WTT APPENDIX 2

Description and detailed energy and GHG balance of individual pathways

Corrections from version 2b of May 2006
There are small changes in the bio-diesel pathways as a result of addition of energy for glycerine purification and accounting for fossil content of methanol. These affect tables in section 4 and 9.1.

WTT APPENDIX 2

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

It details the processes included in each pathway (discussed in ***WTT Appendix 1***) and gives the resulting energy and GHG balance for the total pathway as well as the contribution of each of the main stages.

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.

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).

WTT APPENDIX 2

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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			✓
Common processes				
Z1	Diesel production	✓	✓	✓
Z2	Road tanker	✓	✓	✓
Z3	HFO production	✓	✓	✓
Z5	Rail transport	✓	✓	✓
Z7a	Electricity (EU-mix, MV)	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓

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.

		Standard step	Energy consumed (MJx/MJf)				Net GHG emitted (g CO_2eq/MJf)			Individual GHG		
			Total primary			Fossil						
			Best est.	min	Max		Best est.	min	Max	g CO_2/MJ	g CH_4/MJ	g N_2O/MJ
COG1	**Crude oil to gasoline**											
	Crude Extraction & Processing	1	0.03	0.01	0.04		3.6			3.6	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		**0.14**	0.12	0.17	**0.14**	**12.5**	11.1	14.6	12.5	0.00	0.000
COD1	**Crude oil to diesel**											
	Crude Extraction & Processing	1	0.03	0.01	0.04		3.7			3.7	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		**0.16**	0.14	0.18	**0.16**	**14.2**	12.6	16.0	14.2	0.00	0.000
CON1	**Crude oil to naphtha**											
	Crude Extraction & Processing	1	0.03	0.01	0.04		3.5			3.5	0.00	0.000
	Crude Transport	3	0.01				0.9			0.9	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		**0.11**	0.10	0.13	**0.11**	**9.8**	8.5	11.3	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) (+CC&S 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 consumed (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		3.2			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		2.8			2.7	0.01	0.000
	Total pathway		**0.12**	0.09	0.14	**0.12**	**8.4**	7.2	9.6	5.5	0.13	0.000
GPCG1a	**Piped NG, 7000 km**											
	Extraction & Processing	1	0.03	0.01	0.06		3.6			1.3	0.10	0.000
	Transport	3	0.19	0.06	0.22		14.6			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		2.8			2.7	0.01	0.000
	Total pathway		**0.30**	0.20	0.30	**0.29**	**21.7**	16.0	21.8	14.7	0.29	0.001
GPCG1b	**Piped NG, 4000 km**											
	Extraction & Processing	1	0.03	0.01	0.05		3.3			1.2	0.09	0.000
	Transport	3	0.09	0.03	0.10		7.3			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		2.8			2.7	0.01	0.000
	Total pathway		**0.19**	0.14	0.21	**0.19**	**14.0**	11.0	14.8	9.2	0.20	0.000
GRCG1	**LNG, gaseous distribution**											
	Extraction & Processing	1	0.03	0.01	0.05		3.3			1.2	0.09	0.000
	Liquefaction	2	0.09	0.08	0.09		5.7			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		2.8			2.7	0.01	0.000
	Total pathway		**0.31**	0.29	0.33	**0.30**	**19.9**	19.0	21.2	16.5	0.14	0.000
GRCG1C	**LNG, gaseous distribution, CC&S**											
	Extraction & Processing	1	0.03	0.01	0.05		3.3			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		2.8			2.7	0.01	0.000
	Total pathway		**0.32**	0.30	0.35	**0.32**	**16.4**	15.3	17.8	13.0	0.14	0.000
GRCG2	**LNG, liquid distribution (trucking)**											
	Extraction & Processing	1	0.03	0.01	0.05		3.3			1.2	0.09	0.000
	Liquefaction	2	0.09				5.7			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				3.6			1.2	0.10	0.000
	Compression	5	0.03				1.5			1.5	0.00	0.000
	Total pathway		**0.26**	0.25	0.28	**0.26**	**20.3**	19.9	21.6	14.8	0.24	0.000

2.2 Biomass to CBG

Pathway code		OWCG		
		1	2	3
Code	Process			
Biogas				
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)	✓	✓	✓
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.

		Standard step	Energy consumed (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				32.31			23.7	0.45	-0.006
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.85			2.7	0.01	0.000
	Total WTT GHG emitted						**35.2**	32.3	37.9	26.3	0.46	-0.006
	Credit for renewable combustion CO_2						-75.5			-75.5		
	Total pathway		**0.87**	0.72	1.02	**0.17**	**-40.4**	-43.2	-37.7			
OWCG2	**CBG: liquid manure**											
	Manure transport	2	0.03				-86.92			2.1	-3.87	0.000
	Production, treating and upgrading	4	0.88				25.83			16.2	0.47	-0.004
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.85			2.7	0.01	0.000
	Total WTT GHG emitted						**-58.3**	-85.1	-30.6	21.0	-3.39	-0.004
	Credit for renewable combustion CO_2						-75.5			-75.5		
	Total pathway		**0.97**	0.80	1.12	**0.03**	**-133.8**	-160.7	-106.1			
OWCG3	**CBG: dry manure**											
	Manure transport	2	0.01				-8.22			0.7	-0.39	0.000
	Production, treating and upgrading	4	0.88				25.83			16.2	0.47	-0.004
	Distribution (pipeline)	5	0.00				0.00			0.0	0.00	0.000
	Refuelling station	5	0.06				2.85			2.7	0.01	0.000
	Total WTT GHG emitted						**20.5**	17.6	23.1	19.6	0.09	-0.004
	Credit for renewable combustion CO_2						-75.5			-75.5		
	Total pathway		**0.95**	0.78	1.11	**0.01**	**-55.1**	-57.9	-52.5			

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 consumed (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				3.4			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**	**7.9**	8.0	8.4	7.5	0.02	0.000

3 Ethanol

		S. beet		Wheat								S. cane	Straw			Wood waste via BL	
Pathway code		SBET		WTET								SCET	STET	WFET	WWET	BLCH	BLME
		1	3	1a	1b	2a	2b	3a	3b	4a	4b	1	1	1	1	1	1
Code	Process																
Farming																	
SB1	Sugar Beet Farming	✓	✓														
WT1	Wheat farming			✓	✓	✓	✓	✓	✓	✓	✓						
SC1	Sugar cane farming (Brazil)											✓	✓				
Crop transport and processing																	
SB2	Sugar beet road transport	✓	✓														
SB3a	Sugar beet to ethanol, pulp and slops to animal feed	✓															
SB3c	Sugar beet to ethanol, pulp and slop to biogas		✓														
WT2a	Wheat grain road transport			✓	✓	✓	✓	✓	✓	✓	✓						
WT2b	Wheat straw road transport									✓	✓		✓				
WT3	Wheat grain handling and drying (to dwg, 3%			✓	✓	✓	✓	✓	✓	✓	✓						
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									✓	✓						
WTDa	Credit for DDGS as animal feed			✓		✓		✓		✓							
WTDb	Credit for DDGS as fuel				✓		✓		✓		✓						
W3k	Wheat straw to ethanol (logen)												✓				
SC2	Sugar cane road transport											✓					
SC3	Sugar cane to ethanol											✓					
SC4	Sugar cane ethanol 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 ships (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

Two alternatives use for the pulp and slop by-products are described, namely animal feed and conversion to biogas for cogeneration.

		Standard step	Energy consumed (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
SBET1	**EtOH from sugar beet, animal feed export**											
	Cultivation	1	0.16				20.83			10.5	0.01	0.034
	Road transport	3	0.03				2.12			2.1	0.00	0.000
	Ethanol plant	4	1.64				33.00			35.0	0.11	-0.016
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**57.5**	54.3	61.0	49.1	0.13	0.018
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.86**	1.74	1.99	**0.87**	**-13.9**	-17.1	-10.4			
SBET3	**Ethanol from Sugar beet, pulp to heat**											
	Cultivation	1	0.16				20.83			10.5	0.01	0.034
	Road transport	3	0.03				2.12			2.1	0.00	0.000
	Ethanol plant	4	1.08				5.20			4.9	0.01	0.000
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**29.7**	27.0	31.6	19.0	0.03	0.034
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.30**	1.18	1.42	**0.31**	**-41.7**	-44.4	-39.8			

WTET Wheat grain to ethanol

The first version of the study only considered a single pathway depicting a production plant with a conventional steam boiler and imported electricity. DDGS was deemed to be used as animal feed. We have now incorporated more variants based on the work done in the framework of the UK's Low carbon Vehicle Partnership [*LowCVP 2004*].

