

Cost calculations

Corrections from version 2b of May 2006

There was a significant error in the calculation of the cost of ethanol from straw. Small errors in the ethanol from wood and some hydrogen pathway costs have also been corrected. There are also minor changes in the bio-diesel pathways. Affected sections are

3.1	Ethanol from cellulose
7.2/8.2	Biofuels
7.4/7.5/7.8/7.9 8.4/8.5/8.8/8.9	Hydrogen + ICE
9.1/9.2	Summary tables

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1 General assumptions

For those fuels manufactured in Europe we estimated production costs on the basis of published literature. We used a capital charge of 12% representing a rate of return on investment of about 8% without accounting for a profit tax (which can be considered as an internal money stream within Europe). Capital investment figures were assumed to pertain to the low oil price scenario and an OCF of 0.1 was used. Uncertainty ranges of $\pm 20\%$ and $\pm 40\%$ were applied for established and new technologies respectively.

Operating costs were assumed to be 3% of capital investment for established technologies and 4.5% for new technologies or high-tech plants. A higher rate of 8% was used for refuelling stations.

Variable costs, mostly related to energy, resulted from the prices considered for the relevant fossil and renewable energy carriers.

Annual capital charge	12% (corresponding to 8% real-terms IRR, no tax)
Capex uncertainty range	
Established	20.0%
New	40.0%
OCF	0.10
Opex	% of capex
Low tech	3.0%
High tech	4.5%
Retail	8.0%

2 Feedstocks and raw materials

Fossil fuels

Crude oil	Density	LHV GJ/t	Low scenario		High scenario		Reference
	t/m ³		€/bbl	€/GJ	€/bbl	€/GJ	
	0.820	42.0	25	4.6	50	9.1	
Natural gas		Ratio to crude	€/GJ	OCF	€/GJ		IEA projections
At EU border		0.8	3.7	1.00	7.3		
Remote			2.0		4.0		
Coal			€/GJ	OCF	€/GJ		GEMIS, IEA
Hard			1.5	0.65	2.5		
Brown (Lignite)			1.2		2.0		
Nuclear fuel			€/GJ	OCF	€/GJ		GEMIS
			1.1	0.20	1.3		
Road fuels of fossil origin			€/GJ	OCF	€/GJ		
Gasoline and diesel fuel		Ratio to crude					Historical trend
		1.3	5.9	1.00	11.9		
LPG		Ratio to crude					Historical trend
		1.2	5.5	1.00	11.0		
Marine fuel oil		Ratio to Crude					Historical trend
		0.8	3.7	1.00	7.3		
Synthetic diesel		Ratio to diesel					
		1.2	7.1	1.00	14.2		
Methanol		Ratio to crude (t/t)					Historical trend
		1.0	9.6	0.40	13.5		

EU-mix electricity

EU-mix electricity	Low oil price		High oil price		Reference
	€/MWh		OCF	€/MWh	
		Cum.		Cumulative	
Production	38	38	0.50	57	GEMIS
MV dist.	20	58		77	
LV dist.	7	65		84	

Biomass

(Delivered cost to processing plant)

Delivered cost to processing plant								
	Moisture content	LHV	Low oil price		Own	High oil price		
			(oil at 25 €/bbl)			OCF	(oil at 50 €/bbl)	
			GJ/t	€ /t			€ /GJ	variability
Wheat grain	13%	14.8	95	6.4	16%	0.05	100	6.7
Sugar beet	77%	3.8	25	6.5	16%	0.05	26	6.8
Rapeseed	10%	23.8	237	9.9	14%	0.05	248	10.4
Sunflower seed	10%	23.8	265	11.1	14%	0.05	278	11.7
Wheat straw	16%	14.4	35	2.4	13%	0.05	37	2.5
Waste wood	0%	18.0	50	2.8	13%	0.05	53	2.9
Farmed wood	0%	18.0	77	4.3	5%	0.05	81	4.5
By-products substitutes								
Animal feed substitute		14.4	95	6.6	20%	0.10	105	7.3
Glycerine substitute		20.0	130	6.5	16%	0.68	218	

References: [FfE 1998], [Kaltschmitt 2001], [Fahrzeugbau Langendorf 2001], [Messer 1999], [ETSU 1996], [ESU 1996], [ADEME 2002], [NAS 1998], [DG AGRI 2005], [FAPRI 2005], [Lundmark 2004]

3 Production plants

All tables in this section are built on the same model detailing:

- Plant scale: product production rate in kt/a, PJ/a and MW and hours of operation per annum
- Feed rate in kt/a and PJ/a and feed cost in €/t and M€/a
- Capital expenditure (capex) in M€ and capital charge in M€/a
- Operating costs (opex) split into fixed (proportion of capex) and variable (net energy and chemicals, including energy credits)
- By-products credits including production rate in PJ/a, unit cost in €/t or GJ and value in M€/a

3.1 Bio-fuels

Ethanol from sugar beet		Oil at 25 €/bbl	
Pulp to		Animal feed	Energy
Pathway code		SBET1	SBET3
Plant scale			
Ethanol	kt/a	28	28
	PJ/a	0.76	0.76
	MW	59	59
	h/a	3600	3600
Sugar beet (76.5% moisture)			
	kt/a	375	375
	PJ/a	1.4	1.4
	€/t	25+-16%	
	M€/a	9.4	9.4
Capex	M€	17+-20%	28+-20%
Capital charge @ 12%	M€/a	2.0	3.4
Opex	M€/a	1.6	1.0
Fixed		0.5	0.8
Net energy and chemicals		1.1	0.2
Credit for pulp & slops	PJ/a	-0.3	-0.4
	€/GJ	5.3	
	M€/a	-1.6	-1.2
Total annual production cost	M€/a	11.4	12.6
Total specific production cost	€/GJ	15.0	16.5
of which:			
Sugar beet		12.3	12.3
Capex		2.7	4.4
Opex		2.1	1.3
Credits		-2.1	-1.5

Capex source: [FfE 1998]

Ethanol from sugar beet		Oil at 50 €/bbl	
Pulp to		Animal feed	Energy
Pathway code		SBET1	SBET3
Plant scale			
Ethanol	kt/a	28	28
	PJ/a	0.76	0.76
	MW	59	59
	h/a	3600	3600
Sugar beet (76.5% moisture)			
	kt/a	375	375
	PJ/a	1.4	1.4
	€/t	26+-16%	
	M€/a	9.8	9.8
Capex	M€	19+-20%	31+-20%
Capital charge @ 12%	M€/a	2.2	3.7
Opex	M€/a	2.5	1.3
Fixed		0.6	0.9
Net energy and chemicals		2.0	0.4
Credit for pulp & slops	PJ/a	-0.3	-0.4
	€/GJ	5.6	
	M€/a	-1.6	-2.1
Total annual production cost	M€/a	13.0	12.7
Total specific production cost	€/GJ	17.1	16.7
of which:			
Sugar beet		13.0	13.0
Capex		3.0	4.9
Opex		3.3	1.7
Credits		-2.2	-2.8

WTW APPENDIX 2

Ethanol from wheat grain		Oil at 25 €/bbl							
DDGS to		Animal feed				Energy			
Energy production scheme		Conv. Boiler	CCGT	Coal CHP	Straw CHP	CCGT	CCGT	Coal CHP	Straw CHP
Pathway code		WTET1a	WTET2a	WTET3a	WTET4a	WTET1b	WTET2b	WTET3b	WTET4b
Plant scale	Ethanol								
	kt/a					100			
	PJ/a					2.7			
	MW					93			
	h/a					8000			
Wheat grain (13% moisture)	kt/a					338			
	PJ/a					5.0			
	€/t					95+-16%			
	M€/a					32.1			
Capex	M€	60+-20%	78+-20%	105+-20%	105+-40%	60+-20%	78+-20%	105+-20%	105+-40%
Capital charge @ 12%	M€/a	7.2	9.4	12.6	12.6	7.2	9.4	12.6	12.6
Opex	M€/a	9.1	1.8	4.7	7.3	9.1	1.8	4.7	7.3
Fixed		1.8	2.3	4.7	4.7	1.8	2.3	4.7	4.7
Net energy and chemicals		7.3	-0.5	0.0	2.6	7.3	-0.5	0.0	2.6
Credit for DDGS	kt/a					-114			
	€/t	74				24			
	M€/a	-8.4				-2.7			
Total annual production cost	M€/a	39.9	34.8	41.0	43.5	45.6	40.5	46.7	49.2
Total specific production cost	€/GJ	14.9	13.0	15.3	16.2	17.0	15.1	17.4	18.4
of which:									
Wheat grain		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Capex		2.7	3.5	4.7	4.7	2.7	3.5	4.7	4.7
Opex		3.4	0.7	1.8	2.7	3.4	0.7	1.8	2.7
Credits		-3.2	-3.2	-3.2	-3.2	-1.0	-1.0	-1.0	-1.0

Capex source: [LowCVP 2004]

Ethanol from wheat grain		Oil at 50 €/bbl							
DDGS to		Animal feed				Energy			
Energy production scheme		Conv. Boiler	CCGT	Coal CHP	Straw CHP	CCGT	CCGT	Coal CHP	Straw CHP
Pathway code		WTET1a	WTET2a	WTET3a	WTET4a	WTET1b	WTET2b	WTET3b	WTET4b
Plant scale	Ethanol								
	kt/a					100			
	PJ/a					2.7			
	MW					93			
	h/a					8000			
Wheat grain (13% moisture)	kt/a					338			
	PJ/a					5.0			
	€/t					100+-16%			
	M€/a					33.7			
Capex	M€	66+-20%	86+-20%	116+-20%	116+-40%	66+-20%	86+-20%	116+-20%	116+-40%
Capital charge @ 12%	M€/a	7.9	10.3	13.9	13.9	7.9	10.3	13.9	13.9
Opex	M€/a	14.8	6.8	6.5	7.7	14.8	6.8	6.5	7.7
Fixed		2.0	2.6	5.2	5.2	2.0	2.6	5.2	5.2
Net energy and chemicals		12.8	4.3	1.4	2.5	12.8	4.3	1.4	2.5
Credit for DDGS	kt/a					-114			
	€/t	82				39.6			
	M€/a	-9.3				-4.5			
Total annual production cost	M€/a	47.1	41.5	44.8	46.0	51.9	46.3	49.6	50.8
Total specific production cost	€/GJ	17.6	15.5	16.7	17.2	19.4	17.3	18.5	18.9
of which:									
Wheat grain		12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
Capex		3.0	3.8	5.2	5.2	3.0	3.8	5.2	5.2
Opex		5.5	2.6	2.4	2.9	5.5	2.6	2.4	2.9
Credits		-3.5	-3.5	-3.5	-3.5	-1.7	-1.7	-1.7	-1.7

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Ethanol from cellulose		Oil at 25 €/bbl		
Feedstock		Wheat straw	Wood farmed	Wood waste
Pathway code		STET1	WFET1	WWET1
Plant scale				
Ethanol	kt/a	71	71	
	PJ/a	1.90	1.90	
	MW	66	66	
	h/a	8000	8000	
Feed (0% moisture)				
	kt/a	251	308	
	PJ/a	4.5	5.5	
	€/t	42+-13%	77+-5%	50+-13%
	M€/a	10.5	23.7	15.4
Capex	M€	136+-20%	119+-40%	
Capital charge @ 12%	M€/a	16.3	14.3	
Opex	M€/a	11.5	8.2	
Fixed		8.2	7.1	
Net energy and chemicals		3.3	1.1	
Total annual production cost	M€/a	38.2	46.2	37.9
Total specific production cost	€/GJ	20.1	24.3	19.9
of which:				
Feed		5.5	12.5	8.1
Capex		8.6	7.5	7.5
Opex		6.0	4.3	4.3

Capex source: [Wooley 1999]

Ethanol from cellulose		Oil at 50 €/bbl		
Feedstock		Wheat straw	Wood farmed	Wood waste
Pathway code		STET1	WFET1	WWET1
Plant scale				
Ethanol	kt/a	71	71	
	PJ/a	1.90	1.90	
	MW	66	66	
	h/a	8000	8000	
Feed (0% moisture)				
	kt/a	251	308	
	PJ/a	4.5	5.5	
	€/t	44+-13%	81+-5%	53+-13%
	M€/a	11.0	24.9	16.2
Capex	M€	136+-20%	131+-40%	
Capital charge @ 12%	M€/a	16.3	15.7	
Opex	M€/a	13.1	10.0	
Fixed		8.2	7.8	
Net energy and chemicals		4.9	2.1	
Total annual production cost	M€/a	40.4	50.5	41.8
Total specific production cost	€/GJ	21.3	26.6	22.0
of which:				
Feed		5.8	13.1	8.5
Capex		8.6	8.3	8.3
Opex		6.9	5.2	5.2

WTW APPENDIX 2

Bio-diesel from oil seeds

Oil at 25 €/bbl

Glycerine to		Animal feed			Chemical		
Feedstock		Rape MeOH	Rape EtOH	Sunflower MeOH	Rape MeOH	Rape EtOH	Sunflower MeOH
Pathway code		ROFA1	ROFE1	SOFA1	ROFA2	ROFE2	SOFA2
Plant scale							
Bio-diesel production	kt/a	100	100	100	100	100	100
	PJ/a	3.7	3.8	3.7	3.7	3.8	3.7
	MW	148	150	148	148	150	148
	h/a	7000	7000	7000	7000	7000	7000
Oil seeds (10% moisture)	kt/a	268	258	249	268	258	249
	PJ/a	6.4	6.1	5.9	6.4	6.1	5.9
	€/t	237+-14%	237+-14%	265+-14%	237+-14%	237+-14%	265+-14%
	M€/a	63.3	60.9	66.0	63.3	60.9	66.0
Alcohol	kt/a	11	21	11	11	21	11
	PJ/a	0.2	0.4	0.2	0.2	0.4	0.2
	€/GJ	9.6	13.0	9.6	9.6	13.0	9.6
	M€/a	2.1	5.4	2.1	2.1	5.4	2.1
Capex		30+-20%					
Capital charge @ 12%		3.5					
Opex		3.0	3.0	2.9	3.0	3.0	2.9
Fixed		0.9					
Net energy and chemicals		2.1	2.1	2.0	2.1	2.1	2.0
Credits							
Cake ⁽¹⁾	kt/a	-159	-153	-159	-159	-153	-159
	€/t			76			
Glycerine ⁽²⁾	kt/a	-11	-10	-11	-11	-10	-11
	€/t		108			130	
	M€/a	-13.2	-12.7	-13.2	-13.5	-12.9	-13.5
Total annual production cost		58.7	60.1	61.4	58.4	59.9	61.1
Total specific production cost		15.8	15.9	16.5	15.7	15.8	16.4
of which:							
Oil seeds		17.0	16.1	17.8	17.0	16.1	17.8
Alcohol		0.6	1.4	0.6	0.6	1.4	0.6
Capex		1.0	0.9	1.0	1.0	0.9	1.0
Opex		0.8	0.8	0.8	0.8	0.8	0.8
Credits		-3.6	-3.3	-3.6	-3.6	-3.4	-3.6

Capex sources: [VDI 22 November 2002], [UBA 1999], [Oelmühle Leer Connemann 2000], [ETSU 1996]

⁽¹⁾ Price based on soya meal, 0.80 replacement ratio

⁽²⁾ Animal feed price based on dry wheat grain, 0.99 replacement ratio

WTW APPENDIX 2

Bio-diesel from oil seeds		Oil at 50 €/bbl					
Glycerine to		Animal feed			Chemical		
Feedstock		Rape MeOH	Rape EtOH	Sunflower MeOH	Rape MeOH	Rape EtOH	Sunflower MeOH
Pathway code		ROFA1	ROFE1	SOFA1	ROFA2	ROFE2	SOFA2
Plant scale							
Bio-diesel production	kt/a	100	100	100	100	100	100
	PJ/a	3.7	3.8	3.7	3.7	3.8	3.7
	MW	148	150	148	148	150	148
	h/a	7000	7000	7000	7000	7000	7000
Oil seeds (10% moisture)	kt/a	268	258	249	268	258	249
	PJ/a	6.4	6.1	5.9	6.4	6.1	5.9
	€/t	248+-14%	248+-14%	278+-14%	248+-14%	248+-14%	278+-14%
	M€/a	66.4	63.9	69.3	66.4	63.9	69.3
Alcohol	kt/a	11	21	11	11	21	11
	PJ/a	0.2	0.4	0.2	0.2	0.4	0.2
	€/GJ	13.5	15.5	13.5	13.5	15.5	13.5
	M€/a	2.9	6.5	2.9	2.9	6.5	2.9
Capex	M€	32+-20%					
Capital charge @ 12%	M€/a	3.9					
Opex	M€/a	4.7	4.7	4.6	4.7	4.7	4.6
Fixed		1.0					
Net energy and chemicals		3.7	3.7	3.6	3.7	3.7	3.6
Credits							
Cake ⁽¹⁾	kt/a	-159	-153	-159	-159	-153	-159
	€/t			84			
Glycerine ⁽²⁾	kt/a	-11	-10	-11	-11	-10	-11
	€/t		114			218	
	M€/a	-14.5	-13.9	-14.5	-15.6	-14.9	-15.6
Total annual production cost	M€/a	63.5	65.1	66.2	62.4	64.0	65.1
Total specific production cost	€/GJ	17.1	17.2	17.8	16.8	16.9	17.5
of which:							
Oil seeds		17.9	16.9	18.6	17.9	16.9	18.6
Alcohol		0.8	1.7	0.8	0.8	1.7	0.8
Capex		1.0	1.0	1.0	1.0	1.0	1.0
Opex		1.3	1.2	1.2	1.3	1.2	1.2
Credits		-3.9	-3.7	-3.9	-4.2	-3.9	-4.2

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Biogas from organic waste		Oil at 25 €/bbl	
Feedstock		Manure liquid	Org. waste Liq. 0.2/0.8
Pathway code		OWCG2	OWCG3
Plant scale			
Biogas	kt/a	1.01	
	TJ/a	50.4	
	MW	2.0	
	h/a	7000	
Organic waste		97.6	97.6
	TJ/a	97.6	97.6
	€/TJ	4.1	3.3
	k€/a	205.4	164.3
Capex	k€	4000+-40%	2800+-40%
Capital charge @ 12%	k€/a	480	336
Opex	k€/a	389.1	279.8
Fixed		400.0	280.0
Net energy and chemicals		-10.9	-0.2
Total annual production cost	k€/a	1074	780
Total specific production cost	€/GJ	21.3	15.5

Biogas from organic waste		Oil at 50 €/bbl	
Feedstock		Manure liquid	Org. waste Liq. 0.2/0.8
Pathway code		OWCG2	OWCG3
Plant scale			
Biogas	kt/a	1.01	
	TJ/a	50.4	
	MW	2.0	
	h/a	7000	
Organic waste		97.6	97.6
	TJ/a	97.6	97.6
	€/TJ	4.1	3.3
	k€/a	209.1	167.3
Capex	k€	4400+-40%	3080+-40%
Capital charge @ 12%	k€/a	528	370
Opex	k€/a	425.6	307.7
Fixed		440.0	308.0
Net energy and chemicals		-14.4	-0.3
Total annual production cost	k€/a	1163	845
Total specific production cost	€/GJ	23.1	16.8

