		131	145	6	8
WWEL1	Elec: W Wood, 10 MW gasif	**1.24**	0.05	0.06		0.04	1.11	0.03	1.16	1.34	0.08	0.10	**5.2**	0.8		3.0	1.4		5.2		5	6	0	0
WWEL2	Elec: W Wood, 200 MW gasif	**2.00**	0.02	0.09		0.00	1.88	0.03	1.90	2.10	0.10	0.11	**3.2**	1.1		0.2	1.9		3.2		3	3	0	0
WWEL3	Elec: W Wood, Conv power	**2.01**	0.03	0.09		0.01	1.88	0.03	1.90	2.12	0.11	0.11	**4.0**	1.1		1.0	1.9		4.0		4	4	0	0
WWEL4	Elec: W Wood, Coal co-firing	**1.48**	0.05	0.07		0.04	1.34	0.03	1.16	1.72	0.32	0.24	**7.7**	0.9		3.3	3.6		7.7		7	8	1	0
WFEL1	Elec: F Wood, 200 MW gasif	**1.24**	0.05	0.09		0.01	1.11	0.03	1.15	1.35	0.09	0.11	**7.3**	5.1		0.7	1.4		7.3		6	19	2	12
WFEL2	Elec: F Wood, 10 MW gasif	**2.03**	0.05	0.12		0.00	1.88	0.03	1.92	2.15	0.11	0.12	**9.2**	7.0		0.2	1.9		9.2		7	27	2	18
WFEL3	Elec: F Wood, Conv power	**2.37**	0.07	0.14		0.01	2.19	0.03	2.20	2.53	0.16	0.16	**18.5**	7.7		1.1	9.7		18.5		16	38	2	20
WFEL4	Elec: F Wood, Coal co-firing	**1.48**	0.05	0.10		0.01	1.34	0.03	1.12	1.70	0.35	0.22	**10.1**	5.7		0.8	3.6		10.1		8	25	2	15
EMEL1	Elec: EU-mix	**1.87**	1.73				1.84	0.03	1.87	1.87	0.00	0.00	**129.8**				129.8		129.8		130	130	0	0
WDEL1	Elec: Wind offshore	**0.03**						0.03	0.03	0.03	0.00	0.00												
NUEL1	Elec: Nuclear	**2.74**	2.74	0.62			2.09	0.03	2.66	2.82	0.08	0.08	**4.4**	4.1			0.3		4.4		4	5	0	0
OWEL1a	Elec: Biogas ex municipal waste, local	**3.20**	-0.08				3.19	0.01	2.91	3.57	0.29	0.37	**7.7**				7.7		7.7		7	8	1	1
OWEL1b	Elec: Biogas ex municipal waste, large	**2.39**	0.21				2.36	0.03	2.10	2.68	0.29	0.29	**27.9**				27.9		27.9		22	33	6	5
OWEL2a	Elec: Biogas ex liquid manure, local	**3.06**	0.01		0.06		2.99	0.01	2.74	3.40	0.33	0.33	**-187.2**		-198.0		10.8		-187.2		-244	-123	56	65
OWEL2b	Elec: Biogas ex liquid manure, large	**2.56**	-0.06		0.05		2.48	0.03	2.24	2.88	0.33	0.32	**-161.3**		-177.2		15.9		-161.3		-209	-107	48	54
OWEL3a	Elec: Biogas ex dry manure, local	**3.02**	-0.03		0.02		2.99	0.01	2.72	3.32	0.30	0.30	**-8.0**		-18.8		10.8		-8.0		-14	-2	6	6
OWEL3b	Elec: Biogas ex dry manure, large	**2.53**	-0.09		0.02		2.48	0.03	2.21	2.84	0.32	0.31	**-1.0**		-16.8		15.9		-1.0		-6	5	5	6
BLEL1	Elec: Black liquor	**0.18**	0.01	0.03		0.01	0.11	0.03	0.15	0.22	0.03	0.04	**0.4**			0.4			0.4		1	1	0	0
COHT1	Heat: Heating oil dom. boiler	**1.37**	1.37	0.07		0.01	0.11	1.18	1.00	1.00	0.37	-0.37	**101.8**	5.9		1.0	9.6	85.3	101.8				102	-102
COHT2	Heat: Heating oil ind. boiler	**1.39**	1.38	0.07		0.01	0.11	1.19	1.00	1.00	0.39	-0.39	**100.6**	4.1		1.0	9.6	86.0	100.6		98	103	3	2
GPHT1a	Heat: NG 7000 km, dom. boiler	**1.28**	1.28	0.03		0.19		1.06	0.17	0.33	1.11	-0.94	**76.6**	3.8		15.0		57.7	76.6		70	80	7	3
GPHT1b	Heat: NG 4000 km, dom. boiler	**1.17**	1.17	0.03		0.09		1.05	0.12	0.20	1.05	-0.97	**68.8**	3.5		7.5		57.7	68.8		66	70	3	1