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 fort the lost of soil nutrients from straw. Both DDGS use options are presented (see 3a/b).

WTT APPENDIX 2

		Standard step	Energy consumed (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	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	1.49				25.17			32.2	0.10	-0.031
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**59.2**	51.8	67.2	48.5	0.13	0.026
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.78**	1.76	1.80	**0.89**	**-12.2**	-19.6	-4.1			
WTET1b	**Ethanol from Wheat, Conv NG boiler, DDGS as fuel**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	1.02				16.54			15.7	0.04	0.000
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**50.5**	43.7	57.2	32.0	0.07	0.057
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.30**	1.28	1.33	**0.44**	**-20.8**	-27.7	-14.1			
WTET2a	**Ethanol from Wheat, NG GT+CHP, DDGS as animal feed**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	1.24				12.56			20.8	0.07	-0.033
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**46.6**	39.2	53.2	37.2	0.09	0.025
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.53**	1.51	1.55	**0.65**	**-24.8**	-32.1	-18.2			
WTET2b	**Ethanol from Wheat, NG GT+CHP, DDGS as fuel**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	0.77				3.93			4.3	0.01	-0.002
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**37.9**	31.6	44.7	20.7	0.03	0.056
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.06**	1.04	1.08	**0.20**	**-33.5**	-39.8	-26.7			
WTET3a	**Ethanol from Wheat, lignite CHP, DDGS as animal feed**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	1.46				58.58			68.1	0.00	-0.032
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**92.6**	84.8	100.0	84.5	0.03	0.025
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.74**	1.74	1.75	**0.86**	**21.2**	13.5	28.6			
WTET3b	**Ethanol from Wheat, Lignite CHP, DDGS as fuel**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	0.98				49.95			51.6	-0.06	-0.001
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**83.9**	77.7	91.5	68.0	-0.03	0.056
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.27**	1.27	1.27	**0.41**	**12.6**	6.3	20.1			
WTET4a	**Ethanol from Wheat, Straw CHP, DDGS as animal feed**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	1.40				-9.18			0.3	0.00	-0.032
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**24.8**	17.6	31.5	16.7	0.03	0.025
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.69**	1.69	1.70	**0.28**	**-46.6**	-53.8	-39.9			
WTET4b	**Ethanol from Wheat, Straw CHP, DDGS as fuel**											
	Cultivation	1	0.24				31.92			14.3	0.03	0.058
	Road transport	3	0.03				0.54			0.5	0.00	0.000
	Ethanol plant	4	0.93				-17.82			-16.2	-0.06	-0.001
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**16.2**	8.5	22.9	0.2	-0.03	0.056
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.22**	1.21	1.22	**-0.17**	**-55.2**	-62.9	-48.5			

SCET1 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), also generating surplus heat. The data is based on [*Macedo 2004*]. Ethanol is shipped into Europe where it is blended with gasoline.

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 consumed (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
SCET1	**EtOH from sugar cane (Brazil)**											
	Cultivation	1	0.06				13.09			3.7	0.15	0.020
	Road transport	3	0.01				0.85			0.8	0.00	0.000
	Ethanol plant	4	1.63				-10.31			-10.2	0.00	0.000
	Ethanol transport	5	0.08				0.99			1.0	0.00	0.000
	Refuelling station	5	0.01				5.82			5.8	0.00	0.000
	Total WTT GHG emitted						**10.4**	10.2	10.7	1.1	0.15	0.020
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.79**	1.79	1.80	**0.02**	**-60.9**	-61.2	-60.7			
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				3.18			3.0	0.01	0.000
	Ethanol plant	4	1.80				12.31			12.6	0.02	-0.002
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**18.0**	17.8	18.1	18.0	0.03	-0.002
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.94**	1.84	2.05	**0.27**	**-53.4**	-53.6	-53.3			
WFET1	**EtOH from farmed wood**											
	Cultivation	1	0.11				6.96			3.1	0.00	0.013
	Road transport	3	0.01				0.88			0.9	0.00	0.000
	Ethanol plant	4	1.80				12.31			12.6	0.02	-0.002
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**21.7**	19.0	28.2	18.1	0.02	0.010
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.95**	1.84	2.05	**0.27**	**-49.7**	-52.3	-43.2			
STET1	**EtOH from wheat straw (logen)**											
	Collection	3	0.05				3.35			3.3	0.00	0.000
	Road transport	3	0.01				0.62			0.6	0.00	0.000
	Ethanol plant	4	1.24				3.42			3.3	0.00	0.000
	Ethanol road transport, 150 km	5	0.02				1.10			1.1	0.00	0.000
	Refuelling station	5	0.01				0.44			0.4	0.00	0.000
	Total WTT GHG emitted						**8.9**	8.9	9.0	8.7	0.01	0.000
	Credit for renewable combustion CO_2						-71.4			-71.4		
	Total pathway		**1.32**	1.32	1.32	**0.11**	**-62.4**	-62.5	-62.4			

4 Bio-diesel

Pathway code		ROFA		ROFE		SOFA	
		1	2	1	2	1	2
Code	Process						
Farming							
RF1	Rapeseed Farming	✓	✓	✓	✓		
SF1	Sunflower seed Farming					✓	✓
Crop transport and processing							
WT2a	Wheat grain road transport			✓	✓		
WT3	Wheat grain handling and drying (to dwg, 3% moisture)			✓	✓		
WT4b	Wheat grain to ethanol, NG CCGT			✓	✓		
WTDa	Credit for DDGS as animal feed			✓	✓		
RO2	Rapeseed road transport	✓	✓	✓	✓		
RO3	Rapeseed to raw oil: extraction	✓	✓	✓	✓		
SO2	Sunflower seed road transport					✓	✓
SO3	Sunflower seed to raw oil: extraction					✓	✓
RO4/SO4	Raw oil to refined oil	✓	✓	✓	✓		
RO5/SO5	Refined oil to FAME: esterification						
5a	Glycerine as chemical	✓		✓		✓	
5b	Glycerine as animal feed		✓		✓		✓
Biofuels transport & distribution							
FAd	FAME distribution (blended)	✓	✓	✓	✓	✓	✓
Common processes							
Z1	Diesel production	✓	✓	✓	✓	✓	✓
Z2	Road tanker	✓	✓	✓	✓	✓	✓
Z6	Marginal NG for general use (4000 km piped)	✓	✓	✓	✓	✓	✓
Z7a	Electricity (EU-mix, MV)	✓	✓	✓	✓	✓	✓
Z7b	Electricity (EU-mix, LV)	✓	✓	✓	✓	✓	✓

ROFA1/2 Rape to FAME (RME)

SOFA1/2 Sunflower seed to FAME

For both crops two alternatives disposal routes for the glycerine are considered either as a chemical (replacing a bulk chemical such as propylene glycol) or as animal feed. These represent the extremes of GHG and fossil energy credits: reality will be in between.

ROFE1/2 Rape to FAEE (REE)

The same pathways as ROFA above where methanol has been replaced by (bio)ethanol. Although it 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.