WTW APPENDIX 2

3.2 Synthetic fuels

Synthetic diesel		Oil at 25 €/bbl			
Feedstock		Coal	Wood farmed	Wood waste standard	Wood waste via BL
Pathway code		KOSD1	WFSD1	WWSD1	BLSD1
Plant scale					
Syn-fuels (diesel+naphtha)	kt/a	1462	63		119
	PJ/a	64.3	2.8		5.2
	MW	2234	103		194
	h/a	8000	7500		7500
Feedstock (dry)	kt/a	3374	320		533
	PJ/a	114.7	5.8		9.6
	€/GJ	1.5	4.3+-5%	2.8+-13%	
	M€/a	172.1	24.6	16.0	26.6
Capex	M€	2811+-40%	260+-40%		263+-40%
Capital charge @ 12%	M€/a	337.3	31.2		31.5
Opex	M€/a	126.5	14.7		14.8
Fixed		126.5	11.7		11.8
Net energy and chemicals		0.0	3.0		3.0
Total annual production cost	M€/a	635.9	70.5	61.9	72.9
Total specific production cost	€/GJ	9.9	25.4	22.3	13.9
of which:					
Feedstock		2.7	8.9	5.8	5.1
Capex		5.2	11.2	11.2	6.0
Opex		2.0	5.3	5.3	2.8

Capex sources:

KOSD1: [Gray 2001] (modified)

WF/WWSD1: [Woods 2003]

BLSD1: [ALTENER 2003]

Synthetic diesel		Oil at 50 €/bbl			
Feedstock		Coal	Wood farmed	Wood waste standard	Wood waste via BL
Pathway code		KOSD1	WFSD1	WWSD1	BLSD1
Plant scale					
Syn-fuels (diesel+naphtha)	kt/a	1462	63		119
	PJ/a	64.3	2.8		5.2
	MW	2234	103		194
	h/a	8000	7500		7500
Feedstock (dry)	kt/a	3374	320		533
	PJ/a	114.7	5.8		9.6
	€/GJ	2.5	4.5+-5%	2.9+-13%	
	M€/a	284.0	25.9	16.8	28.0
Capex	M€	3092+-40%	286+-40%		318+-40%
Capital charge @ 12%	M€/a	371.0	34.3		38.1
Opex	M€/a	139.1	15.9		17.3
Fixed		139.1	12.9		14.3
Net energy and chemicals		0.0	3.0		3.0
Total annual production cost	M€/a	794.1	76.1	67.0	83.4
Total specific production cost	€/GJ	12.3	27.4	24.1	15.9
of which:					
Feedstock		4.4	9.3	6.1	5.3
Capex		5.8	12.4	12.4	7.3
Opex		2.2	5.7	5.7	3.3

WTW APPENDIX 2

Methanol		Oil at 25 €/bbl				
Feedstock		NG	Coal	Wood farmed	Wood waste standard	Wood waste via BL
Pathway code		GPME1b	KOME1	WFME1	WWME1	BLME1
Plant scale						
Methanol	kt/a	839	2974	148		391
	PJ/a	16.7	59.2	2.9		7.8
	MW	579	2055	102		270
	h/a	8000	8000	8000		8000
Feedstock (dry)						
	kt/a		3374	320		656
	PJ/a	24.5	99.2	5.8		11.8
	€/GJ	3.7	1.5	4.3+-5%	2.8+-13%	
	M€/a	89.4	148.8	24.6	16.0	32.8
Capex		M€				
		310+-40%	2023+-40%	150+-40%		150+-40%
		310	2023	150		150
Capital charge @ 12%		M€/a	37.2	242.7	18.0	18.0
Opex		M€/a	14.0	91.0	9.3	9.3
Fixed		14.0	91.0	6.8		6.8
	Net energy and chemicals	0.0	0.0	2.5		2.5
Total annual production cost		M€/a	140.6	482.5	51.9	43.3
Total specific production cost		€/GJ	8.4	8.2	17.6	14.7
of which:						
Feedstock		5.4	2.5	8.4	5.4	4.2
	Capex	2.2	4.1	6.1	6.1	2.3
	Opex	0.8	1.5	3.1	3.1	1.2

Capex sources: [Katofsky 1993], [Larsen 1998], [ALTENER 2003]

Methanol		Oil at 50 €/bbl				
Feedstock		NG	Coal	Wood farmed	Wood waste standard	Wood waste via BL
Pathway code		GPME1b	KOME1	WFME1	WWME1	BLME1
Plant scale						
Methanol	kt/a	839	2974	148		391
	PJ/a	16.7	59.2	2.9		7.8
	MW	579	2055	102		270
	h/a	8000	8000	8000		8000
Feedstock (dry)						
	kt/a		3374	320		656
	PJ/a	24.5	99.2	5.8		11.8
	€/GJ	7.3	2.5	4.5+-5%	2.9+-13%	
	M€/a	178.8	245.5	25.9	16.8	34.4
Capex		M€				
		341+-40%	2225+-40%	165+-40%		165+-40%
		341	2225	165		165
Capital charge @ 12%		M€/a	40.9	267.0	19.8	19.8
Opex		M€/a	15.3	100.1	9.9	9.9
Fixed		15.3	100.1	7.4		7.4
	Net energy and chemicals	0.0	0.0	2.5		2.5
Total annual production cost		M€/a	235.1	612.6	55.6	46.5
Total specific production cost		€/GJ	14.1	10.4	18.9	15.8
of which:						
Feedstock		10.7	4.1	8.8	5.7	4.4
	Capex	2.5	4.5	6.7	6.7	2.5
	Opex	0.9	1.7	3.4	3.4	1.3

Note: Minimum cost for methanol taken as per section 2. Cases giving lower values presented for reference only

WTW APPENDIX 2

DME		Oil at 25 €/bbl				
Feedstock		NG	Coal	Wood	Wood waste	Wood waste
		4000 km		farmed	standard	via BL
Pathway code		GPDE1b	KODE1	WFDE1	WWDE1	BLDE1
Plant scale						
DME	kt/a	603	2082	103		273
	PJ/a	17.1	59.2	2.9		7.8
	MW	595	2055	102		269
	h/a	8000	8000	8000		8000
Feedstock (dry)						
	kt/a	489	3374	320		640
	PJ/a	24.0	99.2	5.8		11.5
	€/GJ	3.7	1.5	4.3+-5%	2.8+-13%	
	M€/a	87.8	148.8	24.6	16.0	32.0
Capex						
	M€	310+-40%	2023+-40%	165+-40%		164+-40%
		310	2023	165		164
Capital charge @ 12%		M€/a	37.2	242.7	19.8	19.7
Opex		M€/a	14.0	91.0	10.1	10.1
Fixed			14.0	91.0	7.4	7.4
Net energy and chemicals			0.0	0.0	2.7	2.7
Total annual production cost		M€/a	139.0	482.5	54.6	45.9
Total specific production cost		€/GJ	8.1	8.2	18.6	15.6
of which:						
Feedstock			5.1	2.5	8.4	5.4
Capex			2.2	4.1	6.7	6.7
Opex			0.8	1.5	3.4	3.4

Capex sources: [Katofsky 1993], [Larsen 1998], [ALTENER 2003]

DME		Oil at 50 €/bbl				
Feedstock		NG	Coal	Wood	Wood waste	Wood waste
		4000 km		farmed	standard	via BL
Pathway code		GPDE1b	KODE1	WFDE1	WWDE1	BLDE1
Plant scale						
DME	kt/a	603	2082	103		273
	PJ/a	17.1	59.2	2.9		7.8
	MW	595	2055	102		269
	h/a	8000	8000	8000		8000
Feedstock (dry)						
	kt/a	489	3374	320		640
	PJ/a	24.0	99.2	5.8		11.5
	€/GJ	7.3	2.5	4.5+-5%	2.9+-13%	
	M€/a	175.7	245.5	25.9	16.8	33.6
Capex						
	M€	341+-40%	2225+-40%	182+-40%		180+-40%
		341	2225	182		180
Capital charge @ 12%		M€/a	40.9	267.0	21.8	21.6
Opex		M€/a	15.4	100.1	10.9	10.8
Fixed			15.3	100.1	8.2	8.1
Net energy and chemicals			0.0	0.0	2.7	2.7
Total annual production cost		M€/a	232.0	612.6	58.5	49.4
Total specific production cost		€/GJ	13.5	10.4	19.9	16.8
of which:						
Feedstock			10.3	4.1	8.8	5.7
Capex			2.4	4.5	7.4	7.4
Opex			0.9	1.7	3.7	3.7

Notes:

- The literature references for coal to syn-diesel and coal to methanol were on significantly different plant scales (about twice as large for coal). In our opinion the same scale should be achievable for both. We therefore scaled up the methanol plant size and capex. Even after scaling the figures resulted in a lower unit cost for the syn-diesel which we deemed inconsistent. We therefore increased the syn-diesel plant capex by 30% to obtain more plausible figures.
- Minimum cost for DME was taken as per methanol cost in *section 2* (energy content basis). Cases giving lower values are presented for reference only.

3.3 Hydrogen

Hydrogen (thermal processes) Oil at 25 €/bbl										
Feedstock		NG		Coal	Wood farmed		Wood waste standard		Wood waste via BL	Liquefaction
		On-site	Central		On-site	Central	On-site	Central		
Pathway code		(1)	(2)	KOCH1	WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	
Plant scale										
Hydrogen	kt/a	0.43	48.0	48.0	1.2	27.2	1.2	27.2	55.3	
	PJ/a	0.05	5.8	5.8	0.14	3.3	0.1	3.3	6.6	5.8
	MW	2.4	200	200	5.2	121	5	121	246	200
	h/a	6000	8000	8000	7500	7500	7500	7500	7500	8000
Feedstock	kt/a			385	15	300	15	300	458	
	PJ/a	0.07	7.6	11.3	0.27	5.4	0.27	5.4	8.2	
	€/GJ	4.2	4.2	1.5	4.3+-5%	4.3+-5%	2.8+-13%	2.8+-13%	2.8+-13%	
	M€/a	0.32	32.1	17.0	1.2	23.1	0.8	15.0	22.9	
Capex	M€	3+-40%	60+-40%	300+-40%	7+-40%	100+-40%	7+-40%	100+-40%	100+-40%	180+-40%
Capital charge	M€/a	0.3	7.2	36.0	0.8	12.0	0.8	12.0	12.0	21.6
Opex	M€/a	0.1	2.7	13.5	0.3	4.5	0.3	4.5	4.5	35.9
Fixed		0.13	2.7	13.5	0.3	4.5	0.3	4.5	4.5	8.1
Net energy and chemicals		0.02			-0.01		0.0			27.8
Total annual production cost	M€/a	0.8	42.0	66.5	2.3	39.6	1.9	31.5	39.4	57.5
Total specific production cost	€/GJ	15.3	7.3	11.5	16.4	12.1	13.5	9.7	5.9	10.0
of which:										
Feedstock		6.1	5.6	3.0	8.3	7.1	5.4	4.6	3.4	
Capex		6.5	1.3	6.3	6.0	3.7	6.0	3.7	1.8	3.8
Opex		2.7	0.5	2.3	2.2	1.4	2.2	1.4	0.7	6.2

(1) GPCH1a/b, GRCH1

(2) GPCH2a/b, GPCH3b, GPLCHb, GRCH2, GPLH1b, GRLH2

Capex derived from:

On-site reformer: [Haldor Topsoe 1998]

Central reformer: [Linde 1992]

Coal gasifier: [Katoisky 1993]

Small scale wood gasifier: [DM2 2001], [Questor 2002]

Large scale wood gasifier: [Katoisky 1993]

Black liquor: [ALTENER 2003]

Liquefaction: [NHEG 1992]

Hydrogen (thermal processes) Oil at 50 €/bbl										
Feedstock		NG		Coal	Wood farmed		Wood waste standard		Wood waste via BL	Liquefaction
		On-site	Central		On-site	Central	On-site	Central		
Pathway code		(1)	(2)	KOCH1	WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	
Plant scale										
Hydrogen	kt/a	0.43	48.0	48.0	1.2	27.2	1.2	27.2	55.3	
	PJ/a	0.05	5.8	5.8	0.14	3.3	0.1	3.3	6.6	5.8
	MW	2.4	200	200	5.2	121	5	121	246	200
	h/a	6000	8000	8000	7500	7500	7500	7500	7500	8000
Feedstock	kt/a			385	15	300	15	300	458	
	PJ/a	0.07	7.6	11.3	0.27	5.4	0.27	5.4	8.2	
	€/GJ	8.1	8.1	2.475	4.5+-5%	4.5+-5%	2.9+-13%	2.9+-13%	2.9+-13%	
	M€/a	0.60	61.0	28.0	1.2	24.3	0.8	15.8	24.0	
Capex	M€	3+-40%	66+-40%	330+-40%	8+-40%	110+-40%	8+-40%	110+-40%	110+-40%	198+-40%
Capital charge	M€/a	0.4	7.9	39.6	0.9	13.2	0.9	13.2	13.2	23.8
Opex	M€/a	0.2	3.0	14.9	0.3	5.0	0.3	5.0	5.0	45.9
Fixed		0.14	3.0	14.9	0.3	5.0	0.3	5.0	5.0	8.9
Net energy and chemicals		0.02			-0.01		0.0			37.0
Total annual production cost	M€/a	1.1	71.9	82.5	2.5	42.4	2.0	33.9	42.2	69.6
Total specific production cost	€/GJ	21.8	12.5	14.3	17.7	13.0	14.6	10.4	6.4	12.1
of which:										
Feedstock		11.6	10.6	4.9	8.7	7.4	5.6	4.8	3.6	
Capex		7.1	1.4	6.9	6.6	4.0	6.6	4.0	2.0	4.1
Opex		3.0	0.5	2.6	2.4	1.5	2.4	1.5	0.7	8.0

WTW APPENDIX 2

Electricity generation		Oil at 25 €/bbl				
Feedstock		NG CCGT	Coal		Nuclear	Wind
Pathway code		GPEL1a/b GREL1	Conv. KOEL1	IGCC KOEL2	NUEL1	WDEL1
Plant scale						
Electricity	PJe/a	15.1	15.1	15.1	22.7	5.4
	MW	600	600	600	900	500
	h/a	7000	7000	7000	7000	3000
Feedstock						
	kt/a					
	PJ/a	27.5	27.5	27.5	41.2	
	€/GJ	4.1	1.5	1.5	1.1	
	M€/a	112.3	41.2	41.2	45.8	
Capex	M€	320+-20%	630+-20%	100+-20%	300+-20%	600+-40%
Capital charge	M€/a	38.4	75.6	132.0	276.0	72.0
Opex	M€/a	14.4	28.4	49.5	103.5	27.0
Total annual production cos M€/a		165.1	145.2	222.7	425.3	99.0
Total specific production co: €/GJe		10.9	9.6	14.7	18.8	18.3
of which:						
Feedstock		7.4	2.7	2.7	2.0	0.0
Capex		2.5	5.0	8.7	12.2	13.3
Opex		1.0	1.9	3.3	4.6	5.0

Capex derived from:

NG CCGT: [TAB 1999], [GEMIS]

Coal, conventional: [TAB 1999]

Coal, IGCC: [ENEA 2004]

Nuclear: [GEMIS]

Wind: [DTI 2002]

Electricity generation		Oil at 50 €/bbl				
Feedstock		NG CCGT	Coal		Nuclear	Wind
Pathway code		GPEL1a/b GREL1	Conv. KOEL1	IGCC KOEL2	NUEL1	WDEL1
Plant scale						
Electricity	PJe/a	15.1	15.1	15.1	22.7	5.4
	MW	600	600	600	900	500
	h/a	7000	7000	7000	7000	3000
Feedstock						
	kt/a					
	PJ/a	27.5	27.5	27.5	41.2	
	€/GJ	7.9	2.5	2.5	1.3	
	M€/a	216.9	68.0	68.0	55.0	
Capex	M€	352+-20%	693+-20%	210+-20%	530+-20%	660+-40%
Capital charge	M€/a	42.2	83.2	145.2	303.6	79.2
Opex	M€/a	15.8	31.2	54.5	113.9	29.7
Total annual production cos M€/a		275.0	182.4	267.7	472.5	108.9
Total specific production co: €/GJe		18.2	12.1	17.7	20.8	20.2
of which:						
Feedstock		14.3	4.5	4.5	2.4	0.0
Capex		2.8	5.5	9.6	13.4	14.7
Opex		1.0	2.1	3.6	5.0	5.5

WTW APPENDIX 2

Electrolysers		Oil at 25 €/bbl	
Type		Central	On-site
Plant scale			
Hydrogen	kt/a	48.0	0.9
	PJ/a	5.8	0.1
	MW	200	5
	h/a	8000	6000
Electricity distribution	PJ€/a	8.9	0.2
	€/GJe	5.6	7.5
	M€/a	49.2	1.2
Capex	M€	100+-20%	2.5+-20%
Capital charge	M€/a	12.0	0.3
Opex	M€/a	3.0	0.1
Total annual production cos: M€/a		64.2	1.6
Total specific production co: €/GJe		11.2	15.0
of which:			
Electricity		8.5	11.5
Capex		2.1	2.8
Opex		0.5	0.7

Capex derived from: [GHW 2003], [GHW 2004] (proportional to plant size)

Electrolysers		Oil at 50 €/bbl	
Type		Central	On-site
Plant scale			
Hydrogen	kt/a	48.0	0.9
	PJ/a	5.8	0.1
	MW	200	5
	h/a	8000	6000
Electricity distribution	PJ€/a	8.9	0.2
	€/GJe	5.6	7.5
	M€/a	49.2	1.2
Capex	M€	110+-20%	2.8+-20%
Capital charge	M€/a	13.2	0.3
Opex	M€/a	3.3	0.1
Total annual production cos: M€/a		65.7	1.7
Total specific production co: €/GJe		11.4	15.4
of which:			
Electricity		8.5	11.5
Capex		2.3	3.1
Opex		0.6	0.8

4 Final fuels distribution and retail

Oil at 25 €/bbl

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Fuel	Energy consumption			Energy cost €/GJ	Distribution infrastructure ⁽¹⁶⁾ €/GJ	Refuelling station		
	Diesel MJ/GJ	Electricity kWh/GJ				Capex k€	Opex k€/a	Annual cost k€/a
		MV	LV					
Liquid fuels								
Conv. gasoline and diesel ⁽¹⁾					⁽²⁾			
Gasoline	4.6	0.6	0.9	0.1	0.2			
Diesel	4.6	0.6	0.9	0.1	0.2			
Ethanol ⁽³⁾	11.3	0.7	0.9	0.2	0.6	⁽⁴⁾		
Bio-diesel ⁽³⁾	8.1	0.7	0.9	0.1	0.5	⁽⁴⁾		
Syn-diesel					⁽⁴⁾			
Large scale or import ⁽⁵⁾	4.6	0.6	0.9	0.1	0.2			
Small scale ⁽⁶⁾	6.9	0.2	0.9	0.1	0.5			
Methanol					⁽⁴⁾	50	4	10
Large scale or import ⁽⁷⁾	12.7	0.7	0.9	0.2	2.1			
Small scale ⁽⁸⁾	7.6		0.9	0.1	0.6			
DME						125	10	25
Large scale import ⁽⁷⁾	11.5	0.5	0.9	0.2	2.9	⁽⁹⁾		
Large scale EU ⁽⁷⁾	11.5	0.5	0.9	0.2	1.8			
Small scale ⁽⁸⁾	6.9		0.9	0.1	0.5			
CNG				0.4				
Distribution	10.0	⁽¹⁰⁾			0.2	⁽¹¹⁾		
Retail ⁽¹²⁾			6.1			350	28	70
LPG				0.1				
Distribution	13.8				2.1	⁽⁴⁾		
Retail			0.9			125	10	25
Hydrogen								
Compressed								
Local pipeline grid ⁽¹³⁾					2.7			
Road tanker	16.0			0.1	4.2			
Refuelling (8.8 MPa) ⁽¹⁴⁾						730	106	194
On-site production (2 MPa)			19.6					
Central production (3 MPa)			17.1					
Liquid ⁽¹⁵⁾			0.3			450	37	91
Road tanker	18.4			0.1	3.9			
Liquid dispensed as compressed ⁽¹⁵⁾			6.9			660	77	156