GPHT2a	Heat: NG 7000 km, ind. boiler	**1.43**	1.43	0.03		0.22		1.18	0.28	0.49	1.15	-0.94	**85.8**	4.3		16.7		64.8	85.8		77	89	9	3
GPHT2b	Heat: NG 4000 km, ind. boiler	**1.31**	1.31	0.03		0.10		1.18	0.25	0.34	1.06	-0.97	**77.1**	3.9		8.3		64.8	77.1		74	79	3	2
GRHT1	Heat: LNG dom. boiler	**1.29**	1.29	0.03	0.09	0.09		1.09	0.28	0.31	1.01	-0.98	**74.4**	3.5	5.8	5.6		59.4	74.4		74	76	1	1
GRHT2	Heat: LNG ind. boiler	**1.44**	1.44	0.03	0.10	0.10		1.22	0.43	0.47	1.01	-0.97	**83.2**	3.9	6.5	6.2		66.6	83.2		82	85	1	1
OWHT1	Heat: Municipal waste to heat	**0.86**	0.15				0.81	0.05	0.72	1.01	0.14	0.16	**16.2**				-42.3	58.6	16.2		13	19	3	3
OWHT2	Heat: Liquid manure to heat	**0.95**	0.01				0.90	0.05	0.79	1.11	0.16	0.16	**-84.9**				-143.4	58.6	-84.9		-113	-56	29	29
OWHT3	Heat: Dry manure to heat	**0.93**	-0.01				0.88	0.05	0.76	1.08	0.17	0.15	**0.8**				-57.7	58.6	0.8		-2	4	3	3
WWHT1	Heat: Waste wood dom.c boiler	**0.33**	0.10	0.04		0.01	0.09	0.20	0.29	0.38	0.04	0.04	**5.5**	0.4		0.4		4.6	5.5		5	6	0	0
WFHT1	Heat: Farmed wood dom. boiler	**0.35**	0.11	0.05		0.01	0.09	0.20	0.31	0.39	0.04	0.04	**7.9**	2.9		0.4	0.0	4.6	7.9		7	15	1	7
WWHT2	Heat: Waste wood ind. boiler	**0.27**	0.07	0.03		0.01		0.23	0.24	0.31	0.04	0.04	**3.7**	0.4		0.4		2.8	3.7		4	4	0	0
WFHT2	Heat: Farmed wood ind. boiler	**0.29**	0.08	0.05		0.01		0.23	0.25	0.33	0.04	0.04	**6.1**	2.8		0.4		2.8	6.1		5	13	1	7
GPEH1a	CHP: NG 7000 km, CCGT	**0.36**	0.36	0.07		0.49	-0.23	0.03	0.06	0.59	0.30	0.22	**83.5**	9.2		37.4	36.9		83.5		66	97	17	13
GPEH1b	CHP: NG 4000 km, CCGT	**0.24**	0.24	0.06		0.24	-0.09	0.03	0.10	0.36	0.14	0.12	**74.9**	8.4		19.4	47.1		74.9		67	82	8	7
GREH1	CHP: LNG, CCGT	**0.37**	0.37	0.06	0.21	0.31	-0.24	0.03	0.33	0.42	0.04	0.05	**81.2**	8.5	13.9	19.2	39.7		81.2		79	84	2	3
WWEH1	CHP: Waste wood ind.	**0.44**	0.01	0.14		0.02	0.25	0.03	0.17	0.71	0.27	0.27	**3.1**	1.7		1.5	-0.1		3.1		3	3	0	0
WFEH1	CHP: Farmed wood ind.	**0.46**	0.03	0.19		0.02	0.21	0.03	0.18	0.68	0.28	0.22	**5.9**	11.0		1.5	-6.6		5.9		-9	23	15	17
GPHT3b	CHP: NG 4000 km, CCGT heat	**-0.42**	-0.42	0.06		0.24	-0.83	0.11			-0.42	0.42	**34.7**	8.3		19.1	7.3		34.7				35	-35
WFHT3	CHP: Farmed wood, heat	**-0.38**	0.62	0.08		0.01	-0.59	0.11			-0.38	0.38	**-1.2**	4.8		0.7	-6.6		-1.2				-1	1

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Abstract
WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE FUELS AND POWERTRAINS IN THE EUROPEAN CONTEXT

The JEC research partners [Joint Research Centre of the European Commission, EUCAR and CONCAWE] have updated their joint evaluation of the well-to-wheels energy use and greenhouse gas emissions for a wide range of potential future fuel and powertrain options.

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