WTT APPENDIX 2

		Standard step	Energy consumed (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**											
	Cultivation	1	0.29				51.26			18.2	0.03	0.109
	Drying	1	0.01				0.66			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	FAME manufacture	4	0.84				-6.95			1.9	0.04	-0.033
	Transport and distribution	5	0.02				1.26			1.2	0.00	0.000
	Total WTT GHG emitted						**46.5**	25.3	66.6	22.2	0.08	0.076
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**1.19**	1.10	1.30	**0.46**	**-28.9**	-50.1	-8.8			
ROFA2	**RME, glycerine as animal feed**											
	Cultivation	1	0.29				51.26			18.2	0.03	0.109
	Drying	1	0.01				0.66			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.30			0.3	0.00	0.000
	FAME manufacture	4	0.89				-1.71			7.4	0.05	-0.035
	Transport and distribution	5	0.02				1.26			1.2	0.00	0.000
	Total WTT GHG emitted						**51.8**	30.7	68.3	27.8	0.09	0.074
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**1.24**	1.13	1.34	**0.51**	**-23.6**	-44.7	-7.1			
ROFE1	**REE, glycerine as chemical**											
	Cultivation	1	0.28				48.42			17.2	0.03	0.103
	Drying	1	0.01				0.62			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	FAEE manufacture	4	0.92				-7.29			0.4	0.03	-0.029
	Transport and distribution	5	0.02				1.25			1.2	0.00	0.000
	Total WTT GHG emitted						**43.3**	24.2	63.4	19.7	0.07	0.074
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**1.25**	1.15	1.34	**0.41**	**-32.1**	-51.2	-12.0			
ROFE2	**REE, glycerine as animal feed**											
	Cultivation	1	0.28				48.42			17.2	0.03	0.103
	Drying	1	0.01				0.62			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	FAEE manufacture	4	0.97				-2.56			5.4	0.04	-0.030
	Transport and distribution	5	0.02				1.25			1.2	0.00	0.000
	Total WTT GHG emitted						**48.0**	28.9	71.4	24.6	0.08	0.073
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**1.30**	1.20	1.40	**0.45**	**-27.4**	-46.5	-4.0			
SOFA1	**SME, glycerine as chemical**											
	Cultivation	1	0.18				28.03			12.0	0.01	0.053
	Drying	1	0.01				0.61			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	FAME manufacture	4	0.74				-5.44			3.3	0.04	-0.032
	Transport and distribution	5	0.02				1.26			1.2	0.00	0.000
	Total WTT GHG emitted						**24.7**	12.2	36.1	17.4	0.06	0.021
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**0.98**	0.87	1.07	**0.36**	**-50.7**	-63.3	-39.3			
SOFA2	**SME, glycerine as animal feed**											
	Cultivation	1	0.18				28.03			12.0	0.01	0.053
	Drying	1	0.01				0.61			0.6	0.00	0.000
	Transport, road 50 km	3	0.02				0.28			0.3	0.00	0.000
	FAME manufacture	4	0.79				-0.19			8.9	0.04	-0.034
	Transport and distribution	5	0.02				1.26			1.2	0.00	0.000
	Total WTT GHG emitted						**30.0**	19.2	40.7	22.9	0.06	0.019
	Credit for renewable combustion CO_2						-75.4			-75.4		
	Total pathway		**1.03**	0.94	1.11	**0.41**	**-45.4**	-56.2	-34.7			

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) (+CC&S option)

This option of a GTL plant installed near a remote gas supply is the most likely. 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 (CC&S) could be an attractive option.

KOSD1/1C CTL: Coal to synthetic diesel (+CC&S 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 CC&S, 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.

WTT APPENDIX 2

		Standard step	Energy consumed (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
Syn diesel												
GRSD1	**Syn diesel, remote plant, diesel mix**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.8			1.8	0.13	0.000
	GTL plant	2	0.59	0.54	0.64		16.5			16.5	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		**0.68**	0.63	0.75	**0.68**	**25.0**	22.4	28.9	21.9	0.13	0.000
GRSD2	**Syn diesel, remote plant, neat**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.8			1.8	0.13	0.000
	GTL plant	2	0.59	0.54	0.64		16.5			16.5	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		**0.68**	0.63	0.74	**0.68**	**25.1**	22.4	28.5	22.0	0.13	0.000
GRSD2C	**Syn diesel, remote plant, neat, CC&S**											
	NG Extraction & Processing	1	0.04	0.02	0.08		5.0			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**	**13.0**	10.1	16.3	9.7	0.14	0.000
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				1.1			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**	1.08	1.30	**0.07**	**-66.1**	-66.3	-65.9			
WFSD1	**Syn diesel, farmed wood**											
	Wood farming and chipping	1	0.09				5.5			2.5	0.00	0.010
	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				1.1			1.1	0.00	0.000
	Total WTT GHG emitted						**7.4**	4.4	13.8	4.3	0.00	0.010
	Credit for renewable combustion CO_2						-70.8			-70.8		
	Total pathway		**1.19**	1.08	1.29	**0.06**	**-63.4**	-66.4	-57.0			
BLSD1	**Syn diesel, black liquor**											
	Wood farming 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				1.1			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**	0.86	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) (+CC&S 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 consumed (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		5.2			1.9	0.14	0.000
	NG Transport	3	0.28	0.09	0.31		20.7			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**	0.63	0.79	**0.77**	**38.9**	30.8	39.9	29.2	0.41	0.001
GPDE1b	**Piped NG, 4000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.7			1.7	0.13	0.000
	NG Transport	3	0.13	0.04	0.15		10.3			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**	0.56	0.64	**0.62**	**28.1**	24.3	29.2	21.4	0.28	0.000
GRDE1	**Remote plant**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.3			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**	**20.9**	19.8	22.5	18.0	0.12	0.000
GRDE1C	**Remote plant, CC&S**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.3			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**	**10.9**	10.8	14.9	8.1	0.12	0.000
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	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						**4.5**	4.3	4.8	4.3	0.01	0.000
	Credit for renewable combustion CO_2						-67.3			-67.3		
	Total pathway		**1.07**	0.95	1.22	**0.06**	**-62.7**	-63.0	-62.5			
WFDE1	**Farmed wood**											
	Wood farming and chipping	1	0.08				5.2			2.3	0.00	0.010
	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						**7.0**	5.2	11.8	4.1	0.00	0.010
	Credit for renewable combustion CO_2						-67.3			-67.3		
	Total pathway		**1.07**	0.94	1.20	**0.06**	**-60.3**	-62.10	-55.45			
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**	0.51	0.61	**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) (+CC&S 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 consumed (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		5.4			2.0	0.15	0.000
	NG Transport	3	0.29	0.10	0.32		21.5			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**	0.70	0.87	**0.84**	**41.2**	33.4	42.8	31.3	0.42	0.001
GPME1b	**Piped NG, 4000 km, EU central plant**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.9			1.8	0.13	0.000
	NG Transport	3	0.14	0.05	0.15		10.7			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**	0.63	0.70	**0.69**	**30.0**	26.6	30.9	23.2	0.29	0.000
GRME1	**NG, Remote plant**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.4			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**	0.59	0.64	**0.61**	**23.9**	22.9	25.6	21.0	0.12	0.000
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						**4.7**	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**	**-64.4**	-64.6	-64.1			
WFME1	**Farmed wood**											
	Wood farming and chipping	1	0.08				5.2			2.3	0.00	0.010
	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						**7.2**	5.2	11.5	4.3	0.00	0.010
	Credit for renewable combustion CO_2						-69.1			-69.1		
	Total pathway		**1.07**	0.93	1.19	**0.06**	**-61.9**	-63.8	-57.6			
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	0.64	**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).

WTT APPENDIX 2

		Standard step	Energy consumed (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				0.84			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				6.00			5.6	0.02	0.000
	MTBE transport	3	0.05				4.04			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**	**13.5**	13.4	14.3			
LREB1	**ETBE from imported C4 and wheat ethanol (WTET2a)**											
	Wheat cultivation	1	0.09				11.63			5.2	0.01	0.021
	Road transport	3	0.01				0.20			0.2	0.00	0.000
	Ethanol plant	4	0.42				-0.23			2.8	0.02	-0.012
	ETBE plant	4	0.22				7.69			7.2	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						**20.4**	65.5	70.8	16.4	0.05	0.009
	Credit for renewable combustion CO_2						-23.8			-23.8		
	Total pathway		**0.75**	0.75	0.77	**0.07***	**-3.4**	-5.9	-0.6			

7 Electricity generation

		Natural gas			Coal								Farmed wood			Black liquor	Wind	Nuclear	EU-mix
Pathway code		**GPEL**		**GREL**	**KOEL**		**OWEL**						**WFEL**			**BLEL**	**WDEL**	**NUEL**	**EMEL**
		1a	**1b**	**1**	**1**	**2**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**	**1**	**2**	**3**	**1**	**1**	**1**	**1**
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)			✓															
Biogas																			
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 electricty: gasification, 200MW												✓						
W3c	Wood to electricity: gasification, 10MW													✓					
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.