⁽¹⁾ 250 km, barge/rail/pipeline + 150 km road, also includes ethers

⁽²⁾ Notional cost for marginal tankage, railcars, trucks, etc

⁽³⁾ 2 x 150 km, road

⁽⁴⁾ Notional cost for additional tankage, railcars, trucks, etc

⁽⁵⁾ 250 km, barge/rail/pipeline + 150 km road

⁽⁶⁾ 2 x 150 km, road (e.g. small scale wood-based plant)

⁽⁷⁾ 500 km, 50/50 rail/road

⁽⁸⁾ 150 km, road (e.g. small scale wood-based plant)

⁽⁹⁾ Including long-distance shipping

⁽¹⁰⁾ Natural gas

⁽¹¹⁾ Notional cost for distribution network maintenance

⁽¹²⁾ Including connection to existing gas grid

⁽¹³⁾ 80 km [SWM 1995]

⁽¹⁴⁾ [Sulzer 2000], [Linde 1998], [Worthington 2000], [m-tec 2000]

⁽¹⁵⁾ [Reijerkerk 2001]

⁽¹⁶⁾ Land transport + allowance for extra tankage for bulk imports

WTW APPENDIX 2

Oil at 50 €/bbl

On at 50 €/GJ

Fuel	Energy consumption			Energy cost €/GJ	Distribution infrastructure ⁽¹⁶⁾ €/GJ	Refuelling station		
	Diesel MJ/GJ	Electricity kWh/GJ				Capex k€	Opex k€/a	Annual cost k€/a
		MV	LV					
Liquid fuels								
Conv. gasoline and diesel ⁽¹⁾					⁽²⁾			
Gasoline	4.6	0.6	0.9	0.2	0.2			
Diesel	4.6	0.6	0.9	0.2	0.2			
Ethanol ⁽³⁾	11.3	0.7	0.9	0.3	0.7 ⁽⁴⁾			
Bio-diesel ⁽³⁾	8.1	0.7	0.9	0.2	0.6 ⁽⁴⁾			
Syn-diesel					⁽⁴⁾			
Large scale or import ⁽⁵⁾	4.6	0.6	0.9	0.2	0.2			
Small scale ⁽⁶⁾	6.9	0.2	0.9	0.2	0.5			
Methanol					⁽⁴⁾	55	4	11
Large scale or import ⁽⁷⁾	12.7	0.7	0.9	0.3	2.3			
Small scale ⁽⁸⁾	7.6		0.9	0.2	0.6			
DME						138	11	28
Large scale import ⁽⁷⁾	11.5	0.5	0.9	0.3	3.2 ⁽⁹⁾			
Large scale EU ⁽⁷⁾	11.5	0.5	0.9	0.3	1.9			
Small scale ⁽⁸⁾	6.9		0.9	0.2	0.6			
CNG				0.6				
Distribution	10.0 ⁽¹⁰⁾				0.2 ⁽¹¹⁾			
Retail ⁽¹²⁾			6.1			385	31	77
LPG				0.2				
Distribution	13.8				2.3 ⁽⁴⁾			
Retail			0.9			138	11	28
Hydrogen								
Compressed								
Local pipeline grid ⁽¹³⁾					2.7			
Road tanker	16.0			0.2	4.2			
Refuelling (8.8 MPa) ⁽¹⁴⁾						803	117	213
On-site production (2 MPa)			19.6					
Central production (3 MPa)			17.1					
Liquid ⁽¹⁵⁾			0.3			495	41	100
Road tanker	18.4			0.2	3.9			
Liquid dispensed as compressed ⁽¹⁵⁾			6.9			726	85	172

5 Vehicles

2010+ vehicles relative to gasoline PISI (see also *WTT Appendix 1*)

Engine technology	Fuel	Price differential (€)	Uncertainty range	
			-	+
ICEs conventional				
DISI	Gasoline	290	5%	5%
PISI	CNG (bi-fuel)	2,538	5%	5%
PISI	CNG (dedicated)	1,953	5%	5%
PISI	LPG (bi-fuel)	2,200	5%	5%
DICI	Diesel	1,400	5%	5%
DICI + DPF	Diesel	1,800	5%	5%
DICI	DME	2,775	10%	10%
PISI	C-H ₂ 70 MPa	4,750	0%	15%
PISI	L-H ₂	4,750	0%	15%
ICEs Hybrid				
DISI Hyb.	Gasoline	6,220	0%	50%
PISI Hyb.	CNG	7,373	0%	50%
DICI Hyb.	Diesel	7,630	0%	50%
DICI Hyb. + DPF	Diesel	8,030	0%	50%
PISI Hyb.	C-H ₂ 70 MPa	10,218	0%	100%
PISI Hyb.	L-H ₂	10,218	0%	100%
Fuel cells				
FC	C-H ₂ 70 MPa	11,633	0%	100%
FC	L-H ₂	11,633	0%	100%
FC Hyb.	C-H ₂ 70 MPa	14,945	0%	100%
FC Hyb.	L-H ₂	14,945	0%	100%
Ref+FC Hyb.	Gasoline	24,335	0%	100%
Ref+FC Hyb.	Methanol	24,335	0%	100%

6 Road fuel and vehicle market assumptions

		Total	Gasoline	Diesel
Fuels market 2015⁽¹⁾				
Total	Mt/a		93	204
	Mtoe/a	305	95	209
	PJ/a	12790	3996	8794
Fuel to passenger cars			100%	33%
	PJ/a	6898	3996	2902
Vehicle population				
Passenger car population ⁽¹⁾	M	247	156	91
Specific fuel consumption	GJ/car/a		25.7	31.8
Vehicle lifetime	Years		13	15
New vehicle sales	M/a	18.1	12.0	6.1
Energy and GHG of model vehicle		2010+ ICE		
		Average	PISI	CIDI/DPF
TTW energy	MJ/km	1.84	1.90	1.77
WTW energy	MJ/km	2.12	2.16	2.05
WTW GHG	g/km	161	164	156
Distance driven				
Per vehicle	km/a		13517	17972
Total	Tm/a	3746	2103	1642
Refuelling stations	k	100		
Substitution scenario		5% of distance driven		
		Total	Gasoline	Diesel
Distance driven	Tm/a	187	105	82
Conventional fuels substituted	PJ/a	345	200	145
Alternative vehicle sales	M/a	0.90	0.60	0.30
Required ref. stations coverage	k	20.0		
Base GHG emissions	Mt/a	30.1	17.3	12.8

⁽¹⁾ Source: [Wood MacKenzie 2005]

7 Substitution scenarios (oil @ 25 €/bbl)

7.1 Conventional fuel hybrids, CNG, LPG

Fuel	Combi.	Gasoline	Diesel	CNG									CBG	LPG
Primary resource	Oil			NG									Waste	LPG
		COG1	COD1	Combi. 70/30	4000 km GPCG1b 70%	LNG GRCG1 30%	Combi. 70/30	4000 km GPCG1b 70%	LNG GRCG1 30%	Comb. 70/30	4000 km GPCG1b	LNG GRCG1	org. waste liq. manure 0.2/0.8	
Power train (2010+)	Hybrids>	PISI	DICI	PISI conventional (BF)			PISI conventional (Ded.)			PISI hybrid			PISI (BF)	PISI (BF)
TTW energy MJ/km	1.55	1.63	1.46	1.88			1.87			1.39			1.88	1.90
Distance covered Tm	187	105	82	187			187			187			187	187
Fuel consumed PJ/a	291	171	120	353			351			261			353	356
WTW total energy MJ/km	1.78	1.86	1.69	2.31	2.24	2.46	2.29	2.23	2.44	1.71	1.66	1.82	3.67	2.12
WTW fossil energy MJ/km	1.78	1.86	1.69	2.31	2.24	2.46	2.29	2.23	2.44	1.71	1.66	1.82	0.11	2.12
WTW GHG g/km	136	141	129	138	135	146	137	134	145	103	100	109	-109	141
WTW Savings														
Total energy PJ/a	62	32	30	-36	-24	-65	-33	-21	-62	76	85	55	-291	-1
Fossil energy PJ/a	62	32	30	-36	-24	-65	-33	-21	-62	76	85	55	376	-1
GHG Mt/a	4.7	2.4	2.2	4.3	4.9	2.8	4.4	5.1	3.0	10.9	11.3	9.8	50.4	3.8
Conventional fuels substituted PJ/a														
Gasoline	200	200		200			200			200			200	200
Diesel	145		145	145			145			145			145	145
Refuelling stations required k				20.0			20.0			20.0			20.0	20.0
WTT costs M€/a	-337	-178	-160	734			724			346			4905	1088
Conventional fuel (saving)	-337	-178	-160	-2159			-2159			-2159			-2159	-2159
Alternative fuel				1494			1485			1106			5665	2748
Distribution infrastructure				1399			1399			1399			1399	500
Vehicle costs⁽¹⁾														
Substituted fleet M/a	0.90			0.90			0.90			0.90			0.90	0.90
Gasoline	0.60	0.60		0.60			0.60			0.60			0.60	0.60
Diesel	0.30		0.30	0.30			0.30			0.30			0.30	0.30
Base cost substituted fleet MEUR/a	-548	0	-548	-548			-548			-548			-548	-548
Alternative vehicle costs €/unit		6220	8030	2538			1953			7373			2538	2200
ME/a	6169	3723	2446	2292			1764			6659			2292	1987
Net total cost M€/a	5283	3545	1738	2478			1940			6456			6649	2527
Cost of substitution €/t				310			243			808			832	316
(per unit conv. Fuel) €/GJ				7.2			5.6			18.7			19.3	7.3
Cost of CO₂ avoided €/t	1131	1454	778	579	506	878	437	384	649	593	569	659	132	672

⁽¹⁾ Over base cost of 2010 gasoline PISI

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7.2 Bio-fuels

Fuel		Ethanol (5% blend)													Bio-diesel (5% blend)						
Primary resource		Sugar beet		Wheat grain								Straw	Wood		Rape		Sunfl.	Rape		Sunfl.	
		SBET1	SBET3	WTET1a	WTET2a	WTET3a	WTET4a	WTET1b	WTET2b	WTET3b	WTET4b	STET1	Farmed WFET1	Waste WWET1	ROFA1	ROFE1	SOFA1	ROFA2	ROFE2	SOFA2	
Power train (2010+)		PISI													DICI+DPF						
TTW energy		1.90													1.77						
Distance covered		105													82						
Fuel consumed		200													145						
WTW total energy		5.43	4.36	5.28	4.81	5.21	5.11	4.38	3.91	4.31	4.21	4.41	5.60	5.59	3.87	3.98	3.49	3.96	4.06	3.58	
WTW fossil energy		1.65	0.59	1.68	1.23	1.64	0.53	0.84	0.38	0.79	-0.32	0.20	0.52	0.51	0.81	0.72	0.64	0.90	0.80	0.73	
WTW GHG		111	58	114	90	178	49	98	74	161	33	19	43	36	85	80	47	95	88	50	
WTW Savings																					
Total energy		PJ/a	-343	-231	-328	-278	-321	-310	-233	-184	-226	-216	-236	-361	-360	-150	-158	-118	-157	-165	-126
Fossil energy		PJ/a	54	166	50	98	55	172	140	187	145	261	206	173	174	102	109	115	94	102	108
GHG		Mt/a	5.6	11.1	5.3	7.8	-1.4	12.1	7.0	9.5	0.3	13.8	15.3	12.7	13.5	5.8	6.3	9.0	5.1	5.6	8.2
Conventional fuels substituted		PJ/a	200													145					
Gasoline																					
Diesel																					
Refuelling stations required		k																			
WTT costs		M€/a	1911	2210	1884	1503	1965	2154	2309	1929	2391	2580	2930	3765	2891	1476	1490	1580	1467	1481	1571
Conventional fuel (saving)			-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-1251	-908	-908	-908	-908	-908	-908
Alternative fuel			3162	3461	3134	2754	3216	3405	3560	3180	3641	3831	4181	5016	4142	2384	2398	2489	2375	2390	2480
Distribution infrastructure																					
Vehicle costs ⁽¹⁾																					
Substituted fleet		M/a																			
Gasoline																					
Diesel																					
Base cost substituted fleet		MEUR/a																			
Alternative vehicle costs		€/unit																			
		M€/a																			
Net total cost		M€/a	1911	2210	1884	1503	1965	2154	2309	1929	2391	2580	2930	3765	2891	1476	1490	1580	1467	1481	1571
Cost of substitution		€/t	413	478	407	325	425	466	499	417	517	558	634	814	625	438	442	469	436	440	467
(per unit conv. fuel)		€/GJ	9.6	11.1	9.4	7.5	9.8	10.8	11.6	9.7	12.0	12.9	14.7	18.8	14.5	10.2	10.3	10.9	10.1	10.2	10.8
Cost of CO ₂ avoided		€/t	342	198	358	193		178	331	203		186	192	296	215	254	237	176	290	264	191

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.3 Synthetic fuels

Fuel	Syn-Diesel					DME					
Primary resource	NG	Coal	Wood			NG		Coal	Wood		
	Remote GRSD1	KOSD1	Farmed WFSD1	Waste WWSD1	Waste (BL) BLSD1	Remote GRDE1	4000 km GPDE1b	KODE1	Farmed WFDE1	Waste WWDE1	Waste (BL) BLDE1
Power train (2010+)	DICI+DPF					DICI					
TTW energy MJ/km	1.77					1.72					
Distance covered Tm	82					82					
Fuel consumed PJ/a	145					141					
WTW total energy MJ/km	2.97	3.48	3.88	3.88	3.38	2.64	2.79	3.32	3.56	3.56	2.67
WTW fossil energy MJ/km	2.97	3.48	0.11	0.12	0.06	2.64	2.79	3.32	0.10	0.10	0.05
WTW GHG g/km	171	355	15	10	6	154	166	338	14	10	6
WTW Savings											
Total energy PJ/a	-75	-118	-150	-150	-109	-48	-61	-104	-124	-124	-51
Fossil energy PJ/a	-75	-118	159	159	163	-48	-61	-104	160	160	164
GHG Mt/a	-1.2	-16.3	11.6	12.0	12.3	0.2	-0.8	-15.0	11.7	12.0	12.4
Conventional fuels substituted PJ/a											
Gasoline											
Diesel	145					145					
Refuelling stations required k						20.0					
WTT costs M€/a	172	573	2864	2413	1195	820	1009	1015	2311	1896	814
Conventional fuel (saving)	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908
Alternative fuel	1081	1481	3773	3321	2104	1229	1418	1424	2720	2304	1222
Distribution infrastructure						500	500	500	500	500	500
Vehicle costs⁽¹⁾											
Substituted fleet M/a						0.30					
Gasoline											
Diesel						0.30					
Base cost substituted fleet MEUR/a						-548					
Alternative vehicle costs €/unit						2775					
ME/a						845					
Net total cost M€/a	172	573	2864	2413	1195	1117	1306	1312	2608	2193	1111
Cost of substitution €/t	51	170	851	717	355	332	388	390	775	651	330
(per unit conv. fuel) €/GJ	1.2	3.9	19.7	16.6	8.2	7.7	9.0	9.0	18.0	15.1	7.7
Cost of CO₂ avoided €/t			246	201	97				223	182	90

⁽¹⁾ Over base cost of 2010 gasoline PISl

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7.4 Hydrogen from thermal processes - ICE

Fuel	Hydrogen										Hydrogen			Hydrogen							
Primary resource	NG										Coal			Wood							
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central				
		Compressed				Liq/Comp	Liquid		Comp.		Liquid	Compressed				Liquid					
		Pipeline		Road		Pipeline		Road	Pipeline		Pipeline			Road							
	4000 km	LNG	4000 km	LNG	4000 km	LNG	4000 km	LNG	Pipeline	Road	Farmed	Waste		Farmed							
	GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2	KOCH1	Estim.	WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	WFLH1					
			21%	9%	12%	11%	12%	12%	12%	11%	26%	74%		15%	12%	15%	12%	12%	35%		
Power train (2010+)	ICE										ICE			ICE							
TTW energy	MJ/km	1.68										1.68			1.68						
Distance covered	Tm	187										187			187						
Fuel consumed	PJ/a	314										314			314						
WTW total energy	MJ/km	3.36	3.27	3.55	2.87	3.13	2.88	3.82	3.57	3.92	4.37	4.02	4.72	3.65	3.76	3.30	3.72	3.30	2.53	4.18	
WTW fossil energy	MJ/km	3.36	3.27	3.55	2.87	3.13	2.88	3.82	3.57	3.92	4.36	4.02	4.71	0.27	0.36	0.38	0.32	0.38	0.34	0.11	
WTW GHG	g/km	194	186	201	165	178	166	223	212	230	318	391	245	19	26	24	18	21	17	14	
WTW Savings																					
Total energy	PJ/a	-232	-216	-269	-142	-190	-143	-319	-273	-338	-422	-356	-487	-288	-308	-222	-300	-222	-78	-388	
Fossil energy	PJ/a	-232	-216	-269	-142	-190	-143	-319	-273	-338	-421	-356	-485	346	329	324	336	324	332	376	
GHG	Mt/a	-6.2	-4.8	-7.4	-0.8	-3.2	-1.1	-11.6	-9.6	-12.9	-29.4	-43.0	-15.8	26.6	25.3	25.6	26.7	26.3	26.9	27.5	
Conventional fuels substituted	PJ/a																				
Gasoline		200										200			200						
Diesel		145										145			145						
Refuelling stations required	k	20.0										20.0			20.0						
WTT costs	M€/a	5686	6512	6512	4834	4834	5305	4483	6302	6302	6903	6169	7637	6907	6869	6356	5960	5576	4408	8790	
Conventional fuel (saving)						-2159						-2159				-2159					
Alternative fuel		4917	4803	4803	3124	3124	3595	6642	6642	6642	6218	4459	7977	5915	5159	4646	4250	3867	2699	9130	
Distribution infrastructure		2929	3869	3869	3869	3869	3869	0	1819	1819	2844	3869	1819	3151	3869	3869	3869	3869	3869	1819	
Vehicle costs ⁽¹⁾																					
Substituted fleet	M/a	0.90										0.90			0.90						
Gasoline		0.60										0.60			0.60						
Diesel		0.30										0.30			0.30						
Base cost substituted fleet	M€/a	-548										-548			-548						
Alternative vehicle costs	€/unit	4750			4750				4750		4750	4750	4750	4750		4750			4750		
	M€/a	4290			4290				4290		4290	4290	4290	4290		4290			4290		
Net total cost	M€/a	9428	10254	10254	8575	8575	9046	8225	10043	10043	10644	9910	11378	10648	10610	10097	9701	9318	8150	12531	
Cost of substitution	€/t	1180	1283	1283	1073	1073	1132	1029	1257	1257	1332	1240	1424	1332	1328	1263	1214	1166	1020	1568	
(per unit conv. Fuel)	€/GJ	27.3	29.7	29.7	24.9	24.9	26.2	23.8	29.1	29.1	30.9	28.7	33.0	30.9	30.8	29.3	28.1	27.0	23.6	36.3	
Cost of CO ₂ avoided	€/t													400	420	395	363	355	303	456	