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).

WFEL1-3 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.

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.

WTT APPENDIX 2

		Standard step	Energy consumed (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	**Coal, state-of-the-art conventional technology**											
	Coal provision	3	0.22				36.3			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**	1.23	1.78	**1.58**	**267.2**	231.0	286.8	242.6	0.91	0.012
KOEL2	**Coal, IGCC**											
	Coal provision	3	0.20				32.9			13.9	0.82	0.001
	Power plant	4	1.12				206.2			206.2	0.00	0.000
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**1.35**	1.25	1.46	**1.34**	**239.0**	228.8	250.4	220.0	0.82	0.001
GPEL1a	**Piped NG, 7000 km, CCGT**											
	NG Extraction & Processing	1	0.05	0.03	0.11		6.8			2.5	0.19	0.000
	NG Transport	3	0.36				27.4			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**	1.06	1.36	**1.31**	**139.8**	125.5	142.8	125.6	0.55	0.006
GPEL1b	**Piped NG, 4000 km, CCGT**											
	NG Extraction & Processing	1	0.05	0.02	0.10		6.2			2.3	0.17	0.000
	NG Transport	3	0.17				13.7			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**	0.97	1.20	**1.11**	**125.5**	117.2	130.8	115.2	0.38	0.005
GREL1	**LNG, CCGT**											
	Extraction & Processing	1	0.05	0.02	0.10		6.3			2.3	0.17	0.000
	Liquefaction	2	0.16				10.7			8.8	0.08	0.000
	Transport (shipping)	3	0.16				10.5			10.4	0.00	0.000
	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**	1.23	1.46	**1.33**	**136.5**	130.7	144.5	128.8	0.26	0.006
WFEL1	**Farmed wood, 10 MW gasifier + CCGT**											
	Wood farming	1	0.12				7.8			3.5	0.00	0.014
	Road transport	3	0.00				0.2			0.2	0.00	0.000
	Power generation (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		**2.03**	1.93	2.15	**0.05**	**9.9**	7.3	17.2	3.7	0.04	0.018
WFEL2	**Farmed wood, 200 MW gasifier + CCGT**											
	Wood farming	1	0.09				5.7			2.5	0.00	0.010
	Road transport	3	0.01				0.7			0.7	0.00	0.000
	Power generation (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	1.34	**0.05**	**7.8**	5.6	13.1	3.3	0.03	0.013
WFEL3	**Farmed wood, steam power plant**											
	Wood farming	1	0.14				8.6			3.8	0.00	0.016
	Road transport	3	0.01				1.1			1.1	0.00	0.000
	Power generation (steam turbine)	4	2.19				9.5			0.0	0.09	0.025
	Electricity distribution (LV)	5	0.03				0.0			0.0	0.00	0.000
	Total pathway		**2.37**	2.19	2.52	**0.07**	**19.2**	15.9	27.7	4.9	0.09	0.041
EMEL1	**EU-mix electricity**											
	EU-mix power generation	4	1.84				129.2			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**	**129.2**	129.2	129.2	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				4.05			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	2.81	**2.74**	**4.4**	4.2	4.5	4.1	0.01	0.000
	Non-nuclear fossil energy					0.65						

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		Standard step	Energy consumed (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
OWEL1a	**Electricity from municipal waste (local power plant)**											
	Biogas production	4	1.67				4.60			-4.6	0.60	-0.016
	Local power plant	4	1.52				1.81			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.20**	2.92	3.55	**-0.08**	**6.4**	5.9	7.1	-4.6	0.68	-0.016
OWEL1b	**Electricity from municipal waste (large power plant)**											
	Biogas production	4	1.52				-80.86			-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				107.09			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.39**	2.09	2.67	**0.21**	**26.2**	20.9	31.4	8.4	0.85	-0.006
OWEL2a	**Electricity from liquid manure (local power plant)**											
	Transport of liquid manure (10 km)	2	0.06				-181.78			4.5	-8.10	0.000
	Biogas production	4	1.47				7.71			-2.7	0.57	-0.009
	Local power plant	4	1.52				1.81			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.06**	2.73	3.38	**0.01**	**-172.3**	-220.8	-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				-162.69			4.0	-7.25	0.000
	Biogas production	4	1.64				-93.00			-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				107.09			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.56**	2.26	2.89	**-0.06**	**-148.6**	-194.6	-98.3	-1.4	-6.35	-0.004
OWEL3a	**Electricity from dry manure (local power plant)**											
	Transport of dry manure (10 km)	2	0.02				-17.19			1.4	-0.81	0.000
	Biogas production	4	1.47				7.71			-2.7	0.57	-0.009
	Local power plant	4	1.52				1.81			0.0	0.08	0.000
	Electricity distribution (LV)	5	0.01				0.00			0.0	0.00	0.000
	Total pathway		**3.02**	2.70	3.31	**-0.03**	**-7.7**	-11.9	-2.6	-1.2	-0.16	-0.009
OWEL3b	**Electricity from dry manure (large power plant)**											
	Transport of dry manure (10 km)	2	0.02				-15.39			1.3	-0.72	0.000
	Biogas production	4	1.64				-93.00			-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				107.09			105.5	0.01	0.005
	Electricity distribution (LV)	5	0.03				0.00			0.0	0.00	0.000
	Total pathway		**2.53**	2.16	2.87	**-0.09**	**-1.3**	-6.6	3.7	-4.2	0.17	-0.004
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

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 (+CC&S 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 consumed (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		4.6			1.7	0.1	0.0
	NG Transport	3	0.03	0.01	0.03		2.7			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		86.5			85.8	0.0	0.0
	Compression	5	0.24	0.22	0.26		9.9			9.3	0.0	0.0
	Total pathway		**0.84**	0.81	0.90	**0.83**	**104.7**	102.9	107.6	99.3	0.23	0.001
GPCH1a	**Piped NG, 7000 km, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.09		5.4			2.0	0.15	0.000
	NG Transport	3	0.29	0.10	0.32		21.5			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		84.5			83.9	0.02	0.000
	Compression	5	0.24	0.22	0.26		9.9			9.3	0.02	0.000
	Total pathway		**1.11**	0.95	1.13	**1.09**	**122.2**	113.6	123.6	111.0	0.47	0.001
GPCH1b	**Piped NG, 4000 km, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.9			1.8	0.13	0.000
	NG Transport	3	0.14	0.05	0.15		10.7			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		84.5			83.9	0.02	0.000
	Compression	5	0.24	0.22	0.26		9.9			9.3	0.02	0.000
	Total pathway		**0.95**	0.87	0.98	**0.94**	**110.9**	106.3	112.5	102.9	0.34	0.001
GPCH2a	**Piped NG, 7000 km, central reforming, pipeline**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.9			1.8	0.13	0.000
	NG Transport	3	0.26	0.09	0.29		19.6			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		74.0			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	0.88	**0.85**	**108.4**	100.1	109.9	98.4	0.42	0.001
GPCH2b	**Piped NG, 4000 km, central reforming, pipeline**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.5			1.6	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		9.8			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		74.0			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**	0.64	0.74	**0.71**	**98.2**	94.1	99.7	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		4.6			1.7	0.13	0.000
	NG Transport	3	0.13	0.04	0.14		10.2			6.7	0.15	0.000
	NG Distribution (HP)	3	0.01				0.8			0.8	0.00	0.000
	Central reforming (CC&S)	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**	0.70	0.80	**0.76**	**37.2**	32.8	38.8	29.8	0.31	0.001
GPCH3b	**Piped NG, 4000 km, central reforming, trucking**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.5			1.64	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		9.8			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		74.0			73.67	0.02	0.000
	Gaseous Hyd distribution & comp.	5	0.22	0.21	0.24		10.0			9.50	0.02	0.000
	Total pathway		**0.72**	0.65	0.74	**0.71**	**99.1**	95.3	100.4	92.0	0.30	0.001