⁽¹⁾ Over base cost of 2010 gasoline PISI

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7.5 Hydrogen from thermal processes - ICE hybrid

Fuel	Hydrogen										Hydrogen			Hydrogen							
Primary resource	NG										Coal			Wood							
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central				
		Compressed				Liq/Comp	Liquid		Comp.		Liquid	Compressed				Liquid					
		Pipeline				Road		Pipeline	Road		Pipeline			Road							
		4000 km	LNG	4000 km		4000 km	LNG	4000 km	LNG		Farmed			Waste		Farmed					
		GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2		WFCH1	WFCH2		WWCH1	WWCH2	BLCH1	WFLH1				
	21%	9%	12%	11%	12%	12%	12%	11%	26%	74%	15%	12%	15%	12%	12%	35%					
Power train (2010+)	ICE hybrid										ICE hybrid			ICE hybrid							
TTW energy	MJ/km	1.49										1.49			1.49						
Distance covered	Tm	187										187			187						
Fuel consumed	PJ/a	278										278			278						
WTW total energy	MJ/km	2.94	2.90	3.15	2.55	2.78	2.55	3.38	3.02	3.31	4.10	4.02	4.18	3.65	3.76	3.30	3.72	3.30	2.53	4.18	
WTW fossil energy	MJ/km	2.94	2.90	3.15	2.55	2.78	2.55	3.38	3.02	3.31	4.09	4.02	4.17	0.27	0.36	0.38	0.32	0.38	0.34	0.11	
WTW GHG	g/km	170	165	178	146	158	148	198	179	194	296	346	245	17	23	22	16	18	15	12	
WTW Savings																					
Total energy	PJ/a	-154	-146	-193	-81	-124	-82	-237	-169	-223	-371	-356	-387	-288	-308	-222	-300	-222	-78	-388	
Fossil energy	PJ/a	-154	-146	-193	-81	-124	-82	-237	-169	-223	-371	-356	-385	346	329	324	336	324	332	376	
GHG	Mt/a	-1.7	-0.8	-3.2	2.7	0.5	2.5	-6.9	-3.4	-6.2	-25.3	-34.7	-15.8	27.0	25.8	26.1	27.1	26.7	27.3	27.9	
Conventional fuels substituted	PJ/a																				
Gasoline		200										200			200						
Diesel		145										145			145						
Refuelling stations required	k	20.0										20.0			20.0						
WTT costs	M€/a	5127	5967	5967	4479	4479	4896	3728	5547	5547	6196	5662	6730	6235	6282	5828	5477	5137	4102	7752	
Conventional fuel (saving)					-2159							-2159					-2159				
Alternative fuel		4358	4257	4257	2769	2769	3186	5888	5888	5888	5512	3953	7071	5243	4573	4118	3767	3427	2392	8093	
Distribution infrastructure		2929	3869	3869	3869	3869	3869	0	1819	1819	2844	3869	1819	3151	3869	3869	3869	3869	3869	1819	
Vehicle costs ⁽¹⁾																					
Substituted fleet	M/a	0.90										0.90			0.90						
Gasoline		0.60										0.60			0.60						
Diesel		0.30										0.30			0.30						
Base cost substituted fleet	M€/a	-548										-548			-548						
Alternative vehicle costs	€/unit	10218			10218				10218		10218	10218	10218	10218			10218			10218	
	M€/a	9228			9228				9228		9228	9228	9228	9228			9228			9228	
Net total cost	M€/a	13807	14646	14646	13158	13158	13575	12408	14226	14226	14876	14342	15410	14914	14962	14507	14156	13816	12781	16431	
Cost of substitution	€/t	1728	1833	1833	1646	1646	1699	1553	1780	1780	1861	1795	1928	1866	1872	1815	1771	1729	1599	2056	
(per unit conv. Fuel)	€/GJ	40.0	42.5	42.5	38.2	38.2	39.4	36.0	41.2	41.2	43.1	41.6	44.7	43.2	43.4	42.1	41.0	40.1	37.1	47.6	
Cost of CO ₂ avoided	€/t				4810	24160	5479							552	580	556	523	518	469	589	

⁽¹⁾ Over base cost of 2010 gasoline PISI

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7.6 Hydrogen from thermal processes - FC

Fuel	Hydrogen									Hydrogen			Hydrogen								
Primary resource	NG									Coal			Wood								
	Combi.	On-site reforming			Central reforming						Combi.	Central		Combi.	Local		Central		Central		
		Compressed			Liq/Comp			Liquid				Comp.			Compressed			Road			
		Pipeline			Road			Road				Pipeline			Pipeline			Road			
		4000 km			4000 km			4000 km				4000 km			4000 km			4000 km			
		GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2	KOCH1		Estim.	WFCH1		WFCH2	WWCH1	WWCH2	BLCH1	WFLH1		
		21%	9%	12%	11%	12%	12%	12%	11%	50%	50%	15%	12%	15%	12%	12%	35%				
Power train (2010+)		FC									FC			FC							
TTW energy	MJ/km	0.94									0.94			0.94							
Distance covered	Tm	187									187			187							
Fuel consumed	PJ/a	176									176			176							
WTW total energy	MJ/km	1.88	1.83	1.99	1.61	1.76	1.61	2.14	2.01	2.20	2.45	2.25	2.65	2.05	2.11	1.85	2.09	1.85	1.42	2.35	
WTW fossil energy	MJ/km	1.88	1.83	1.99	1.61	1.76	1.61	2.14	2.01	2.20	2.45	2.25	2.64	0.15	0.20	0.22	0.18	0.22	0.19	0.06	
WTW GHG	g/km	109	104	112	92	100	93	125	119	129	232	219	245	10	14	13	10	11	9	8	
WTW Savings																					
Total energy	PJ/a	44	53	23	94	67	94	-5	21	-16	-63	-26	-99	12	1	49	6	49	130	-44	
Fossil energy	PJ/a	44	53	23	94	67	94	-5	21	-16	-62	-26	-98	368	358	356	363	356	360	385	
GHG	Mt/a	9.8	10.6	9.1	12.8	11.5	12.7	6.8	7.9	6.0	-13.3	-10.9	-15.8	28.2	27.4	27.6	28.2	28.0	28.4	28.7	
Conventional fuels substituted	PJ/a																				
Gasoline		200									200			200							
Diesel		145									145			145							
Refuelling stations required	k	20.0									20.0			20.0							
WTT costs	M€/a	3910	4404	4404	3463	3463	3727	4689	3386	3386	4173	4212	4135	4311	4604	4316	4094	3879	3224	4782	
Conventional fuel (saving)						-2159						-2159					-2159				
Alternative fuel		2759	2695	2695	1753	1753	2017	3727	3727	3727	3489	2502	4476	3319	2894	2607	2384	2170	1514	5123	
Distribution infrastructure		3311	3869	3869	3869	3869	3869	3122	1819	1819	2844	3869	1819	3151	3869	3869	3869	3869	3869	1819	
Vehicle costs ⁽¹⁾																					
Substituted fleet	M/a	0.90									0.90			0.90							
Gasoline		0.60									0.60			0.60							
Diesel		0.30									0.30			0.30							
Base cost substituted fleet	M€/a	-548									-548			-548							
Alternative vehicle costs	€/unit	11633			11633				11633		11633	11633	11633	11633			11633			11633	
	M€/a	10506			10506				10506		10506	10506	10506	10506			10506			10506	
Net total cost	M€/a	13868	14362	14362	13420	13420	13684	14646	13343	13343	14131	14169	14092	14268	14561	14274	14051	13837	13181	14739	
Cost of substitution	€/t	1735	1797	1797	1679	1679	1712	1833	1670	1670	1768	1773	1763	1785	1822	1786	1758	1731	1649	1844	
(per unit conv. Fuel)	€/GJ	40.2	41.6	41.6	38.9	38.9	39.7	42.5	38.7	38.7	41.0	41.1	40.9	41.4	42.2	41.4	40.7	40.1	38.2	42.7	
Cost of CO ₂ avoided	€/t	1415	1355	1579	1045	1171	1079	2169	1690	2218				506	531	517	497	494	465	513	
Max		2548	2399	2802	1885	2114	1931	3944	3144	4186				880	915	898	871	870	836	883	

⁽¹⁾ Over base cost of 2010 gasoline PISI

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7.7 Hydrogen from thermal processes - FC hybrid

Fuel	Hydrogen										Hydrogen			Hydrogen							
Primary resource	NG										Coal			Wood							
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central				
		Compressed				Liq/Comp		Liquid			Comp.	Liquid		Compressed				Road			
		Pipeline		Road		Pipeline		Road			Pipeline	Road		Pipeline		Pipeline		Road			
		4000 km	LNG	4000 km	LNG	4000 km	LNG	4000 km	LNG					Farmed		Waste	Farmed				
		GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2		KOCH1	Estim.		WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	WFLH1		
		21%	9%	12%	11%	12%	12%	12%	11%		50%	50%		15%	12%	15%	12%	12%	35%		
Power train (2010+)	FC hybrid										FC hybrid			FC hybrid							
TTW energy	MJ/km	0.84										0.84			0.84						
Distance covered	Tm	187										187			187						
Fuel consumed	PJ/a	157										157			157						
WTW total energy	MJ/km	1.68	1.63	1.77	1.44	1.56	1.44	1.91	1.79	1.96	2.18	2.01	2.36	1.82	1.88	1.65	1.86	1.65	1.26	2.09	
WTW fossil energy	MJ/km	1.68	1.63	1.77	1.44	1.56	1.44	1.91	1.79	1.96	2.18	2.01	2.35	0.13	0.18	0.19	0.16	0.19	0.17	0.05	
WTW GHG	g/km	97	93	100	82	89	83	111	106	115	207	195	218	9	13	12	9	10	8	7	
WTW Savings																					
Total energy	PJ/a	82	90	64	127	103	127	39	62	29	-12	20	-45	55	44	87	48	87	159	5	
Fossil energy	PJ/a	82	90	64	127	103	127	39	62	29	-12	20	-44	371	362	360	366	360	364	386	
GHG	Mt/a	12.0	12.7	11.4	14.7	13.5	14.6	9.3	10.3	8.7	-8.6	-6.4	-10.8	28.4	27.7	27.9	28.5	28.2	28.6	28.9	
Conventional fuels substituted	PJ/a																				
Gasoline		200										200			200						
Diesel		145										145			145						
Refuelling stations required	k	20.0										20.0			20.0						
WTT costs	M€/a	3608	4109	4109	3270	3270	3506	4281	2978	2978	3791	3937	3645	3947	4287	4031	3833	3641	3058	4221	
Conventional fuel (saving)						-2159						-2159				-2159					
Alternative fuel		2456	2399	2399	1561	1561	1796	3318	3318	3318	3107	2228	3985	2955	2577	2321	2123	1932	1348	4561	
Distribution infrastructure		3311	3869	3869	3869	3869	3869	3122	1819	1819	2844	3869	1819	3151	3869	3869	3869	3869	3869	1819	
Vehicle costs ⁽¹⁾																					
Substituted fleet	M/a	0.90										0.90			0.90						
Gasoline		0.60										0.60			0.60						
Diesel		0.30										0.30			0.30						
Base cost substituted fleet	M€/a	-548										-548			-548						
Alternative vehicle costs	€/unit	14945			14945					14945	14945	14945	14945	14945		14945				14945	
	M€/a	13497			13497					13497	13497	13497	13497	13497		13497				13497	
Net total cost	M€/a	16557	17058	17058	16219	16219	16455	17230	15927	15927	16740	16886	16594	16896	17236	16980	16782	16590	16007	17170	
Cost of substitution	€/t	2072	2134	2134	2030	2030	2059	2156	1993	1993	2095	2113	2076	2114	2157	2125	2100	2076	2003	2148	
(per unit conv. Fuel)	€/GJ	48.0	49.5	49.5	47.0	47.0	47.7	50.0	46.2	46.2	48.5	49.0	48.1	49.0	50.0	49.2	48.7	48.1	46.4	49.8	
Cost of CO ₂ avoided	€/t	1377	1339	1496	1101	1201	1128	1850	1541	1840				595	621	609	590	588	560	595	
Max		2533	2429	2716	2031	2217	2067	3399	2911	3493				1071	1109	1093	1065	1066	1033	1065	

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.8 Hydrogen from electrolysis - ICE

Fuel	Hydrogen								Hydrogen			
Primary resource	Electricity ex NG								Coal			
	Combi.	Local		Central				Combi.	Local		Central	
		Compressed		Pipeline		Liquid			Compressed		Liquid	

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel		Hydrogen				Hydrogen				Hydrogen			
Primary resource		Nuclear				Wind				EU-mix			
		Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central	
			Compressed		Liquid		Compressed		Liquid		Compressed		Liquid
				Pipeline	Road			Pipeline	Road			Pipeline	Road
			NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.
			30%	35%	35%		30%	35%	35%		30%	35%	35%
		Power train (2010+)		ICE				ICE				ICE	
TTW energy	MJ/km	1.68				1.68				1.68			
Distance covered	Tm	187				187				187			
Fuel consumed	PJ/a	314				314				314			
WTW total energy	MJ/km	10.39	10.10	10.18	10.87	3.29	2.99	3.08	3.76	8.04	7.74	7.83	8.52
WTW fossil energy	MJ/km	10.39	10.10	10.15	10.87	0.37	0.32	0.39	0.39	6.35	7.74	5.75	5.75
WTW GHG	g/km	28	12	12	59	31	16	15	59	365	349	349	395
WTW Savings													
Total energy	PJ/a	-1551	-1495	-1510	-1639	-221	-164	-180	-309	-1110	-1054	-1070	-1199
Fossil energy	PJ/a	-1549	-1495	-1505	-1639	327	336	323	323	-793	-1054	-682	-682
GHG	Mt/a	24.8	27.8	27.9	19.2	24.4	27.2	27.2	19.2	-38.3	-35.3	-35.2	-43.9
Conventional fuels substituted	PJ/a												
Gasoline		200				200				200			
Diesel		145				145				145			
Refuelling stations required	k	20.0				20.0				20.0			
WTT costs	M€/a	11459	12305	11930	10264	11327	12173	11798	10132	8887	9732	9358	7691
Conventional fuel (saving)		-2159				-2159				-2159			
Alternative fuel		10467	10595	10221	10604	10335	10463	10089	10472	7895	8022	7648	8032
Distribution infrastructure		3151	3869	3869	1819	3151	3869	3869	1819	3151	3869	3869	1819
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90				0.90				0.90			
Gasoline		0.60				0.60				0.60			
Diesel		0.30				0.30				0.30			
Base cost substituted fleet	MEUR/a	-548				-548				-548			
Alternative vehicle costs	€/unit	10218	10217.5	10217.5		10218	10217.5	10217.5		10218	10217.5	10217.5	
	M€/a	9228	9228	9228		9228	9228	9228		9228	9228	9228	
Net total cost	M€/a	20139	20984	20610	18943	20007	20852	20478	18811	17566	18412	18037	16370
Cost of substitution	€/t	2520	2626	2579	2370	2503	2609	2562	2354	2198	2304	2257	2048
(per unit conv. Fuel)	€/GJ	58.4	60.8	59.8	54.9	58.0	60.5	59.4	54.5	50.9	53.4	52.3	47.5
Cost of CO ₂ avoided	€/t	811	754	739	988	820	767	752	982				

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.9 Hydrogen from electrolysis - ICE hybrid

Fuel		Hydrogen								Hydrogen			
Primary resource		Electricity ex NG								Coal			
		Combi.	Local		Central				Combi.	Local		Central	
			Compressed				Liquid			Compressed		Liquid	
			Pipeline				Road					Road	
		4000 km		LNG		4000 km		LNG		4000 km		LNG	
		GPEL1b CH1		GREL1 CH1		GPEL1b CH2		Estim.		GPEL1b LH1		Estim.	
		21%		9%		25%		11%		25%		11%	
Power train (2010+)		ICE hybrid								ICE hybrid			
TTW energy	MJ/km	1.49								1.49			
Distance covered	Tm	187								187			
Fuel consumed	PJ/a	278								278			
WTW total energy	MJ/km	5.40	5.05	5.57	5.13	5.64	5.46	6.25	6.37	6.19	6.19	6.69	
WTW fossil energy	MJ/km	5.40	5.05	5.57	5.13	5.63	5.46	6.25	6.37	6.19	6.19	6.69	
WTW GHG	g/km	319	301	327	301	327	326	368	644	629	629	671	
WTW Savings													
Total energy	PJ/a	-616	-550	-646	-564	-660	-627	-774	-796	-764	-764	-857	
Fossil energy	PJ/a	-616	-550	-646	-564	-657	-627	-774	-796	-764	-764	-857	
GHG	Mt/a	-29.6	-26.2	-31.1	-26.2	-31.1	-30.9	-38.8	-90.5	-87.7	-87.7	-95.6	
Conventional fuels substituted													
Gasoline		200								200			
Diesel		145								145			
Refuelling stations required		20.0								20.0			
WTT costs	M€/a	8091	8922	8922	8590	8590	6880	6880	7724	8555	8223	6513	
Conventional fuel (saving)		-2159								-2159			
Alternative fuel		7099	7212	7212	6880	6880	7220	7220	6732	6845	6514	6854	
Distribution infrastructure		3151	3869	3869	3869	3869	1819	1819	3151	3869	3869	1819	
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90								0.90			
Gasoline		0.60								0.60			
Diesel		0.30								0.30			
Base cost substituted fleet	MEUR/a	-548								-548			
Alternative vehicle costs	€/unit	10218	10217.5				10217.5		10218	10217.5		10217.5	
	M€/a	9228	9228				9228		9228	9228		9228	
Net total cost	M€/a	16770	17601	17601	17270	17270	15559	15559	16404	17235	16903	15192	
Cost of substitution	€/t	2098	2202	2202	2161	2161	1947	1947	2053	2157	2115	1901	
(per unit conv. Fuel)	€/GJ	48.6	51.0	51.0	50.1	50.1	45.1	45.1	47.6	50.0	49.0	44.0	
Cost of CO ₂ avoided													

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel		Hydrogen				Hydrogen				Hydrogen				
Primary resource		Nuclear				Wind				EU-mix				
		Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central		
			Compressed		Liquid		Compressed		Liquid		Compressed		Liquid	
				Pipeline	Road			Pipeline	Road			Pipeline	Road	
			NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.	
			30%	35%	35%		30%	35%	35%		30%	35%	35%	
Power train (2010+)		ICE hybrid				ICE hybrid				ICE hybrid				
TTW energy	MJ/km	1.49				1.49				1.49				
Distance covered	Tm	187				187				187				
Fuel consumed	PJ/a	278				278				278				
WTW total energy	MJ/km	9.21	8.95	9.02	9.63	2.92	2.65	2.73	3.34	7.13	6.86	6.94	7.55	
WTW fossil energy	MJ/km	9.20	8.95	9.00	9.63	0.33	0.29	0.35	0.35	5.63	6.86	5.10	5.10	
WTW GHG	g/km	25	11	11	52	27	14	14	52	324	310	309	351	
WTW Savings														
Total energy	PJ/a	-1329	-1280	-1294	-1408	-150	-101	-115	-229	-939	-889	-903	-1017	
Fossil energy	PJ/a	-1328	-1280	-1289	-1408	335	343	332	332	-658	-889	-559	-559	
GHG	Mt/a	25.4	28.1	28.2	20.4	25.0	27.5	27.6	20.4	-30.5	-27.9	-27.8	-35.5	
Conventional fuels substituted		PJ/a												
Gasoline		200				200				200				
Diesel		145				145				145				
Refuelling stations required		k	20.0				20.0				20.0			
WTT costs		M€/a	10270	11101	10769	9059	10153	10984	10652	8941	7990	8820	8489	6778
Conventional fuel (saving)			-2159				-2159				-2159			
Alternative fuel			9278	9391	9059	9399	9161	9274	8942	9282	6998	7111	6779	7119
Distribution infrastructure			3151	3869	3869	1819	3151	3869	3869	1819	3151	3869	3869	1819
Vehicle costs ⁽¹⁾														
Substituted fleet		M/a	0.90				0.90				0.90			
Gasoline			0.60				0.60				0.60			
Diesel			0.30				0.30				0.30			
Base cost substituted fleet		MEUR/a	-548				-548				-548			
Alternative vehicle costs		€/unit	10218	10217.5	10217.5		10218	10217.5	10217.5		10218	10217.5	10217.5	
		M€/a	9228	9228	9228		9228	9228	9228		9228	9228	9228	
Net total cost		M€/a	18949	19780	19448	17738	18832	19663	19331	17621	16669	17500	17168	15458
Cost of substitution		€/t	2371	2475	2434	2220	2356	2460	2419	2205	2086	2190	2148	1934
(per unit conv. Fuel)		€/GJ	54.9	57.3	56.4	51.4	54.6	57.0	56.0	51.1	48.3	50.7	49.8	44.8
Cost of CO ₂ avoided		€/t	745	704	691	869	752	715	701	863				

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.10 Hydrogen from electrolysis - FC

Fuel		Hydrogen								Hydrogen			
Primary resource		Electricity ex NG								Coal			
		Combi.	Local		Central				Combi.	Local		Central	
			Compressed				Liquid			Compressed		Liquid	
			Pipeline				Road			Pipeline		Road	
		4000 km		LNG		4000 km		LNG		4000 km		LNG	
		GPEL1b CH1		GREL1 CH1		GPEL1b CH2		Estim.		GPEL1b LH1		Estim.	
		21%		9%		25%		11%		25%		11%	
Power train (2010+)		FC								FC			
TTW energy	MJ/km	0.94								0.94			
Distance covered	Tm	187								187			
Fuel consumed	PJ/a	176								176			
WTW total energy	MJ/km	3.46	3.20	3.52	3.25	3.57	3.63	3.96	4.11	3.92	3.92	4.45	
WTW fossil energy	MJ/km	3.46	3.20	3.52	3.25	3.56	3.63	3.96	4.11	3.92	3.92	4.45	
WTW GHG	g/km	204	190	207	190	207	216	233	415	398	398	446	
WTW Savings													
Total energy	PJ/a	-252	-203	-264	-212	-272	-284	-345	-373	-338	-338	-437	
Fossil energy	PJ/a	-252	-203	-264	-212	-271	-284	-345	-373	-338	-338	-437	
GHG	Mt/a	-8.1	-5.5	-8.6	-5.5	-8.6	-10.4	-13.5	-47.6	-44.4	-44.4	-53.4	
Conventional fuels substituted													
Gasoline	PJ/a	200								200			
Diesel	PJ/a	145								145			
Refuelling stations required		20.0								20.0			
WTT costs													
Conventional fuel (saving)	M€/a	5486	6275	6275	6065	6065	4230	4230	5253	6043	5833	3998	
Alternative fuel	M€/a	4494	4565	4565	4355	4355	4570	4570	4261	4333	4123	4338	
Distribution infrastructure	M€/a	3151	3869	3869	3869	3869	1819	1819	3151	3869	3869	1819	
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90								0.90			
Gasoline	M/a	0.60								0.60			
Diesel	M/a	0.30								0.30			
Base cost substituted fleet	MEUR/a	-548								-548			
Alternative vehicle costs	€/unit	11633	11633				11633		11633	11633		11633	
	M€/a	10506	10506				10506		10506	10506		10506	
Net total cost		15443	16232	16232	16022	16022	14187	14187	15211	16000	15790	13955	
Cost of substitution		1932	2031	2031	2005	2005	1775	1775	1903	2002	1976	1746	
(per unit conv. Fuel)		44.8	47.1	47.1	46.5	46.5	41.1	41.1	44.1	46.4	45.8	40.5	
Cost of CO ₂ avoided													

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel		Hydrogen				Hydrogen				Hydrogen			
Primary resource		Nuclear				Wind				EU-mix			
		Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central	
			Compressed		Liquid		Compressed		Liquid		Compressed		Liquid
				Pipeline	Road			Pipeline	Road			Pipeline	Road
			NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.
		30%	35%	35%	30%	35%	35%	30%	35%	35%			
Power train (2010+)		FC				FC				FC			
TTW energy	MJ/km	0.94				0.94				0.94			
Distance covered	Tm	187				187				187			
Fuel consumed	PJ/a	176				176				176			
WTW total energy	MJ/km	5.83	5.66	5.71	6.10	1.85	1.68	1.73	2.11	4.51	4.34	4.39	4.78
WTW fossil energy	MJ/km	5.83	5.66	5.70	6.10	0.21	0.18	0.22	0.22	3.56	4.34	3.23	3.23
WTW GHG	g/km	16	7	7	33	17	9	9	33	205	196	196	222
WTW Savings													
Total energy	PJ/a	-696	-665	-673	-746	50	82	73	1	-449	-417	-426	-499
Fossil energy	PJ/a	-695	-665	-671	-746	357	362	355	355	-271	-417	-209	-209
GHG	Mt/a	27.2	28.9	28.9	24.0	26.9	28.5	28.5	24.0	-8.2	-6.5	-6.5	-11.4
Conventional fuels substituted	PJ/a												
Gasoline		200				200				200			
Diesel		145				145				145			
Refuelling stations required	k	20.0				20.0				20.0			
WTT costs	M€/a	6865	7654	7444	5609	6791	7580	7370	5535	5421	6211	6001	4166
Conventional fuel (saving)			-2159				-2159				-2159		
Alternative fuel		5873	5945	5735	5950	5799	5870	5660	5876	4429	4501	4291	4506
Distribution infrastructure		3151	3869	3869	1819	3151	3869	3869	1819	3151	3869	3869	1819
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90				0.90				0.90			
Gasoline		0.60				0.60				0.60			
Diesel		0.30				0.30				0.30			
Base cost substituted fleet	MEUR/a	-548				-548				-548			
Alternative vehicle costs	€/unit	11633	11633		11633	11633	11633		11633	11633	11633		11633
	M€/a	10506	10506		10506	10506	10506		10506	10506	10506		10506
Net total cost	M€/a	16822	17612	17402	15566	16748	17537	17327	15492	15379	16168	15958	14123
Cost of substitution	€/t	2105	2204	2177	1948	2096	2194	2168	1939	1924	2023	1997	1767
(per unit conv. Fuel)	€/GJ	48.8	51.1	50.5	45.1	48.6	50.8	50.2	44.9	44.6	46.9	46.3	40.9
Cost of CO ₂ avoided	€/t	619	610	603	649	622	615	608	646				

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.11 Hydrogen from electrolysis - FC hybrid

Fuel		Hydrogen								Hydrogen				
Primary resource		Electricity ex NG								Coal				
		Combi.	Local		Central				Combi.	Local		Central		
			Compressed			Liquid				Compressed		Liquid		
			Pipeline				Road							
		4000 km		LNG	4000 km		LNG	4000 km		LNG				
		GPEL1b CH1		GREL1 CH1	GPEL1b CH2		Estim.	GPEL1b LH1		Estim.	KOEL1 CH1	KOEL1 CH2	KOEL1 LH1	
		21%		9%	25%		11%	25%		11%	30%	35%	35%	
Power train (2010+)		FC hybrid								FC hybrid				
TTW energy	MJ/km	0.84								0.84				
Distance covered	Tm	187								187				
Fuel consumed	PJ/a	157								157				
WTW total energy	MJ/km	3.08	2.85	3.14	2.89	3.18	3.23	3.52	3.66	3.49	3.49	3.96		
WTW fossil energy	MJ/km	3.08	2.85	3.14	2.89	3.17	3.23	3.52	3.66	3.49	3.49	3.96		
WTW GHG	g/km	182	169	184	169	184	193	207	369	354	354	397		
WTW Savings														
Total energy	PJ/a	-181	-137	-191	-145	-199	-209	-264	-288	-258	-258	-345		
Fossil energy	PJ/a	-181	-137	-191	-145	-198	-209	-263	-288	-258	-258	-345		
GHG	Mt/a	-3.9	-1.6	-4.3	-1.6	-4.4	-6.0	-8.7	-39.0	-36.3	-36.3	-44.2		
Conventional fuels substituted														
Gasoline	PJ/a	200								200				
Diesel	PJ/a	145								145				
Refuelling stations required		20.0								20.0				
WTT costs	M€/a	4993	5775	5775	5588	5588	3729	3729	4787	5568	5381	3522		
Conventional fuel (saving)					-2159					-2159				
Alternative fuel		4001	4065	4065	3878	3878	4070	4070	3795	3858	3671	3863		
Distribution infrastructure		3151	3869	3869	3869	3869	1819	1819	3151	3869	3869	1819		
Vehicle costs ⁽¹⁾														
Substituted fleet	M/a	0.90								0.90				
Gasoline		0.60								0.60				
Diesel		0.30								0.30				
Base cost substituted fleet	MEUR/a	-548								-548				
Alternative vehicle costs	€/unit	14945	14945				14945		14945	14945		14945		
	M€/a	13497	13497				13497		13497	13497		13497		
Net total cost	M€/a	17942	18724	18724	18537	18537	16678	16678	17736	18517	18330	16471		
Cost of substitution	€/t	2245	2343	2343	2320	2320	2087	2087	2219	2317	2294	2061		
(per unit conv. Fuel)	€/GJ	52.0	54.3	54.3	53.7	53.7	48.4	48.4	51.4	53.7	53.1	47.8		
Cost of CO ₂ avoided														

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel	Hydrogen					Hydrogen				Hydrogen				
Primary resource	Nuclear					Wind				EU-mix				
	Combi.	Local	Central			Combi.	Local	Central		Combi.	Local	Central		
		Compressed		Liquid	Compressed		Liquid	Compressed			Liquid			
			Pipeline	Road			Pipeline	Road			Pipeline	Road		
		NUEL1 CH1	Estim.	Estim.	WDEL1 CH1		Estim.	Estim.	EMEL1 CH1		Estim.	Estim.		
		30%	35%	35%	30%		35%	35%	30%		35%	35%		
Power train (2010+)		FC hybrid				FC hybrid				FC hybrid				
TTW energy	MJ/km	0.84				0.84				0.84				
Distance covered	Tm	187				187				187				
Fuel consumed	PJ/a	157				157				157				
WTW total energy	MJ/km	5.19	5.04	5.09	5.43	1.65	1.50	1.54	1.88	4.02	3.87	3.91	4.25	
WTW fossil energy	MJ/km	5.19	5.04	5.07	5.43	0.18	0.16	0.19	0.19	3.17	3.87	2.88	2.88	
WTW GHG	g/km	14	6	6	29	15	8	8	29	182	174	174	198	
WTW Savings														
Total energy	PJ/a	-576	-548	-556	-621	88	116	108	44	-356	-328	-336	-401	
Fossil energy	PJ/a	-576	-548	-554	-621	362	366	360	360	-198	-328	-142	-142	
GHG	Mt/a	27.5	29.0	29.0	24.6	27.3	28.7	28.7	24.6	-4.0	-2.5	-2.5	-6.9	
Conventional fuels substituted		PJ/a												
Gasoline		200			200			200						
Diesel		145			145			145						
Refuelling stations required		k	20.0			20.0			20.0					
WTT costs		M€/a	6221	7003	6816	4957	6155	6937	6750	4891	4936	5718	5531	3672
Conventional fuel (saving)			-2159			-2159			-2159					
Alternative fuel			5229	5293	5106	5298	5163	5227	5040	5232	3944	4008	3821	4013
Distribution infrastructure			3151	3869	3869	1819	3151	3869	3869	1819	3151	3869	3869	1819
Vehicle costs ⁽¹⁾														
Substituted fleet	M/a	0.90			0.90			0.90						
Gasoline		0.60			0.60			0.60						
Diesel		0.30			0.30			0.30						
Base cost substituted fleet	MEUR/a	-548			-548			-548						
Alternative vehicle costs	€/unit	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945	
	M€/a	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497	
Net total cost		M€/a	19170	19952	19765	17906	19104	19886	19699	17840	17885	18667	18480	16621
Cost of substitution		€/t	2399	2497	2473	2241	2391	2488	2465	2232	2238	2336	2312	2080
(per unit conv. Fuel)		€/GJ	55.6	57.8	57.3	51.9	55.4	57.7	57.1	51.7	51.9	54.1	53.6	48.2
Cost of CO ₂ avoided		€/t	697	687	681	726	700	693	687	724				

⁽¹⁾ Over base cost of 2010 gasoline PISI

7.12 Hydrogen from on-board reformer + FC

Fuel		Hydrogen								
Primary resource		Gasoline	Naphtha	Diesel	MeOH					
					NG	NG	Coal	Wood		
					Remote	4000 km		Farmed	Waste	
									standard	via BL
		COG1	CON1	COD1	GRME1	GPME1b	KOME1	WFME1	WWME1	BLME1
Power train (2010+)		Reformer + FC								
TTW energy	MJ/km	1.62			1.48					
Distance covered	Tm	187			187					
Fuel consumed	PJ/a	304			277					
WTW total energy	MJ/km	1.85	1.80	1.88	2.38	2.50	2.86	3.06	3.06	2.35
WTW fossil energy	MJ/km	1.85	1.80	1.88	2.38	2.50	2.86	3.06	3.06	2.35
WTW GHG	g/km	140	134	144	145	154	297	18	14	11
WTW Savings										
Total energy	PJ/a	50	59	44	-50	-71	-139	-177	-177	-44
Fossil energy	PJ/a	50	59	44	-50	-71	-139	-177	-177	-44
GHG	Mt/a	3.8	5.1	3.1	3.0	1.3	-25.5	26.8	27.5	28.1
Conventional fuels substituted										
Gasoline	PJ/a	200								
Diesel		145								
Refuelling stations required					20.0	20.0				
WTT costs	M€/a	-255	-255	-255	1353	1353	1353	3142	2327	922
Conventional fuel (saving)						-2159				
Alternative fuel		1904	1904	1904	3312	3312	3312	5101	4287	2882
Distribution infrastructure					200	200	200	200	200	200
Vehicle costs ⁽¹⁾										
Substituted fleet	M/a									
Gasoline		0.90								
Diesel		0.60								
Base cost substituted fleet	MEUR/a	0.30								
Alternative vehicle costs	€/unit	-548								
	M€/a	24335								
		21978								
Net total cost	M€/a	21174	21174	21174	22782	22782	22782	24571	23757	22351
Cost of substitution	€/t	2650	2650	2650	2851	2851	2851	3075	2973	2797
(per unit conv. Fuel)	€/GJ	61.4	61.4	61.4	66.1	66.1	66.1	71.2	68.9	64.8
Cost of CO ₂ avoided	€/t	5552	4189	6858	7610	17387		917	865	795

⁽¹⁾ Over base cost of 2010 gasoline PISI

8 Substitution scenarios (oil @ 50 €/bbl)

8.1 Conventional fuel hybrids, CNG, LPG

Fuel	Combi.	Gasoline	Diesel	CNG									CBG	LPG
Primary resource	Oil			NG									Waste	LPG
		COG1	COD1	Combi. 70/30	4000 km GPCG1b 70%	LNG GRCG1 30%	Combi. 70/30	4000 km GPCG1b 70%	LNG GRCG1 30%	Comb. 70/30	4000 km GPCG1b	LNG GRCG1	org. waste liq. manure 0.2/0.8	
Power train (2010+)	Hybrids	PISI	DICI	PISI conventional (BF)			PISI conventional (Ded.)			PISI hybrid			PISI (BF)	PISI (BF)
TTW energy MJ/km	1.55	1.63	1.46	1.88			1.87			1.39			1.88	1.90
Distance covered Tm	187	105	82	187			187			187			187	187
Fuel consumed PJ/a	291	171	120	353			351			261			353	356
WTW total energy MJ/km	1.78	1.86	1.69	2.31	2.24	2.46	2.29	2.23	2.44	1.71	1.66	1.82	3.67	2.12
WTW fossil energy MJ/km	1.78	1.86	1.69	2.31	2.24	2.46	2.29	2.23	2.44	1.71	1.66	1.82	0.11	2.12
WTW GHG g/km	136	141	129	138	135	146	137	134	145	103	100	109	-109	141
WTW Savings														
Total energy PJ/a	62	32	30	-36	-24	-65	-33	-21	-62	76	85	55	-291	-1
Fossil energy PJ/a	62	32	30	-36	-24	-65	-33	-21	-62	76	85	55	376	-1
GHG Mt/a	4.7	2.4	2.2	4.3	4.9	2.8	4.4	5.1	3.0	10.9	11.3	9.8	50.4	3.8
Conventional fuels substituted PJ/a														
Gasoline	200	200		200			200			200			200	200
Diesel	145		145	145			145			145			145	145
Refuelling stations required k				20.0			20.0			20.0			20.0	20.0
WTT costs M€/a	-661	-348	-313	154			136			-584			3489	1131
Conventional fuel (saving)	-661	-348	-313	-4226			-4226			-4226			-4226	-4226
Alternative fuel				2842			2824			2103			6176	4808
Distribution infrastructure				1539			1539			1539			1539	550
Vehicle costs⁽¹⁾														
Substituted fleet M/a	0.90			0.90			0.90			0.90			0.90	0.90
Gasoline	0.60	0.60		0.60			0.60			0.60			0.60	0.60
Diesel	0.30		0.30	0.30			0.30			0.30			0.30	0.30
Base cost substituted fleet MEUR/a	-548	0	-548	-548			-548			-548			-548	-548
Alternative vehicle costs €/unit		6220	8030	2538			1953			7373			2538	2200
ME/a	6169	3723	2446	2292			1764			6659			2292	1987
Net total cost M€/a	4960	3375	1585	1898			1352			5526			5233	2570
Cost of substitution €/t				238			169			692			655	322
(per unit conv. Fuel) €/GJ				5.5			3.9			16.0			15.2	7.5
Cost of CO₂ avoided €/t	1062	1385	710	444	387	673	305	268	452	508	487	564	104	684