		Standard step	Energy consumed (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		4.4			1.6	0.12	0.000
	NG Transport	3	0.12	0.11	0.13		9.6			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		36.8			33.8	0.11	0.002
	Liquid hyd distribution & vap/comp	5	0.17				8.2			7.8	0.02	0.000
	Total pathway		**1.28**	1.14	1.35	**1.27**	**132.8**	124.5	137.3	122.8	0.40	0.002
GRCH1	**LNG, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.08		4.9			1.8	0.14	0.000
	NG Liquefaction	2	0.13				8.4			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		84.4			83.8	0.02	0.000
	Compression	5	0.24	0.22	0.26		9.9			9.3	0.02	0.000
	Total pathway		**1.12**	1.08	1.18	**1.10**	**119.4**	117.4	122.7	113.4	0.25	0.001
GRCH2	**LNG, central reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.07		4.5			1.6	0.12	0.000
	NG Liquefaction	2	0.12				7.7			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		74.0			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	0.92	**0.86**	**106.0**	104.1	108.8	100.7	0.22	0.001
GRCH3	**Remote NG, methanol, on-site reforming**											
	NG Extraction & Processing	1	0.04	0.02	0.09		5.4			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	0.22	0.21	0.23		84.6			84.5	0.00	0.000
	Hydrogen compression	5	0.22	0.21	0.24		9.1			8.5	0.02	0.000
	Total pathway		**1.13**	1.11	1.17	**1.12**	**118.5**	117.3	120.9	114.4	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 consumed (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		4.8			1.8	0.13	0.000
	NG Transport	3	0.26	0.09	0.29		19.3			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		41.0			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	1.39	**1.33**	**140.6**	128.0	144.2	127.1	0.56	0.002
GPLH1b	**Piped NG, 4000 km, central reforming + liquefaction**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.4			1.6	0.12	0.000
	NG Transport	3	0.12	0.04	0.14		9.6			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		36.8			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**	1.00	1.23	**1.13**	**126.3**	118.2	131.5	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		4.9			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		39.7			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**	1.30	1.58	**1.42**	**138.7**	131.5	147.8	133.2	0.22	0.002
GRLH2	**LNG, central reforming + liquefaction**											
	NG Extraction & Processing	1	0.03	0.02	0.07		4.4			1.6	0.12	0.000
	NG Liquefaction	2	0.11	0.00	0.00		7.5			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		72.9			72.6	0.02	0.000
	Hyd liquefaction	4	0.67	0.47	0.88		39.6			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**	1.23	1.47	**1.34**	**136.9**	130.3	144.8	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 (+CC&S 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 consumed (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				30.8			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**	1.38	1.41	**1.38**	**232.8**	232.0	233.6	214.4	0.79	0.001
KOCH1C	**Coal EU-mix, gasifier + CO shift, CC&S**											
	Coal provision	3	0.22				36.0			15.2	0.90	0.001
	Gasifier + CO shift + CC&S	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**	1.76	1.79	**1.76**	**50.9**	50.1	51.6	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 consumed (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
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**	1.12	1.32	**0.19**	**10.7**	9.9	11.4	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**	11.2	12.8	11.3	0.03	0.000
WFCH1	**Farmed wood , on-site gasification, 10 MW (biomass)**											
	Wood farming and chipping	1	0.08				5.3			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**	1.14	1.35	**0.22**	**15.2**	13.1	19.7	10.4	0.03	0.013
WFCH2	**Farmed wood, large scale gasification, 200 MW (biomass)**											
	Wood farming	1	0.06				4.0			1.8	0.00	0.007
	Road transport	3	0.01				0.5			0.5	0.00	0.000
	Med scale gasifier (200 MW) + CO shift	4	0.68				0.6			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**	**14.2**	12.9	18.2	11.1	0.02	0.009
WFLH1	**Farmed wood, large scale gasification, 200 MW (biomass), liquefaction**											
	Wood farming	1	0.06				3.9			1.7	0.00	0.007
	Road transport	3	0.01				1.1			0.8	0.00	0.001
	Med scale gasifier (200 MW) + CO shift	4	0.67				2.1			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**	1.33	1.63	**0.07**	**8.1**	6.6	12.9	4.6	0.00	0.012
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**	0.48	0.55	**0.20**	**10.0**	9.3	10.8	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**	**2**	**3**	**1**	**1**	**1**	
Code	Process	CH1	CH1	CH2	LH1	CH1	CH1	CH2	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)						✓	✓						
KE	Electricity from Coal						✓	✓						
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)													
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				✓									✓
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 consumed (MJex/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		10.6			3.9	0.29	0.000
	NG Transport	3	0.57	0.48	0.63		45.0			29.6	0.65	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	0.04	0.000
	Total pathway		**2.73**	2.50	2.98	**2.73**	**227.9**	214.1	243.4	202.3	1.00	0.009
GPEL1b/CH1	**Piped NG 4000 km, CCGT, on-site electrolysis**											
	NG Extraction & Processing	1	0.08	0.04	0.15		9.7			3.6	0.27	0.000
	NG Transport	3	0.27	0.23	0.30		22.7			13.9	0.37	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	0.03	0.000
	Total pathway		**2.41**	2.23	2.63	**2.41**	**203.8**	193.1	217.1	185.7	0.68	0.009
GPEL1b/CH2	**Piped NG, 4000 km, CCGT, central electrolysis, pipe**											
	NG Extraction & Processing	1	0.08	0.04	0.15		9.6			3.5	0.26	0.000
	NG Transport	3	0.27	0.22	0.30		22.5			13.8	0.37	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		160.9			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		**2.46**	2.26	2.68	**2.45**	**203.8**	192.0	217.5	185.9	0.67	0.009
GPEL1b/LH1	**Piped NG 4000 km, CCGT, central electrolysis, liquefaction**											
	NG Extraction & Processing	1	0.08	0.04	0.15		9.5			3.5	0.26	0.000
	NG Transport	3	0.27	0.22	0.30		22.2			13.6	0.36	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	0.12	0.002
	Liquid hyd distribution & delivery	1	0.04				2.8			2.8	0.00	0.000
	Total pathway		**2.87**	2.63	3.06	**2.87**	**231.9**	218.1	243.5	211.5	0.76	0.010
GREL1/CH1	**LNG, CCGT, on-site electrolysis**											
	NG Extraction & Processing	1	0.08	0.04	0.15		9.7			3.6	0.27	0.000
	NG Liquefaction	2	0.25				16.6			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**	2.53	3.00	**2.75**	**219.9**	206.8	235.1	207.5	0.42	0.009

WTT APPENDIX 2

		Standard step	Energy consumed (MJex/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
WFEL2/CH1	**Farmed wood, CCGT, on-site electrolysis**											
	Wood harvesting and chipping	1	0.14				8.7			3.9	0.00	0.016
	Mixed transport	3	0.01				1.1			1.1	0.00	0.000
	Gasification (200 MW)+ CCGT	4	1.71				2.1			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				0.5			0.2	0.00	0.001
	Total pathway		**2.60**	2.42	2.82	**0.12**	**12.5**	9.1	21.6	5.2	0.05	0.021
WFEL3/CH1	**Farmed wood, conv. power plant, on-site electrolysis**											
	Wood harvesting and chipping	1	0.21				13.2			5.9	0.00	0.024
	Mixed transport	3	0.02				1.7			1.7	0.00	0.000
	Conv power plant (200 MW), cond. turbine	4	3.39				14.7			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				1.2			0.3	0.01	0.003
	Total pathway		**4.42**	4.11	4.77	**0.19**	**30.7**	25.7	43.6	7.8	0.14	0.066
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**	0.72	0.85	**0.19**	**9.1**	8.4	9.9	8.5	0.02	0.000
EMEL1/CH1	**EU-mix electricity, on-site electrolysis**											
	EU-mix power generation	1	2.85				200.3			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	3.83	**3.39**	**208.1**	199.5	217.7	194.6	0.47	0.009
EMEL1/LH1	**EU-mix electricity, central electrolysis, liquefaction**											
	EU-mix power generation	1	2.79				195.9			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		38.2			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**	4.04	4.47	**3.97**	**235.9**	227.8	246.9	220.7	0.53	0.010
NUEL1/CH1	**Nuclear electricity, on-site electrolysis**											
	Nuclear fuel provision	3	0.96				6.2			5.8	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**	4.79	5.31	**5.02**	**7.0**	6.6	7.4	6.6	0.01	0.000
KOEL1/CH1	**Coal electricity, on-site electrolysis**											
	Coal provision (EU-mix)	3	0.34				56.3			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				16.3			14.8	0.1	0.0
	Total pathway		**3.17**	2.64	3.60	**3.16**	**430.4**	376.4	473.7	390.9	1.46	0.020
KOEL1/CH2	**Coal electricity, central electrolysis**											
	Coal provision (EU-mix)	3	0.34				55.9			23.6	1.39	0.001
	Coal power station	4	2.06				355.4			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**	2.66	3.60	**3.17**	**420.4**	367.2	461.5	382.0	1.42	0.019
KOEL1/LH1	**Coal electricity, central electrolysis, liquefaction**											
	Coal provision (EU-mix)	3	0.34				55.0			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		79.0			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**	3.18	4.10	**3.73**	**487.0**	430.5	524.4	442.5	1.65	0.022