⁽¹⁾ Over base cost of 2010 gasoline PISI

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8.2 Bio-fuels

Fuel		Ethanol (5% blend)													Bio-diesel (5% blend)					
Primary resource		Sugar beet		Wheat grain								Straw	Wood		Rape		Sunfl.	Rape		Sunfl.
		SBET1	SBET3	WTET1a	WTET2a	WTET3a	WTET4a	WTET1b	WTET2b	WTET3b	WTET4b	STET1	Farmed WFET1	Waste WWET1	ROFA1	ROFE1	SOFA1	ROFA2	ROFE2	SOFA2
Power train (2010+)		PISI													DICI+DPF					
TTW energy	MJ/km	1.90													1.77					
Distance covered	Tm	105													82					
Fuel consumed	PJ/a	200													145					
WTW total energy	MJ/km	5.43	4.36	5.28	4.81	5.21	5.11	4.38	3.91	4.31	4.21	4.41	5.60	5.59	3.87	3.98	3.49	3.96	4.06	3.58
WTW fossil energy	MJ/km	1.65	0.59	1.68	1.23	1.64	0.53	0.84	0.38	0.79	-0.32	0.20	0.52	0.51	0.81	0.72	0.64	0.90	0.80	0.73
WTW GHG	g/km	111	58	114	90	178	49	98	74	161	33	19	43	36	85	80	47	95	88	50
WTW Savings																				
Total energy	PJ/a	-343	-231	-328	-278	-321	-310	-233	-184	-226	-216	-236	-361	-360	-150	-158	-118	-157	-165	-126
Fossil energy	PJ/a	54	166	50	98	55	172	140	187	145	261	206	173	174	102	109	115	94	102	108
GHG	Mt/a	5.6	11.1	5.3	7.8	-1.4	12.1	7.0	9.5	0.3	13.8	15.3	12.7	13.5	5.8	6.3	9.0	5.1	5.6	8.2
Conventional fuels substituted		200													145					
Gasoline																				
Diesel																				
Refuelling stations required																				
WTT costs	M€/a	1156	1081	1256	841	1084	1172	1612	1197	1440	1528	1992	3059	2141	813	827	920	770	788	877
Conventional fuel (saving)		-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-2448	-1778	-1778	-1778	-1778	-1778	-1778
Alternative fuel		3604	3529	3704	3289	3532	3620	4061	3645	3889	3976	4440	5507	4589	2591	2605	2698	2548	2567	2655
Distribution infrastructure																				
Vehicle costs ⁽¹⁾																				
Substituted fleet	M/a																			
Gasoline																				
Diesel																				
Base cost substituted fleet	MEUR/a																			
Alternative vehicle costs	€/unit																			
	M€/a																			
Net total cost	M€/a	1156	1081	1256	841	1084	1172	1612	1197	1440	1528	1992	3059	2141	813	827	920	770	788	877
Cost of substitution	€/t	250	234	272	182	234	253	349	259	311	330	431	661	463	241	246	273	229	234	260
(per unit conv. fuel)	€/GJ	5.8	5.4	6.3	4.2	5.4	5.9	8.1	6.0	7.2	7.6	10.0	15.3	10.7	5.6	5.7	6.3	5.3	5.4	6.0
Cost of CO ₂ avoided	€/t	207	97	239	108		97	231	126		110	130	240	159	140	131	102	152	141	107

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.3 Synthetic fuels

Fuel		Syn-Diesel					DME					
Primary resource		NG	Coal	Wood			NG		Coal	Wood		
		Remote GRSD1	KOSD1	Farmed WFSD1	Waste WWSD1	Waste (BL) BLSD1	Remote GRDE1	4000 km GPDE1b	KODE1	Farmed WFDE1	Waste WWDE1	Waste (BL) BLDE1
Power train (2010+)		DICI+DPF					DICI					
TTW energy	MJ/km	1.77					1.72					
Distance covered	Tm	82					82					
Fuel consumed	PJ/a	145					141					
WTW total energy	MJ/km	2.97	3.48	3.88	3.88	3.38	2.64	2.79	3.32	3.56	3.56	2.67
WTW fossil energy	MJ/km	2.97	3.48	0.11	0.12	0.06	2.64	2.79	3.32	0.10	0.10	0.05
WTW GHG	g/km	171	355	15	10	6	154	166	338	14	10	6
WTW Savings												
Total energy	PJ/a	-75	-118	-150	-150	-109	-48	-61	-104	-124	-124	-51
Fossil energy	PJ/a	-75	-118	159	159	163	-48	-61	-104	160	160	164
GHG	Mt/a	-1.2	-16.3	11.6	12.0	12.3	0.2	-0.8	-15.0	11.7	12.0	12.4
Conventional fuels substituted		PJ/a										
Gasoline												
Diesel		145					145					
Refuelling stations required		k					20.0					
WTT costs		M€/a										
Conventional fuel (saving)		345	68	2298	1824	629	478	994	544	1702	1266	93
Alternative fuel		-1778	-1778	-1778	-1778	-1778	-1778	-1778	-1778	-1778	-1778	-1778
Distribution infrastructure		2123	1847	4076	3602	2407	1707	2223	1773	2931	2495	1322
							550	550	550	550	550	550
Vehicle costs ⁽¹⁾												
Substituted fleet	M/a	0.30										
Gasoline												
Diesel		0.30										
Base cost substituted fleet	MEUR/a	-548										
Alternative vehicle costs	€/unit	2775										
	M€/a	845										
Net total cost	M€/a	345	68	2298	1824	629	775	1292	841	1999	1563	390
Cost of substitution	€/t	102	20	683	542	187	230	384	250	594	464	116
(per unit conv. fuel)	€/GJ	2.4	0.5	15.8	12.6	4.3	5.3	8.9	5.8	13.8	10.8	2.7
Cost of CO ₂ avoided		€/t		198	152	51				171	130	32

⁽¹⁾ Over base cost of 2010 gasoline PISI

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8.4 Hydrogen from thermal processes - ICE

Fuel	Hydrogen										Hydrogen			Hydrogen							
Primary resource	NG										Coal			Wood							
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central				
		Compressed				Liq/Comp	Liquid		Comp.		Liquid	Compressed				Liquid					
		Pipeline				Road		Pipeline	Road		Pipeline			Pipeline		Road					
		4000 km	LNG	4000 km	LNG	4000 km	4000 km	4000 km	LNG		Farmed			Waste		Farmed					
		GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2		WFCH1	WFCH2		WWCH1	WWCH2	BLCH1	WFLH1				
	21%	9%	12%	11%	12%	12%	12%	11%	KOCH1	Estim.	15%	12%	15%	12%	12%	35%					
Power train (2010+)	ICE										ICE			ICE							
TTW energy	MJ/km	1.68										1.68			1.68						
Distance covered	Tm	187										187			187						
Fuel consumed	PJ/a	314										314			314						
WTW total energy	MJ/km	3.36	3.27	3.55	2.87	3.13	2.88	3.82	3.57	3.92	4.37	4.02	4.72	3.65	3.76	3.30	3.72	3.30	2.53	4.18	
WTW fossil energy	MJ/km	3.36	3.27	3.55	2.87	3.13	2.88	3.82	3.57	3.92	4.36	4.02	4.71	0.27	0.36	0.38	0.32	0.38	0.34	0.11	
WTW GHG	g/km	194	186	201	165	178	166	223	212	230	318	391	245	19	26	24	18	21	17	14	
WTW Savings																					
Total energy	PJ/a	-232	-216	-269	-142	-190	-143	-319	-273	-338	-422	-356	-487	-288	-308	-222	-300	-222	-78	-388	
Fossil energy	PJ/a	-232	-216	-269	-142	-190	-143	-319	-273	-338	-421	-356	-485	346	329	324	336	324	332	376	
GHG	Mt/a	-6.2	-4.8	-7.4	-0.8	-3.2	-1.1	-11.6	-9.6	-12.9	-29.4	-43.0	-15.8	26.6	25.3	25.6	26.7	26.3	26.9	27.5	
Conventional fuels substituted	PJ/a																				
Gasoline		200										200			200						
Diesel		145										145			145						
Refuelling stations required	k	20.0										20.0			20.0						
WTT costs	M€/a	5894	6866	6866	4784	4784	5255	4705	6705	6705	6321	5360	7282	5700	5570	4945	4615	4127	2860	7944	
Conventional fuel (saving)						-4226						-4226					-4226				
Alternative fuel		6898	6836	6836	4754	4754	5225	8931	8931	8931	7419	5331	9508	6460	5540	4916	4586	4098	2831	10170	
Distribution infrastructure		3221	4256	4256	4256	4256	4256	0	2000	2000	3128	4256	2000	3467	4256	4256	4256	4256	4256	2000	
Vehicle costs ⁽¹⁾																					
Substituted fleet	M/a	0.90										0.90			0.90						
Gasoline		0.60										0.60			0.60						
Diesel		0.30										0.30			0.30						
Base cost substituted fleet	M€/a	-548										-548			-548						
Alternative vehicle costs	€/unit	4750			4750				4750		4750	4750	4750	4750		4750			4750		
	M€/a	4290			4290				4290		4290	4290	4290	4290		4290			4290		
Net total cost	M€/a	9635	10607	10607	8526	8526	8996	8446	10447	10447	10063	9102	11023	9442	9311	8687	8357	7869	6602	11686	
Cost of substitution	€/t	1206	1327	1327	1067	1067	1126	1057	1307	1307	1259	1139	1379	1181	1165	1087	1046	985	826	1462	
(per unit conv. Fuel)	€/GJ	27.9	30.8	30.8	24.7	24.7	26.1	24.5	30.3	30.3	29.2	26.4	32.0	27.4	27.0	25.2	24.2	22.8	19.1	33.9	
Cost of CO ₂ avoided	€/t													355	369	339	313	300	245	425	

⁽¹⁾ Over base cost of 2010 gasoline PISI

WTW APPENDIX 2

8.5 Hydrogen from thermal processes - ICE hybrid

Fuel	Hydrogen										Hydrogen			Hydrogen								
Primary resource	NG										Coal			Wood								
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central					
		Compressed				Liq/Comp	Liquid		Comp.		Liquid	Compressed				Liquid						
		Pipeline		Road		Pipeline	Road	Pipeline			Pipeline	Road										
	4000 km	LNG	4000 km	LNG	4000 km	4000 km	4000 km	LNG			Farmed	Waste		Farmed								
	GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2	KOCH1	Estim.	WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	WFLH1						
			21%	9%	12%	11%	12%	12%	12%	11%	26%	74%		15%	12%	15%	12%	12%	35%			
Power train (2010+)	ICE hybrid										ICE hybrid			ICE hybrid								
TTW energy	MJ/km	1.49										1.49			1.49							
Distance covered	Tm	187										187			187							
Fuel consumed	PJ/a	278										278			278							
WTW total energy	MJ/km	2.94	2.90	3.15	2.55	2.78	2.55	3.38	3.02	3.31	4.10	4.02	4.18	3.65	3.76	3.30	3.72	3.30	2.53	4.18		
WTW fossil energy	MJ/km	2.94	2.90	3.15	2.55	2.78	2.55	3.38	3.02	3.31	4.09	4.02	4.17	0.27	0.36	0.38	0.32	0.38	0.34	0.11		
WTW GHG	g/km	170	165	178	146	158	148	198	179	194	296	346	245	17	23	22	16	18	15	12		
WTW Savings																						
Total energy	PJ/a	-154	-146	-193	-81	-124	-82	-237	-169	-223	-371	-356	-387	-288	-308	-222	-300	-222	-78	-388		
Fossil energy	PJ/a	-154	-146	-193	-81	-124	-82	-237	-169	-223	-371	-356	-385	346	329	324	336	324	332	376		
GHG	Mt/a	-1.7	-0.8	-3.2	2.7	0.5	2.5	-6.9	-3.4	-6.2	-25.3	-34.7	-15.8	27.0	25.8	26.1	27.1	26.7	27.3	27.9		
Conventional fuels substituted	PJ/a																					
Gasoline		200										200			200							
Diesel		145										145			145							
Refuelling stations required	k	20.0										20.0			20.0							
WTT costs	M€/a	5110	6089	6089	4244	4244	4661	3690	5690	5690	5478	4755	6201	4966	4940	4387	4094	3662	2539	6789		
Conventional fuel (saving)						-4226						-4226					-4226					
Alternative fuel		6115	6059	6059	4214	4214	4631	7916	7916	7916	6576	4725	8427	5726	4911	4357	4065	3632	2509	9014		
Distribution infrastructure		3221	4256	4256	4256	4256	4256	0	2000	2000	3128	4256	2000	3467	4256	4256	4256	4256	4256	2000		
Vehicle costs ⁽¹⁾																						
Substituted fleet	M/a	0.90										0.90			0.90							
Gasoline		0.60										0.60			0.60							
Diesel		0.30										0.30			0.30							
Base cost substituted fleet	M€/a	-548										-548			-548							
Alternative vehicle costs	€/unit	10218			10218				10218		10218	10218	10218	10218			10218			10218		
	M€/a	9228			9228				9228		9228	9228	9228	9228			9228			9228		
Net total cost	M€/a	13789	14768	14768	12923	12923	13340	12369	14370	14370	14157	13434	14881	13646	13620	13066	12774	12341	11218	15468		
Cost of substitution	€/t	1725	1848	1848	1617	1617	1669	1548	1798	1798	1772	1681	1862	1707	1704	1635	1598	1544	1404	1936		
(per unit conv. Fuel)	€/GJ	40.0	42.8	42.8	37.5	37.5	38.7	35.9	41.7	41.7	41.0	38.9	43.1	39.6	39.5	37.9	37.0	35.8	32.5	44.8		
Cost of CO ₂ avoided	€/t				4724	23729	5384							505	528	501	472	462	412	554		

⁽¹⁾ Over base cost of 2010 gasoline PISI

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8.6 Hydrogen from thermal processes - FC

Fuel		Hydrogen									Hydrogen			Hydrogen								
Primary resource		NG									Coal			Wood								
		Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local		Central		Central			
			Compressed				Liq/Comp		Liquid			Comp.			Liquid		Compressed				Liquid	
			4000 km		Pipeline		4000 km		Road			Pipeline			Road		Farmed		Pipeline		Road	
			4000 km		LNG		4000 km		4000 km			4000 km			LNG		Farmed		Waste		Farmed	
			GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2		WFCH1	WFCH2		WWCH1	WWCH2	BLCH1	WFLH1				
		21%	9%	12%	11%	12%	12%	12%	12%	11%	50%	50%	15%	12%	15%	12%	12%	35%				
Power train (2010+)		FC									FC			FC								
TTW energy	MJ/km	0.94									0.94			0.94								
Distance covered	Tm	187									187			187								
Fuel consumed	PJ/a	176									176			176								
WTW total energy	MJ/km	1.88	1.83	1.99	1.61	1.76	1.61	2.14	2.01	2.20	2.45	2.25	2.65	2.05	2.11	1.85	2.09	1.85	1.42	2.35		
WTW fossil energy	MJ/km	1.88	1.83	1.99	1.61	1.76	1.61	2.14	2.01	2.20	2.45	2.25	2.64	0.15	0.20	0.22	0.18	0.22	0.19	0.06		
WTW GHG	g/km	109	104	112	92	100	93	125	119	129	232	219	245	10	14	13	10	11	9	8		
WTW Savings																						
Total energy	PJ/a	44	53	23	94	67	94	-5	21	-16	-63	-26	-99	12	1	49	6	49	130	-44		
Fossil energy	PJ/a	44	53	23	94	67	94	-5	21	-16	-62	-26	-98	368	358	356	363	356	360	385		
GHG	Mt/a	9.8	10.6	9.1	12.8	11.5	12.7	6.8	7.9	6.0	-13.3	-10.9	-15.8	28.2	27.4	27.6	28.2	28.0	28.4	28.7		
Conventional fuels substituted	PJ/a																					
Gasoline		200									200			200								
Diesel		145									145			145								
Refuelling stations required	k	20.0									20.0			20.0								
WTT costs	M€/a	3286	3865	3865	2697	2697	2961	4218	2785	2785	3064	3020	3108	2865	3138	2788	2602	2329	1618	3480		
Conventional fuel (saving)						-4226						-4226				-4226						
Alternative fuel		3870	3835	3835	2668	2668	2932	5011	5011	5011	4163	2991	5334	3625	3108	2758	2573	2299	1588	5706		
Distribution infrastructure		3642	4256	4256	4256	4256	4256	3434	2000	2000	3128	4256	2000	3467	4256	4256	4256	4256	4256	2000		
Vehicle costs ⁽¹⁾																						
Substituted fleet	M/a	0.90									0.90			0.90								
Gasoline		0.60									0.60			0.60								
Diesel		0.30									0.30			0.30								
Base cost substituted fleet	M€/a	-548									-548			-548								
Alternative vehicle costs	€/unit	11633			11633				11633		11633	11633	11633	11633			11633			11633		
	M€/a	10506			10506				10506		10506	10506	10506	10506			10506			10506		
Net total cost	M€/a	13244	13822	13822	12654	12654	12919	14176	12742	12742	13022	12978	13066	12822	13095	12745	12560	12286	11575	13438		
Cost of substitution	€/t	1657	1730	1730	1583	1583	1617	1774	1594	1594	1629	1624	1635	1604	1639	1595	1572	1537	1448	1681		
(per unit conv. Fuel)	€/GJ	38.4	40.1	40.1	36.7	36.7	37.5	41.1	36.9	36.9	37.8	37.6	37.9	37.2	38.0	37.0	36.4	35.6	33.6	39.0		
Cost of CO ₂ avoided	€/t	1351	1304	1520	985	1105	1019	2099	1614	2118				455	477	461	445	439	408	468		
Max		2479	2342	2735	1823	2044	1868	3860	3057	4066				828	861	842	817	814	779	836		

⁽¹⁾ Over base cost of 2010 gasoline PISI

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8.7 Hydrogen from thermal processes - FC hybrid