9 Summary of energy and GHG balances

9.1 Oil-based fuels, CBG/CBG, 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			
COG1	Conventional gasoline	**0.14**	0.14	0.03		0.01	0.08	0.02	0.12	0.17	0.02	0.03	**13**	4		1	7	1	13		11	15	1	2
COD1	Conventional diesel	**0.16**	0.16	0.03		0.01	0.10	0.02	0.14	0.18	0.02	0.02	**14**	4		1	9	1	14		13	16	2	2
CON1	Conventional naphtha	**0.11**	0.11	0.03		0.01	0.05	0.02	0.10	0.13	0.01	0.02	**10**	4		1	4	1	10		9	11	1	2
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**	3	0	2		2	8		8	8	0	0
GMCG1	CNG: EU-mix	**0.12**	0.12	0.02		0.02		0.07	0.10	0.14	0.02	0.03	**8**	3		2		3	8		7	10	1	1
GPCG1a	CNG: Pipeline 7000 km	**0.30**	0.29	0.03		0.19		0.07	0.19	0.30	0.10	0.01	**22**	4		15		3	22		16	22	6	0
GPCG1b	CNG: Pipeline 4000 km	**0.19**	0.19	0.03		0.09		0.07	0.14	0.21	0.05	0.02	**14**	3		7		3	14		11	15	3	1
GRCG1	CNG: LNG, Vap, Pipe	**0.31**	0.30	0.03	0.09	0.12		0.07	0.28	0.33	0.02	0.03	**20**	3	6	7		3	20		19	21	1	1
GRCG1C	CNG: LNG, Vap, Pipe, CC&S	**0.32**	0.32	0.03	0.10	0.12		0.07	0.29	0.34	0.02	0.03	**16**	3	2	7		3	16		15	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**	3	6	6		5	20		20	22	1	1
OWCG1	CBG: municipal waste	**0.87**	0.17				0.81	0.06	0.72	1.02	0.15	0.15	**-40**				32	3	35	-76	-43	-38	3	3
OWCG2	CBG: liquid manure	**0.97**	0.03		0.03		0.88	0.06	0.80	1.12	0.17	0.16	**-134**		-87		26	3	-58	-76	-161	-106	27	28
OWCG3	CBG: dry manure	**0.95**	0.01		0.01		0.88	0.06	0.78	1.11	0.17	0.16	**-55**		-8		26	3	20	-76	-58	-52	3	3
SBET1	EtOH: Sugar beet, pulp to fodder	**1.86**	0.87	0.16		0.03	1.64	0.03	1.74	1.96	0.12	0.11	**-14**	21		2	33	2	57	-71	-18	-10	4	4
SBET3	EtOH: Sugar beet, pulp to heat	**1.30**	0.31	0.16		0.03	1.08	0.03	1.17	1.41	0.13	0.12	**-42**	21		2	5	2	30	-71	-44	-39	2	3
WTET1a	EtOH: Wheat, conv NG boiler, DDGS as AF	**1.78**	0.89	0.24		0.03	1.49	0.03	1.76	1.80	0.02	0.02	**-12**	32		1	25	2	59	-71	-19	-5	7	7
WTET1b	EtOH: Wheat, conv NG boiler, DDGS as fuel	**1.30**	0.44	0.24		0.03	1.02	0.03	1.28	1.33	0.02	0.02	**-21**	32		1	17	2	51	-71	-28	-13	7	8
WTET2a	EtOH: Wheat, NG GT+CHP, DDGS as AF	**1.53**	0.65	0.24		0.03	1.24	0.03	1.51	1.55	0.02	0.02	**-25**	32		1	13	2	47	-71	-32	-19	7	6
WTET2b	EtOH: Wheat, NG GT+CHP, DDGS as fuel	**1.06**	0.20	0.24		0.03	0.77	0.03	1.04	1.08	0.02	0.02	**-33**	32		1	4	2	38	-71	-41	-27	7	7
WTET3a	EtOH: Wheat, Lignite CHP, DDGS as AF	**1.74**	0.86	0.24		0.03	1.46	0.03	1.74	1.75	0.00	0.00	**21**	32		1	59	2	93	-71	14	28	7	7
WTET3b	EtOH: Wheat, Lignite CHP, DDGS as fuel	**1.27**	0.41	0.24		0.03	0.98	0.03	1.27	1.27	0.01	0.00	**13**	32		1	50	2	84	-71	5	20	8	7
WTET4a	EtOH: Wheat, Straw CHP, DDGS as AF	**1.69**	0.28	0.24		0.03	1.40	0.03	1.69	1.70	0.00	0.00	**-47**	32		1	-9	2	25	-71	-53	-39	7	7
WTET4b	EtOH: Wheat, Straw CHP, DDGS as fuel	**1.22**	-0.17	0.24		0.03	0.93	0.03	1.21	1.22	0.00	0.00	**-55**	32		1	-18	2	16	-71	-62	-48	7	7
WWET1	EtOH: W Wood	**1.94**	0.27	0.08		0.04	1.80	0.03	1.84	2.05	0.10	0.11	**-53**	1		3	12	2	18	-71	-54	-53	0	0
WFET1	EtOH: F wood	**1.95**	0.27	0.11		0.01	1.80	0.03	1.85	2.05	0.10	0.10	**-50**	7		1	12	2	22	-71	-52	-44	2	6
STET1	EtOH: Wheat straw	**1.32**	0.11	0.05		0.01	1.24	0.03	1.32	1.32	0.00	0.00	**-62**	3		1	3	2	9	-71	-62	-62	0	0
SCET1	EtOH: Sugar cane (Brazil)	**1.79**	0.02	0.06		0.01	1.63	0.09	1.79	1.80	0.00	0.00	**-61**	13		1	-10	7	10	-71	-61	-61	0	0
GRMB1	MTBE: remote plant	**0.30**	0.30	0.01	0.23	0.05		0.01	0.30	0.31	0.00	0.01	**14**	1	8	4		0	14		13	14	0	1
LREB1	ETBE: imported C4 and wheat ethanol	**0.75**	0.07	0.09		0.01	0.64	0.02	0.75	0.77	0.01	0.01	**-3**	12		0	7	1	20	-24	-6	0	2	3
ROFA1	RME: Gly as chemical	**1.19**	0.46	0.31		0.02	0.84	0.02	1.10	1.30	0.09	0.11	**-29**	52		0	-7	1	47	-75	-50	-9	21	20
ROFA2	RME: Gly as animal feed	**1.24**	0.51	0.31		0.02	0.89	0.02	1.13	1.34	0.11	0.10	**-24**	52		0	-2	1	52	-75	-45	-7	21	17
ROFE1	REE: Gly as chemical	**1.25**	0.41	0.29		0.02	0.92	0.02	1.15	1.34	0.10	0.09	**-32**	49		0	-7	1	43	-75	-51	-12	19	20
ROFE2	REE: Gly as animal feed	**1.30**	0.45	0.29		0.02	0.97	0.02	1.20	1.40	0.10	0.10	**-27**	49		0	-3	1	48	-75	-46	-4	19	23
SOFA1	SME: Gly as chemical	**0.98**	0.36	0.20		0.02	0.74	0.02	0.87	1.07	0.10	0.09	**-51**	29		0	-5	1	25	-75	-63	-39	13	11
SOFA2	SME: Gly as animal feed	**1.03**	0.41	0.20		0.02	0.79	0.02	0.94	1.11	0.09	0.08	**-45**	29		0	0	1	30	-75	-56	-35	11	11