Fuel	Hydrogen										Hydrogen			Hydrogen								
Primary resource	NG										Coal			Wood								
	Combi.	On-site reforming		Central reforming						Combi.	Central		Combi.	Local	Central	Local	Central					
		Compressed				Liq/Comp		Liquid			Comp.	Liquid		Compressed				Road				
		Pipeline		Road		Road		Pipeline	Road		Pipeline			Waste		Road						
		4000 km	LNG	4000 km	LNG	4000 km	LNG	4000 km	LNG		Farmed			Farmed								
		GPCH1b	GRCH1	GPCH2b	GRCH2	GPCH3b	GPLCHb	GPLH1b	GRLH2		KOCH1	Estim.		WFCH1	WFCH2	WWCH1	WWCH2	BLCH1	WFLH1			
		21%	9%	12%	11%	12%	12%	12%	11%		50%	50%		15%	12%	15%	12%	12%	35%			
Power train (2010+)	FC hybrid										FC hybrid			FC hybrid								
TTW energy	MJ/km	0.84										0.84			0.84							
Distance covered	Tm	187										187			187							
Fuel consumed	PJ/a	157										157			157							
WTW total energy	MJ/km	1.68	1.63	1.77	1.44	1.56	1.44	1.91	1.79	1.96	2.18	2.01	2.36	1.82	1.88	1.65	1.86	1.65	1.26	2.09		
WTW fossil energy	MJ/km	1.68	1.63	1.77	1.44	1.56	1.44	1.91	1.79	1.96	2.18	2.01	2.35	0.13	0.18	0.19	0.16	0.19	0.17	0.05		
WTW GHG	g/km	97	93	100	82	89	83	111	106	115	207	195	218	9	13	12	9	10	8	7		
WTW Savings																						
Total energy	PJ/a	82	90	64	127	103	127	39	62	29	-12	20	-45	55	44	87	48	87	159	5		
Fossil energy	PJ/a	82	90	64	127	103	127	39	62	29	-12	20	-44	371	362	360	366	360	364	386		
GHG	Mt/a	12.0	12.7	11.4	14.7	13.5	14.6	9.3	10.3	8.7	-8.6	-6.4	-10.8	28.4	27.7	27.9	28.5	28.2	28.6	28.9		
Conventional fuels substituted	PJ/a																					
Gasoline		200										200			200							
Diesel		145										145			145							
Refuelling stations required	k	20.0										20.0			20.0							
WTT costs	M€/a	2862	3445	3445	2405	2405	2640	3669	2236	2236	2608	2693	2524	2468	2797	2485	2321	2077	1444	2855		
Conventional fuel (saving)						-4226						-4226					-4226					
Alternative fuel		3446	3415	3415	2375	2375	2610	4462	4462	4462	3706	2663	4750	3227	2768	2456	2291	2047	1414	5081		
Distribution infrastructure		3642	4256	4256	4256	4256	4256	3434	2000	2000	3128	4256	2000	3467	4256	4256	4256	4256	4256	2000		
Vehicle costs ⁽¹⁾																						
Substituted fleet	M/a	0.90										0.90			0.90							
Gasoline		0.60										0.60			0.60							
Diesel		0.30										0.30			0.30							
Base cost substituted fleet	M€/a	-548										-548			-548							
Alternative vehicle costs	€/unit	14945			14945				14945		14945	14945	14945	14945		14945			14945			
	M€/a	13497			13497				13497		13497	13497	13497	13497		13497			13497			
Net total cost	M€/a	15811	16394	16394	15354	15354	15589	16618	15185	15185	15557	15642	15473	15417	15746	15434	15270	15026	14393	15804		
Cost of substitution	€/t	1978	2051	2051	1921	1921	1951	2079	1900	1900	1947	1957	1936	1929	1970	1931	1911	1880	1801	1978		
(per unit conv. Fuel)	€/GJ	45.8	47.5	47.5	44.5	44.5	45.2	48.2	44.0	44.0	45.1	45.4	44.9	44.7	45.7	44.7	44.3	43.6	41.7	45.8		
Cost of CO ₂ avoided	€/t	1315	1287	1438	1042	1137	1068	1784	1470	1754				543	568	553	537	532	504	548		
Max		2468	2373	2653	1970	2151	2006	3326	2833	3399				1018	1055	1037	1011	1010	977	1016		

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.8 Hydrogen from electrolysis - ICE

Fuel		Hydrogen							Hydrogen				
Primary resource		Electricity ex NG							Coal				
		Combi.	Local		Central				Combi.	Local		Central	
			Compressed			Liquid				Compressed		Liquid	
			Pipeline			Road				Pipeline		Road	
		4000 km		LNG	4000 km	LNG	4000 km	LNG			Pipeline	Road	
		GPEL1b CH1	GREL1 CH1	GPEL1b CH2	Estim.	GPEL1b LH1	Estim.	KOEL1 CH1	KOEL1 CH2	KOEL1 LH1			
		21%		9%	25%	11%	25%	11%	30%	35%	35%		
Power train (2010+)		ICE							ICE				
TTW energy	MJ/km	1.68							1.68				
Distance covered	Tm	187							187				
Fuel consumed	PJ/a	314							314				
WTW total energy	MJ/km	6.17	5.70	6.28	5.78	6.36	6.47	7.05	7.32	6.99	6.99	7.93	
WTW fossil energy	MJ/km	6.17	5.70	6.28	5.78	6.35	6.47	7.05	7.32	6.99	6.99	7.93	
WTW GHG	g/km	364	339	369	339	369	386	415	740	710	710	795	
WTW Savings													
Total energy	PJ/a	-760	-671	-780	-687	-796	-816	-924	-974	-913	-913	-1088	
Fossil energy	PJ/a	-760	-671	-780	-687	-792	-816	-924	-974	-913	-913	-1088	
GHG	Mt/a	-38.1	-33.4	-39.0	-33.4	-38.9	-42.2	-47.6	-108.4	-102.8	-102.8	-118.8	
Conventional fuels substituted													
Gasoline		200							200				
Diesel		145							145				
Refuelling stations required		20.0							20.0				
WTT costs	M€/a	9619	10556	10556	10154	10154	8282	8282	7697	8634	8232	6360	
Conventional fuel (saving)		-4226							-4226				
Alternative fuel		10379	10526	10526	10124	10124	10508	10508	8457	8604	8202	8586	
Distribution infrastructure		3467	4256	4256	4256	4256	2000	2000	3467	4256	4256	2000	
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90							0.90				
Gasoline		0.60							0.60				
Diesel		0.30							0.30				
Base cost substituted fleet	MEUR/a	-548							-548				
Alternative vehicle costs	€/unit	4750	4750				4750		4750	4750		4750	
	M€/a	4290	4290				4290		4290	4290		4290	
Net total cost	M€/a	13361	14297	14297	13896	13896	12024	12024	11439	12375	11974	10102	
Cost of substitution	€/t	1672	1789	1789	1739	1739	1505	1505	1431	1549	1498	1264	
(per unit conv. Fuel)	€/GJ	38.7	41.5	41.5	40.3	40.3	34.9	34.9	33.2	35.9	34.7	29.3	
Cost of CO ₂ avoided													

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel		Hydrogen				Hydrogen				Hydrogen			
Primary resource		Nuclear				Wind				EU-mix			
		Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central	
			Compressed		Liquid		Compressed		Liquid		Compressed		Liquid
				Pipeline	Road			Pipeline	Road			Pipeline	Road
			NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.
			30%	35%	35%		30%	35%	35%		30%	35%	35%
			Power train (2010+)		ICE				ICE				ICE
TTW energy	MJ/km	1.68				1.68				1.68			
Distance covered	Tm	187				187				187			
Fuel consumed	PJ/a	314				314				314			
WTW total energy	MJ/km	10.39	10.10	10.18	10.87	3.29	2.99	3.08	3.76	8.04	7.74	7.83	8.52
WTW fossil energy	MJ/km	10.39	10.10	10.15	10.87	0.37	0.32	0.39	0.39	6.35	7.74	5.75	5.75
WTW GHG	g/km	28	12	12	59	31	16	15	59	365	349	349	395
WTW Savings													
Total energy	PJ/a	-1551	-1495	-1510	-1639	-221	-164	-180	-309	-1110	-1054	-1070	-1199
Fossil energy	PJ/a	-1549	-1495	-1505	-1639	327	336	323	323	-793	-1054	-682	-682
GHG	Mt/a	24.8	27.8	27.9	19.2	24.4	27.2	27.2	19.2	-38.3	-35.3	-35.2	-43.9
Conventional fuels substituted	PJ/a												
Gasoline		200				200				200			
Diesel		145				145				145			
Refuelling stations required	k	20.0				20.0				20.0			
WTT costs	M€/a	10449	11386	10984	9112	10241	11177	10775	8903	8881	9817	9416	7544
Conventional fuel (saving)			-4226				-4226				-4226		
Alternative fuel		11209	11356	10954	11338	11000	11147	10746	11129	9641	9788	9386	9770
Distribution infrastructure		3467	4256	4256	2000	3467	4256	4256	2000	3467	4256	4256	2000
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90				0.90				0.90			
Gasoline		0.60				0.60				0.60			
Diesel		0.30				0.30				0.30			
Base cost substituted fleet	MEUR/a	-548				-548				-548			
Alternative vehicle costs	€/unit	4750	4750		4750	4750	4750	4750	4750	4750	4750		4750
	M€/a	4290	4290		4290	4290	4290	4290	4290	4290	4290		4290
Net total cost	M€/a	14191	15127	14726	12854	13982	14918	14517	12645	12622	13559	13157	11285
Cost of substitution	€/t	1776	1893	1843	1608	1750	1867	1817	1582	1579	1697	1646	1412
(per unit conv. Fuel)	€/GJ	41.1	43.9	42.7	37.3	40.5	43.3	42.1	36.7	36.6	39.3	38.1	32.7
Cost of CO ₂ avoided	€/t	572	543	528	671	573	549	533	660				

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.9 Hydrogen from electrolysis - ICE hybrid

Fuel		Hydrogen								Hydrogen			
Primary resource		Electricity ex NG								Coal			
		Combi.	Local		Central				Combi.	Local		Central	
			Compressed			Liquid				Compressed		Liquid	
			Pipeline				Road						
		4000 km		LNG	4000 km	LNG	4000 km	LNG			Pipeline	Road	
		GPEL1b CH1		GREL1 CH1	GPEL1b CH2	Estim.	GPEL1b LH1	Estim.	KOEL1 CH1	KOEL1 CH2	KOEL1 LH1		
		21%		9%	25%	11%	25%	11%	30%	35%	35%		
Power train (2010+)		ICE hybrid								ICE hybrid			
TTW energy	MJ/km	1.49								1.49			
Distance covered	Tm	187								187			
Fuel consumed	PJ/a	278								278			
WTW total energy	MJ/km	5.40	5.05	5.57	5.13	5.64	5.46	6.25	6.37	6.19	6.19	6.69	
WTW fossil energy	MJ/km	5.40	5.05	5.57	5.13	5.63	5.46	6.25	6.37	6.19	6.19	6.69	
WTW GHG	g/km	319	301	327	301	327	326	368	644	629	629	671	
WTW Savings													
Total energy	PJ/a	-616	-550	-646	-564	-660	-627	-774	-796	-764	-764	-857	
Fossil energy	PJ/a	-616	-550	-646	-564	-657	-627	-774	-796	-764	-764	-857	
GHG	Mt/a	-29.6	-26.2	-31.1	-26.2	-31.1	-30.9	-38.8	-90.5	-87.7	-87.7	-95.6	
Conventional fuels substituted													
Gasoline	PJ/a	200								200			
Diesel		145								145			
Refuelling stations required		20.0								20.0			
WTT costs	M€/a	8440	9359	9359	9003	9003	7088	7088	6736	7656	7300	5384	
Conventional fuel (saving)					-4226					-4226			
Alternative fuel		9200	9330	9330	8974	8974	9314	9314	7496	7626	7270	7610	
Distribution infrastructure		3467	4256	4256	4256	4256	2000	2000	3467	4256	4256	2000	
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90								0.90			
Gasoline		0.60								0.60			
Diesel		0.30								0.30			
Base cost substituted fleet	MEUR/a	-548								-548			
Alternative vehicle costs	€/unit	4750		4750			4750		4750	4750		4750	
	M€/a	4290		4290			4290		4290	4290		4290	
Net total cost	M€/a	12181	13101	13101	12745	12745	10829	10829	10478	11397	11041	9126	
Cost of substitution	€/t	1524	1639	1639	1595	1595	1355	1355	1311	1426	1382	1142	
(per unit conv. Fuel)	€/GJ	35.3	38.0	38.0	37.0	37.0	31.4	31.4	30.4	33.0	32.0	26.5	
Cost of CO ₂ avoided													

⁽¹⁾ Over base cost of 2010 gasoline PISI

WTW APPENDIX 2

Fuel	Hydrogen					Hydrogen				Hydrogen			
Primary resource	Nuclear					Wind				EU-mix			
	Combi.	Local	Central			Combi.	Local	Central		Combi.	Local	Central	
		Compressed		Liquid	Compressed		Liquid	Compressed			Liquid		
			Pipeline	Road			Pipeline	Road	Pipeline		Road		
		NUEL1 CH1	Estim.	Estim.	WDEL1 CH1		Estim.	Estim.	EMEL1 CH1		Estim.	Estim.	
		30%	35%	35%	30%		35%	35%	30%		35%	35%	
Power train (2010+)		ICE hybrid				ICE hybrid				ICE hybrid			
TTW energy	MJ/km	1.49				1.49				1.49			
Distance covered	Tm	187				187				187			
Fuel consumed	PJ/a	278				278				278			
WTW total energy	MJ/km	9.21	8.95	9.02	9.63	2.92	2.65	2.73	3.34	7.13	6.86	6.94	7.55
WTW fossil energy	MJ/km	9.20	8.95	9.00	9.63	0.33	0.29	0.35	0.35	5.63	6.86	5.10	5.10
WTW GHG	g/km	25	11	11	52	27	14	14	52	324	310	309	351
WTW Savings													
Total energy	PJ/a	-1329	-1280	-1294	-1408	-150	-101	-115	-229	-939	-889	-903	-1017
Fossil energy	PJ/a	-1328	-1280	-1289	-1408	335	343	332	332	-658	-889	-559	-559
GHG	Mt/a	25.4	28.1	28.2	20.4	25.0	27.5	27.6	20.4	-30.5	-27.9	-27.8	-35.5
Conventional fuels substituted		PJ/a											
Gasoline		200				200				200			
Diesel		145				145				145			
Refuelling stations required		k				20.0				20.0			
WTT costs	M€/a	9176	10095	9739	7824	8991	9910	9554	7639	7785	8705	8349	6433
Conventional fuel (saving)		-4226				-4226				-4226			
Alternative fuel		9935	10066	9710	10050	9750	9881	9525	9865	8545	8675	8319	8659
Distribution infrastructure		3467	4256	4256	2000	3467	4256	4256	2000	3467	4256	4256	2000
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90				0.90				0.90			
Gasoline		0.60				0.60				0.60			
Diesel		0.30				0.30				0.30			
Base cost substituted fleet	MEUR/a	-548				-548				-548			
Alternative vehicle costs	€/unit	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750
	M€/a	4290	4290	4290	4290	4290	4290	4290	4290	4290	4290	4290	4290
Net total cost	M€/a	12917	13837	13481	11565	12732	13652	13296	11380	11527	12446	12090	10175
Cost of substitution	€/t	1616	1731	1687	1447	1593	1708	1664	1424	1442	1557	1513	1273
(per unit conv. Fuel)	€/GJ	37.5	40.1	39.1	33.5	36.9	39.6	38.5	33.0	33.4	36.1	35.1	29.5
Cost of CO ₂ avoided	€/t	508	493	479	567	508	496	482	558				

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.10 Hydrogen from electrolysis - FC

Fuel		Hydrogen								Hydrogen			
Primary resource		Electricity ex NG								Coal			
		Combi.	Local		Central				Combi.	Local		Central	
			Compressed			Liquid				Compressed		Liquid	
			Pipeline			Road				Pipeline		Road	
		4000 km		LNG	4000 km		LNG	4000 km		LNG	4000 km		LNG
		GPEL1b	GREL1	GPEL1b	Estim.	GPEL1b	Estim.	KOEL1	KOEL1	KOEL1			
		CH1	CH1	CH2		LH1		CH1	CH2	LH1			
			21%	9%	25%	11%	25%	11%		30%	35%	35%	
Power train (2010+)		FC								FC			
TTW energy	MJ/km	0.94								0.94			
Distance covered	Tm	187								187			
Fuel consumed	PJ/a	176								176			
WTW total energy	MJ/km	3.46	3.20	3.52	3.25	3.57	3.63	3.96	4.11	3.92	3.92	4.45	
WTW fossil energy	MJ/km	3.46	3.20	3.52	3.25	3.56	3.63	3.96	4.11	3.92	3.92	4.45	
WTW GHG	g/km	204	190	207	190	207	216	233	415	398	398	446	
WTW Savings													
Total energy	PJ/a	-252	-203	-264	-212	-272	-284	-345	-373	-338	-338	-437	
Fossil energy	PJ/a	-252	-203	-264	-212	-271	-284	-345	-373	-338	-338	-437	
GHG	Mt/a	-8.1	-5.5	-8.6	-5.5	-8.6	-10.4	-13.5	-47.6	-44.4	-44.4	-53.4	
Conventional fuels substituted		PJ/a											
Gasoline		200								200			
Diesel		145								145			
Refuelling stations required		k								20.0			
WTT costs		M€/a											
Conventional fuel (saving)		5064	5935	5935	5710	5710	3670	3670	3985	4857	4632	2591	
Alternative fuel		5823	5906	5906	5680	5680	5896	5896	4745	4827	4602	4817	
Distribution infrastructure		3467	4256	4256	4256	4256	2000	2000	3467	4256	4256	2000	
Vehicle costs ⁽¹⁾													
Substituted fleet	M/a	0.90								0.90			
Gasoline		0.60								0.60			
Diesel		0.30								0.30			
Base cost substituted fleet	MEUR/a	-548								-548			
Alternative vehicle costs	€/unit	11633	11633				11633		11633	11633		11633	
	M€/a	10506	10506				10506		10506	10506		10506	
Net total cost	M€/a	15021	15893	15893	15667	15667	13627	13627	13943	14814	14589	12549	
Cost of substitution	€/t	1880	1989	1989	1960	1960	1705	1705	1745	1854	1826	1570	
(per unit conv. Fuel)	€/GJ	43.6	46.1	46.1	45.4	45.4	39.5	39.5	40.4	43.0	42.3	36.4	
Cost of CO ₂ avoided		€/t											

⁽¹⁾ Over base cost of 2010 gasoline PISI

WTW APPENDIX 2

Fuel		Hydrogen				Hydrogen				Hydrogen			
Primary resource		Nuclear				Wind				EU-mix			
		Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central	
			Compressed	Liquid			Compressed	Liquid			Compressed	Liquid	
			Pipeline	Road			Pipeline	Road			Pipeline	Road	
		NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.	
		30%	35%	35%		30%	35%	35%		30%	35%	35%	
Power train (2010+)		FC				FC				FC			
TTW energy	MJ/km	0.94				0.94				0.94			
Distance covered	Tm	187				187				187			
Fuel consumed	PJ/a	176				176				176			
WTW total energy	MJ/km	5.83	5.66	5.71	6.10	1.85	1.68	1.73	2.11	4.51	4.34	4.39	4.78
WTW fossil energy	MJ/km	5.83	5.66	5.70	6.10	0.21	0.18	0.22	0.22	3.56	4.34	3.23	3.23
WTW GHG	g/km	16	7	7	33	17	9	9	33	205	196	196	222
WTW Savings													
Total energy	PJ/a	-696	-665	-673	-746	50	82	73	1	-449	-417	-426	-499
Fossil energy	PJ/a	-695	-665	-671	-746	357	362	355	355	-271	-417	-209	-209
GHG	Mt/a	27.2	28.9	28.9	24.0	26.9	28.5	28.5	24.0	-8.2	-6.5	-6.5	-11.4
Conventional fuels substituted	PJ/a												
Gasoline		200				200				200			
Diesel		145				145				145			
Refuelling stations required	k	20.0				20.0				20.0			
WTT costs	M€/a	5529	6401	6176	4135	5412	6284	6059	4018	4649	5521	5296	3255
Conventional fuel (saving)		-4226				-4226				-4226			
Alternative fuel		6289	6371	6146	6361	6172	6254	6029	6244	5409	5491	5266	5481
Distribution infrastructure		3467	4256	4256	2000	3467	4256	4256	2000	3467	4256	4256	2000
Vehicle costs⁽¹⁾													
Substituted fleet	M/a	0.90				0.90				0.90			
Gasoline		0.60				0.60				0.60			
Diesel		0.30				0.30				0.30			
Base cost substituted fleet	MEUR/a	-548				-548				-548			
Alternative vehicle costs	€/unit	11633	11633	11633	11633	11633	11633	11633	11633	11633	11633	11633	11633
	M€/a	10506	10506	10506	10506	10506	10506	10506	10506	10506	10506	10506	10506
Net total cost	M€/a	15487	16358	16133	14093	15369	16241	16016	13976	14607	15478	15253	13213
Cost of substitution	€/t	1938	2047	2019	1763	1923	2032	2004	1749	1828	1937	1909	1653
(per unit conv. Fuel)	€/GJ	44.9	47.4	46.8	40.9	44.6	47.1	46.4	40.5	42.3	44.9	44.2	38.3
Cost of CO₂ avoided	€/t	570	566	559	588	571	569	562	583				