9.2 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	**0.68**	0.68	0.04	0.59	0.04		0.02	0.63	0.75	0.05	0.07	**25**	5	16	3		1	25		22	29	3	4
GRSD2	Syn-diesel: Rem GTL, Sea, Rail/Road	**0.68**	0.68	0.04	0.59	0.04		0.02	0.63	0.74	0.05	0.06	**25**	5	16	3		1	25		22	29	3	3
GRSD2C	Syn-diesel: Rem GTL, Sea, Rail/Road, CC&S	**0.76**	0.76	0.04	0.67	0.04		0.02	0.71	0.82	0.05	0.06	**13**	5	4	3		1	13		10	16	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	**129**	27			101	1	129		121	137	8	8
KOSD1C	Syn-diesel: CTL, CC&S, Diesel mix	**1.06**	1.05	0.17			0.86	0.02	0.98	1.14	0.08	0.08	**39**	29			9	1	39		31	47	8	8
WWSD1	Syn-diesel: W Wood, diesel mix	**1.19**	0.07	0.06		0.04	1.08	0.02	1.08	1.30	0.12	0.11	**-66**	1		3	0	1	5	-71	-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	0.09	**-63**	6		1		1	7	-71	-66	-57	3	6
BLSD1	Syn-diesel: W Wood, Black liquor	**0.91**	0.04	0.05		0.01	0.83	0.02	0.86	0.97	0.05	0.06	**-68**	1		1		1	2	-71	-68	-68	0	0
GPME1a	MeOH: NG 7000 km, Syn, Rail/Road	**0.84**	0.84	0.04		0.30	0.47	0.03	0.70	0.87	0.14	0.03	**41**	5		22	12	2	41		33	43	8	2
GPME1b	MeOH: NG 4000 km, Syn, Rail/Road	**0.69**	0.69	0.04		0.15	0.47	0.03	0.63	0.70	0.06	0.02	**30**	5		12	12	2	30		27	31	3	1
GRME1	MeOH: Rem Syn, Sea, Rail/Road	**0.61**	0.61	0.04	0.47	0.08		0.03	0.59	0.64	0.02	0.03	**24**	4	12	6		2	24		23	26	1	2
KOME1	MeOH: Coal EU-mix, Cen, Rail/Road	**0.93**	0.93			0.16	0.74	0.03	0.84	1.03	0.09	0.10	**127**			27	98	2	127		118	137	9	10
WWME1	MeOH: W Wood, Road	**1.07**	0.06	0.06		0.03	0.96	0.02	0.94	1.20	0.13	0.13	**-64**	1		3	0	1	5	-69	-65	-64	0	0
WFME1	MeOH: F Wood, Road	**1.07**	0.06	0.08		0.01	0.96	0.02	0.93	1.19	0.14	0.12	**-62**	5		1	0	1	7	-69	-64	-58	2	4
BLME1	MeOH: W Wood, Black liquor	**0.59**	0.03	0.05		0.01	0.52	0.02	0.54	0.64	0.05	0.05	**-67**	1		1	0	1	2	-69	-67	-67	0	0
GPDE1a	DME: NG 7000 km, Syn, Rail/Road	**0.77**	0.77	0.04		0.29	0.41	0.03	0.63	0.79	0.14	0.02	**39**	5		21	11	2	39		31	40	8	1
GPDE1b	DME: NG 4000 km, Syn, Rail/Road	**0.62**	0.62	0.04		0.14	0.41	0.03	0.56	0.64	0.06	0.02	**28**	5		11	11	2	28		24	29	4	1
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**	4	11	4		2	21		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	**128**			27	100	2	128		118	137	10	8
GRDE1C	DME: Rem Syn, Sea, Rail/Road, CC&S	**0.54**	0.54	0.03	0.42	0.06		0.03	0.54	0.61	0.00	0.07	**11**	4	1	4		2	11		11	15	0	4
WWDE1	DME: W Wood, Road	**1.07**	0.06	0.06		0.03	0.96	0.02	0.95	1.22	0.12	0.15	**-63**	1		3	0	1	5	-67	-63	-63	0	0
WFDE1	DME: F Wood, Road	**1.07**	0.06	0.08		0.01	0.96	0.02	0.94	1.20	0.13	0.13	**-60**	5		1	0	1	7	-67	-62	-55	2	5
BLDE1	DME: W Wood, Black liquor	**0.55**	0.03	0.04		0.01	0.49	0.02	0.51	0.61	0.04	0.05	**-65**	1		1	0	1	2	-67	-65	-65	0	0

9.3 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 Urban 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	0.90	0.03	0.05	**105**	5		4	87	10	105	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	0.95	1.13	0.15	0.02	**122**	5		22	85	10	122	114	124	9	1
GPCH1b	C-H2, NG 4000 km, O/S Ref	**0.95**	0.94	0.04		0.15	0.52	0.24	0.87	0.98	0.08	0.03	**111**	5		12	85	10	111	106	113	5	2
GPCH2a	C-H2: NG 7000 km, Cen ref, Pipe	**0.86**	0.85	0.04		0.27	0.32	0.22	0.71	0.88	0.15	0.03	**108**	5		20	74	9	108	100	110	8	1
GPCH2b	C-H2: NG 4000 km, Cen Ref, Pipe	**0.72**	0.71	0.04		0.14	0.32	0.22	0.64	0.74	0.07	0.03	**98**	4		11	74	9	98	94	100	4	2
GPCH2bC	C-H2: NG 4000 km, Cen Ref, Pipe, CC&S	**0.77**	0.76	0.04		0.14	0.37	0.22	0.70	0.80	0.08	0.03	**37**	5		11	12	9	37	33	39	4	2
GPCH3b	C-H2: NG 4000 km, Cen Ref, Road	**0.72**	0.71	0.04		0.14	0.32	0.22	0.65	0.74	0.06	0.02	**99**	4		11	74	10	99	95	100	4	1
GPLCHb	C-H2: NG 4000 km, Cen Ref, Liq, Road, Vap/comp.	**1.28**	0.71	0.03		0.13	0.94	0.17	1.14	1.35	0.14	0.08	**133**	4		10	110	8	133	124	137	8	5
GRCH1	C-H2: LNG, O/S Ref	**1.12**	1.10	0.04	0.13	0.19	0.52	0.24	1.08	1.18	0.03	0.06	**119**	5	8	12	84	10	119	117	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	0.92	0.04	0.05	**106**	4	8	11	74	9	106	104	109	2	3
GRCH3	C-H2: Rem NG, methanol, O/S Ref	**1.13**	1.12	0.04	0.57	0.08	0.22	0.22	1.11	1.17	0.02	0.04	**119**	5	14	5	85	9	119	117	121	1	2
KOCH1	C-H2: Coal EU-mix, cen Ref, Pipe	**1.40**	1.38			0.19	0.99	0.22	1.38	1.41	0.02	0.02	**233**			31	193	9	233	232	234	1	1
KOCH1C	C-H2: Coal EU-mix, cen Ref, Pipe, CC&S	**1.77**	1.76			0.22	1.33	0.22	1.76	1.79	0.02	0.02	**51**			36	6	9	51	50	52	1	1
WWCH1	C-H2: Wood W, O/S gasif	**1.22**	0.19	0.06		0.00	0.94	0.22	1.12	1.32	0.10	0.10	**11**	1		0	1	9	11	10	11	1	1
WWCH2	C-H2: Wood W, Cen gasif. Pipe	**0.97**	0.23	0.04		0.03	0.68	0.22	0.89	1.05	0.08	0.08	**12**	1		2	0	9	12	11	13	1	1
BLCH1	C-H2: Wood W, Black liquor	**0.51**	0.20	0.04		0.01	0.25	0.22	0.48	0.55	0.03	0.04	**10**	0		0		9	10	9	11	1	1
WFCH1	C-H2: Wood F, O/S gasif	**1.24**	0.22	0.08		0.00	0.94	0.22	1.14	1.35	0.10	0.10	**15**	5		0	1	9	15	13	20	2	4
WFCH2	C-H2: Wood F, Cen gasif, pipe	**0.97**	0.23	0.06		0.01	0.68	0.22	0.89	1.05	0.08	0.09	**14**	4		1	1	9	14	13	18	1	4
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	2.83	0.42	0.11	**225**	11		44	162	9	225	201	232	25	7
GPEL1b/CH1	C-H2: NG 4000 km, CCGT, O/S Ely	**2.40**	2.40	0.08		0.30	1.88	0.15	2.16	2.56	0.24	0.16	**202**	10		23	162	8	202	188	212	14	9
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	2.64	0.26	0.19	**202**	10		23	161	9	202	187	213	16	11
GREL1/CH1	C-H2: LNG, O/S Ely	**2.75**	2.75	0.08		0.63	1.88	0.16	2.51	3.00	0.24	0.25	**220**	10		40	162	8	220	206	235	14	15
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	2.39	2.82	0.21	0.22	**13**	9		1	2	0	13	9	22	3	9
WFEL3/CH1	C-H2: F Wood, Conv power, O/S Ely	**4.43**	0.11	0.21		0.02	3.97	0.23	4.05	4.71	0.38	0.29	**31**	13		2	15	1	31	26	44	5	13
EMEL1/CH1	C-H2: Elec EU-mix, O/S Ely	**3.62**	3.39				3.43	0.19	3.45	3.79	0.17	0.17	**208**				200	8	208	200	216	8	8
KOEL1/CH1	C-H2: Elec coal EU-mix, O/S Ely	**3.17**	3.16			0.34	2.65	0.18	2.64	3.60	0.53	0.42	**423**			56	352	15	423	376	473	47	50
KOEL1/CH2	C-H2: Elec coal EU-mix, Cen ely, Pipe	**3.19**	3.17			0.34	2.62	0.22	2.66	3.54	0.53	0.35	**414**			56	350	9	414	366	458	48	43
NUEL1/CH1	C-H2: Elec nuclear, O/S Ely	**5.03**	5.02			0.96	3.82	0.25	4.76	5.29	0.27	0.27	**7**			6	0	0	7	7	7	0	0
WDEL1/CH2	C-H2: Wind, Cen Ely, Pipe	**0.79**	0.19			0.02	0.55	0.22	0.72	0.84	0.06	0.06	**9**					9	9	8	10	1	1
GPLH1a	L-H2:NG 7000 km, Cen Ref, Liq, Road	**1.33**	1.33	0.04		0.27	0.32	0.71	1.11	1.37	0.22	0.04	**141**	5		20	73	43	141	128	143	13	2
GPLH1b	L-H2: NG 4000 km, Cen Ref, Liq, Road	**1.13**	1.13	0.03		0.13	0.32	0.65	1.00	1.22	0.14	0.08	**126**	4		10	73	39	126	118	131	8	5
GRLH1	L-H2: Rem Ref, Liq, Sea, Road	**1.42**	1.42	0.04	1.08	0.26		0.04	1.30	1.57	0.12	0.15	**139**	5	130	1		3	139	132	147	7	9
GRLH2	L-H2: LNG, Cen Ref, Liq, Road	**1.34**	1.34	0.03	0.11	0.16	0.32	0.72	1.22	1.47	0.11	0.13	**137**	4	8	10	73	42	137	130	144	7	7
WFLH1	L-H2: Wood F, Cen gasif, Liq, Road	**1.50**	0.07	0.06		0.01	1.41	0.02	1.33	1.63	0.17	0.13	**8**	4		1	3	0	8	7	13	1	5
GPEL1b/LH1	L-H2: NG 4000 km, CCGT, Cen Ely, Liq, Road	**2.86**	2.86	0.08		0.29	1.83	0.66	2.57	3.03	0.29	0.17	**230**	9		22	159	40	230	213	240	17	10
EMEL1/LH1	L-H2: Elec EU-mix, Cen Ely, Liq, Road	**4.22**	3.97				3.35	0.88	4.02	4.42	0.21	0.20	**236**				196	40	236	227	245	9	9
KOEL1/LH1	L-H2: Elec coal EU-mix, Cen Ely, Liq, Road	**3.73**	3.72			0.34	3.35	0.04	3.18	4.16	0.55	0.43	**474**			55	417	3	474	431	531	44	56

9.4 Electricity

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 Urban for renewable combustion CO_2	Range			
KOEL1	Elec:EU-mix Coal conv.	**1.59**	1.58	0.22			1.34	0.03	1.23	1.78	0.35	0.19	**267**	36			231		267	231	287	36	20
KOEL2	Elec:EU-mix Coal IGCC	**1.35**	1.34	0.20			1.12	0.03	1.25	1.46	0.10	0.11	**239**	33			206		239	229	250	10	11
GPEL1a	Elec: NG 7000 km, CCGT	**1.31**	1.31	0.05		0.38	0.84	0.03	1.06	1.36	0.25	0.05	**140**	7		28	105		140	126	143	14	3
GPEL1b	Elec: NG 4000 km, CCGT	**1.11**	1.11	0.05		0.19	0.84	0.03	0.97	1.20	0.14	0.09	**126**	6		15	105		126	117	131	8	5
GREL1	Elec: LNG, CCGT	**1.33**	1.33	0.05	0.16	0.24	0.84	0.03	1.23	1.46	0.10	0.14	**137**	6	11	15	105		137	131	144	6	8
WFEL1	Elec: F Wood, 10 MW gasif	**2.03**	0.05	0.12		0.00	1.88	0.03	1.93	2.15	0.10	0.12	**10**	8		0	2		10	7	17	3	7
WFEL2	Elec: F Wood, 200 MW gasif	**1.24**	0.05	0.09		0.01	1.11	0.03	1.15	1.34	0.09	0.10	**8**	6		1	1		8	6	13	2	5
WFEL3	Elec: F Wood, Conv power	**2.37**	0.07	0.14		0.01	2.19	0.03	2.19	2.52	0.18	0.16	**19**	9		1	9		19	16	28	3	9
EMEL1	Elec: EU-mix	**1.87**	1.73				1.84	0.03	1.87	1.87	0.00	0.00	**129**				129		129	129	129	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	2.81	0.08	0.07	**4**	4			0		4	4	5	0	0
OWEL1a	Elec: Biogas ex municipal waste, local	**3.20**	-0.08				3.19	0.01	2.92	3.55	0.28	0.35	**6**				6		6	6	7	0	1
OWEL1b	Elec: Biogas ex municipal waste, large	**2.39**	0.21				2.36	0.03	2.09	2.67	0.30	0.29	**26**				26		26	21	31	5	5
OWEL2a	Elec: Biogas ex liquid manure, local	**3.06**	0.01		0.06		2.99	0.01	2.73	3.38	0.33	0.31	**-172**		-182		10		-172	-221	-123	48	50
OWEL2b	Elec: Biogas ex liquid manure, large	**2.56**	-0.06		0.05		2.48	0.03	2.26	2.89	0.30	0.32	**-149**		-163		14		-149	-195	-98	46	50
OWEL3a	Elec: Biogas ex dry manure, local	**3.02**	-0.03		0.02		2.99	0.01	2.70	3.31	0.32	0.29	**-8**		-17		10		-8	-12	-3	4	5
OWEL3b	Elec: Biogas ex dry manure, large	**2.53**	-0.09		0.02		2.48	0.03	2.16	2.87	0.36	0.34	**-1**		-15		14		-1	-7	4	5	5
BLEL1	Elec: Black liquor	**0.18**	0.01	0.03		0.01	0.11	0.03	0.15	0.22	0.04	0.04	**0**			0			0	1	1	0	0