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.11 Hydrogen from electrolysis - FC hybrid

Fuel		Hydrogen								Hydrogen									
Primary resource		Electricity ex NG								Coal									
		Combi.	Local		Central				Combi.	Local		Central							
			Compressed				Liquid			Compressed		Liquid							
			Pipeline				Road			Pipeline		Road							
		4000 km		LNG		4000 km		LNG		4000 km		LNG							
		GPEL1b CH1		GREL1 CH1		GPEL1b CH2		Estim.		GPEL1b LH1		Estim.		KOEL1 CH1		KOEL1 CH2		KOEL1 LH1	
		21%		9%		25%		11%		25%		11%		30%		35%		35%	
Power train (2010+)		FC hybrid								FC hybrid									
TTW energy	MJ/km	0.84								0.84									
Distance covered	Tm	187								187									
Fuel consumed	PJ/a	157								157									
WTW total energy	MJ/km	3.08	2.85	3.14	2.89	3.18	3.23	3.52	3.66	3.49	3.49	3.96							
WTW fossil energy	MJ/km	3.08	2.85	3.14	2.89	3.17	3.23	3.52	3.66	3.49	3.49	3.96							
WTW GHG	g/km	182	169	184	169	184	193	207	369	354	354	397							
WTW Savings																			
Total energy	PJ/a	-181	-137	-191	-145	-199	-209	-264	-288	-258	-258	-345							
Fossil energy	PJ/a	-181	-137	-191	-145	-198	-209	-263	-288	-258	-258	-345							
GHG	Mt/a	-3.9	-1.6	-4.3	-1.6	-4.4	-6.0	-8.7	-39.0	-36.3	-36.3	-44.2							
Conventional fuels substituted																			
Gasoline	PJ/a	200								200									
Diesel	PJ/a	145								145									
Refuelling stations required		20.0								20.0									
WTT costs	M€/a	4425	5288	5288	5088	5088	3024	3024	3465	4328	4127	2064							
Conventional fuel (saving)					-4226					-4226									
Alternative fuel		5185	5259	5259	5058	5058	5250	5250	4225	4298	4098	4289							
Distribution infrastructure		3467	4256	4256	4256	4256	2000	2000	3467	4256	4256	2000							
Vehicle costs ⁽¹⁾																			
Substituted fleet	M/a	0.90								0.90									
Gasoline		0.60								0.60									
Diesel		0.30								0.30									
Base cost substituted fleet	MEUR/a	-548								-548									
Alternative vehicle costs	€/unit	14945	14945				14945		14945	14945		14945							
	M€/a	13497	13497				13497		13497	13497		13497							
Net total cost	M€/a	17374	18237	18237	18037	18037	15973	15973	16414	17277	17076	15013							
Cost of substitution	€/t	2174	2282	2282	2257	2257	1999	1999	2054	2162	2137	1879							
(per unit conv. Fuel)	€/GJ	50.4	52.9	52.9	52.3	52.3	46.3	46.3	47.6	50.1	49.5	43.5							
Cost of CO ₂ avoided																			

⁽¹⁾ Over base cost of 2010 gasoline PISI

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Fuel Primary resource	Hydrogen				Hydrogen				Hydrogen			
	Nuclear				Wind				EU-mix			
	Combi.	Local	Central		Combi.	Local	Central		Combi.	Local	Central	
		Compressed		Liquid		Compressed		Liquid		Compressed		Liquid
		Pipeline		Road		Pipeline		Road		Pipeline		Road
		NUEL1 CH1	Estim.	Estim.		WDEL1 CH1	Estim.	Estim.		EMEL1 CH1	Estim.	Estim.
		30%	35%	35%		30%	35%	35%		30%	35%	35%
Power train (2010+)	FC hybrid				FC hybrid				FC hybrid			
TTW energy MJ/km	0.84				0.84				0.84			
Distance covered Tm	187				187				187			
Fuel consumed PJ/a	157				157				157			
WTW total energy MJ/km	5.19	5.04	5.09	5.43	1.65	1.50	1.54	1.88	4.02	3.87	3.91	4.25
WTW fossil energy MJ/km	5.19	5.04	5.07	5.43	0.18	0.16	0.19	0.19	3.17	3.87	2.88	2.88
WTW GHG g/km	14	6	6	29	15	8	8	29	182	174	174	198
WTW Savings												
Total energy PJ/a	-576	-548	-556	-621	88	116	108	44	-356	-328	-336	-401
Fossil energy PJ/a	-576	-548	-554	-621	362	366	360	360	-198	-328	-142	-142
GHG Mt/a	27.5	29.0	29.0	24.6	27.3	28.7	28.7	24.6	-4.0	-2.5	-2.5	-6.9
Conventional fuels substituted PJ/a												
Gasoline	200				200				200			
Diesel	145				145				145			
Refuelling stations required k	20.0				20.0				20.0			
WTT costs M€/a	4840	5703	5502	3438	4736	5599	5398	3334	4057	4919	4719	2655
Conventional fuel (saving)		-4226				-4226				-4226		
Alternative fuel	5600	5673	5473	5664	5496	5569	5368	5560	4816	4890	4689	4881
Distribution infrastructure	3467	4256	4256	2000	3467	4256	4256	2000	3467	4256	4256	2000
Vehicle costs ⁽¹⁾												
Substituted fleet M/a	0.90				0.90				0.90			
Gasoline	0.60				0.60				0.60			
Diesel	0.30				0.30				0.30			
Base cost substituted fleet MEUR/a	-548				-548				-548			
Alternative vehicle costs €/unit	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945	14945
ME/a	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497	13497
Net total cost M€/a	17789	18652	18451	16387	17685	18548	18347	16283	17005	17868	17668	15604
Cost of substitution €/t	2226	2334	2309	2051	2213	2321	2296	2038	2128	2236	2211	1953
(per unit conv. Fuel) €/GJ	51.6	54.1	53.5	47.5	51.3	53.8	53.2	47.2	49.3	51.8	51.2	45.2
Cost of CO ₂ avoided €/t	647	643	636	665	648	646	640	661				

⁽¹⁾ Over base cost of 2010 gasoline PISI

8.12 Hydrogen from on-board reformer + FC

Fuel		Hydrogen								
Primary resource		Gasoline	Naphtha	Diesel	MeOH					
					NG	NG	Coal	Wood		
					Remote	4000 km		Farmed	Waste	
									standard	via BL
		COG1	CON1	COD1	GRME1	GPME1b	KOME1	WFME1	WWME1	BLME1
Power train (2010+)		Reformer + FC								
TTW energy	MJ/km	1.62			1.48					
Distance covered	Tm	187			187					
Fuel consumed	PJ/a	304			277					
WTW total energy	MJ/km	1.85	1.80	1.88	2.38	2.50	2.86	3.06	3.06	2.35
WTW fossil energy	MJ/km	1.85	1.80	1.88	2.38	2.50	2.86	3.06	3.06	2.35
WTW GHG	g/km	140	134	144	145	154	297	18	14	11
WTW Savings										
Total energy	PJ/a	50	59	44	-50	-71	-139	-177	-177	-44
Fossil energy	PJ/a	50	59	44	-50	-71	-139	-177	-177	-44
GHG	Mt/a	3.8	5.1	3.1	3.0	1.3	-25.5	26.8	27.5	28.1
Conventional fuels substituted	PJ/a									
Gasoline		200								
Diesel		145								
Refuelling stations required	k				20.0	20.0				
WTT costs	M€/a	-499	-499	-499	463	628	463	1490	635	-11
Conventional fuel (saving)						-4226				
Alternative fuel		3727	3727	3727	4469	4635	4469	5496	4641	3996
Distribution infrastructure					220	220	220	220	220	220
Vehicle costs ⁽¹⁾										
Substituted fleet	M/a	0.90								
Gasoline		0.60								
Diesel		0.30								
Base cost substituted fleet	MEUR/a	-548								
Alternative vehicle costs	€/unit	24335								
	M€/a	21978								
Net total cost	M€/a	20930	20930	20930	21892	22057	21892	22919	22064	21419
Cost of substitution	€/t	2619	2619	2619	2739	2760	2739	2868	2761	2680
(per unit conv. Fuel)	€/GJ	60.7	60.7	60.7	63.5	64.0	63.5	66.5	64.0	62.1
Cost of CO ₂ avoided	€/t	5488	4141	6779	7313	16834		856	803	762

⁽¹⁾ Over base cost of 2010 gasoline PISI

9 Cost summary

9.1 Oil @ 25 €/bbl

Fuel	Powertrain	Alt. fuel consumed PJ/a	Fuel substituted		Base case GHG Mt CO _{2eq} /a	WTW savings ^(1,2)				Incremental cost over ref. scenario G€ /a			Cost of substitution		Cost of CO ₂ avoided € /t CO _{2eq}
			Gasoline	Diesel		Energy (PJ/a)		GHG		G€ /a			€ /t fossil fuel	€ / 100 km	
			PJ/a	PJ/a		Total	Fossil	Mt CO _{2eq} /a	% of base	WTT	Vehicles	Total			
Oil price @25 €/bbl															
Gasoline															
Diesel															
Both fuels															
Conventional	Hybrids	291	200	145	30.1	62	62	4.7	16%	-0.3	5.6	5.3		2.82	1131
CNG (pipeline 4000 km / LNG)			200	145	30.1										
	PISI (BF)	353				-36	-36	4.3	14%	0.7	1.7	2.5	310	1.32	579
	PISI (ded.)	351				-33	-33	4.4	15%	0.7	1.2	1.9	243	1.04	437
	Hybrid	261				76	76	10.9	36%	0.3	6.1	6.5	808	3.45	593
CBG (mixed sources)	PISI (BF)	353				-291	376	50.4	167%	4.9	1.7	6.6	832	3.55	132
LPG (remote)	PISI (BF)	356	356		30.1	-1	-1	3.8	12%	1.1	1.4	2.5	316	1.35	672
Ethanol	PISI	200	200		17.3										
Sugar beet															
Pulp to fodder						-343	54	5.6	32%	1.9		1.9	413	1.82	342
Pulp to heat						-231	166	11.1	65%	2.2		2.2	478	2.10	198
Ex wheat															
DDGS to animal feed															
Conv. Boiler						-328	50	5.3	30%	1.9		1.9	407	1.79	358
NG GT + CHP						-278	98	7.8	45%	1.5		1.5	325	1.43	193
Lignite CHP						-321	55	-1.4	-8%	2.0		2.0	425	1.87	
Straw CHP						-310	172	12.1	70%	2.2		2.2	466	2.05	178
DDGS to energy															
Conv. Boiler						-233	140	7.0	40%	2.3		2.3	499	2.20	331
NG CCGT						-184	187	9.5	55%	1.9		1.9	417	1.83	203
Lignite CHP						-226	145	0.3	2%	2.4		2.4	517	2.27	8481
Straw CHP						-216	261	13.8	80%	2.6		2.6	558	2.45	186
Ex straw						-236	206	15.3	89%	2.9		2.9	634	2.79	192
Ex wood						-361	173	12.9	75%	3.6		3.6	776	3.41	279
Bio-diesel	CIDI+DPF	145		145	12.8										
Glycerine as chemical															
RME						-150	102	5.8	45%	1.5		1.5	438	1.80	254
REE						-158	109	6.3	49%	1.5		1.5	442	1.81	237
SME						-118	115	9.0	70%	1.6		1.6	469	1.92	176
Glycerine as animal feed															
RME						-157	94	5.1	39%	1.5		1.5	436	1.79	290
REE						-165	102	5.6	44%	1.5		1.5	440	1.80	264
SME						-126	108	8.2	64%	1.6		1.6	467	1.91	191
Synthetic diesel fuels		145		145	12.8										
Syn-diesel ex NG (remote) CIDI+DPF						-75	-75	-1.2	-9%	0.2		0.2	51	0.21	
Syn-diesel ex coal CIDI+DPF						-118	-118	-16.3	-127%	0.6		0.6	170	0.70	
Syn-diesel ex wood CIDI+DPF						-150	159	11.7	91%	2.8		2.8	824	3.38	237
Syn-diesel ex wood via BL CIDI+DPF						-109	163	12.3	96%	1.2		1.2	355	1.46	97
DME ex NG (remote) CIDI						-48	-48	0.2	2%	0.8	0.3	1.1	332	1.36	
DME ex coal CIDI						-104	-104	-15.0	-117%	1.0	0.3	1.3	390	1.60	
DME ex wood CIDI						-124	160	11.8	92%	2.2	0.3	2.5	750	3.07	215
DME wood via BL CIDI						-51	164	12.4	96%	0.8	0.3	1.1	330	1.35	90

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Fuel	Powertrain	Alt. fuel consumed	Fuel substituted		Base case	WTW savings ^(1,2)				Incremental cost over ref. scenario			Cost of substitution		Cost of CO ₂ avoided
			Gasoline	Diesel		GHG	Energy (PJ/a)		GHG	G€ /a			€/ t fossil fuel	€/ 100 km	
			PJ/a	PJ/a	Mt CO _{2eq} /a		Total	Fossil		Mt CO _{2eq} /a	% of base	WTT			Vehicles
Oil price @25 €/bbl															
Hydrogen from thermal processes			200	145	30.1										
Ex NG reforming	ICE PISI	314				-232	-232	-6.2	-21%	5.7	3.7	9.4	1180	5.03	1415
	ICE hybrid	278				-154	-154	-1.7	-6%	5.1	8.7	13.8	1728	7.37	
	FC	176				44	44	9.8	33%	3.9	10.0	13.9	1735	7.40	
	FC hybrid	157				82	82	12.0	40%	3.6	12.9	16.6	2072	8.84	
Ex coal gasification	ICE PISI	314				-422	-421	-29.4	-98%	6.9	3.7	10.6	1332	5.68	1377
	ICE hybrid	278				-329	-328	-22.7	-76%	6.2	8.7	14.9	1861	7.94	
	FC	176				-63	-62	-13.3	-44%	4.2	10.0	14.1	1768	7.54	
	FC hybrid	157				-12	-12	-8.6	-28%	3.8	12.9	16.7	2095	8.94	
Ex wood gasification	ICE PISI	314				-288	346	26.6	88%	6.9	3.7	10.6	1332	5.69	400
	ICE hybrid	278				-198	352	27.0	90%	6.2	8.7	14.9	1866	7.96	552
	FC	176				12	368	28.2	94%	4.3	10.0	14.3	1785	7.62	506
	FC hybrid	157				55	371	28.4	94%	3.9	12.9	16.9	2114	9.02	595
Hydrogen from electrolysis															
Electricity ex			200	145	30.1										
NG	ICE PISI	314				-760	-760	-38.1	-127%	9.6	3.7	13.4	1672	7.13	
	ICE hybrid	278				-616	-616	-29.6	-98%	8.4	8.7	17.1	2142	9.14	
	FC	176				-252	-252	-8.1	-27%	5.1	10.0	15.0	1880	8.02	
	FC hybrid	157				-181	-181	-3.9	-13%	4.4	12.9	17.4	2174	9.28	
Coal	ICE PISI	314				-974	-974	-108.4	-360%	7.7	3.7	11.4	1431	6.11	
	ICE hybrid	278				-796	-796	-90.5	-300%	6.7	8.7	15.4	1929	8.23	
	FC	176				-373	-373	-47.6	-158%	4.0	10.0	13.9	1745	7.44	
	FC hybrid	157				-288	-288	-39.0	-130%	3.5	12.9	16.4	2054	8.76	
Nuclear	ICE PISI	314				-1551	-1549	24.8	82%	10.4	3.7	14.2	1776	7.58	572
	ICE hybrid	278				-1329	-1328	25.4	84%	9.2	8.7	17.9	2234	9.53	702
	FC	176				-696	-695	27.2	90%	5.5	10.0	15.5	1938	8.27	570
	FC hybrid	157				-576	-576	27.5	91%	4.8	12.9	17.8	2226	9.50	647
Wind	ICE PISI	314				-221	327	24.4	81%	10.2	3.7	14.0	1750	7.47	573
	ICE hybrid	278				-150	335	25.0	83%	9.0	8.7	17.7	2211	9.43	706
	FC	176				50	357	26.9	89%	5.4	10.0	15.4	1923	8.21	571
	FC hybrid	157				88	362	27.3	91%	4.7	12.9	17.7	2213	9.44	648
Indirect hydrogen															
Gasoline	Ref + FC	304	200	145	30.1	50	50	3.8	13%	-0.3	21.4	21.2	2650	11.31	5552
Naphtha						59	59	5.1	17%	-0.3	21.4	21.2	2650	11.31	4189
Diesel						44	44	3.1	10%	-0.3	21.4	21.2	2650	11.31	6858
Methanol ex NG		277													
Remote/import						-50	-50	3.0	10%	1.4	21.4	22.8	2851	12.16	7610
4000 km NG						-71	-71	1.3	4%	1.4	21.4	22.8	2851	12.16	17387
Methanol ex coal						-139	-139	-25.5	-85%	1.4	21.4	22.8	2851	12.16	
Methanol ex wood						-177	-177	26.9	89%	2.2	21.4	23.7	3054	12.63	879
Methanol ex wood via BL						-44	-44	28.1	93%	0.9	21.4	22.4	2973	11.93	795

⁽¹⁾ i.e. a negative number denotes an increase

⁽²⁾ Relative to the "business-as-usual" scenario: gasoline PISI for ethanol, diesel CIDI for diesel fuels and combined scenario for other fuels

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9.2 Oil @ 50 €/bbl

Fuel	Powertrain	Alt. fuel consumed PJ/a	Fuel substituted		Base case GHG Mt CO _{2eq} /a	WTW savings ^(1,2)				Incremental cost over ref. scenario			Cost of substitution		Cost of CO ₂ avoided €/t CO _{2eq}
			Gasoline	Diesel		Energy (PJ/a)		GHG	G€/a			€/t fossil fuel	€/100 km		
						Total	Fossil		Mt CO _{2eq} /a	% of base	WTT			Vehicles	
Oil price @50 €/bbl															
Gasoline															
Diesel															
Both fuels															
Conventional	Hybrids	291	200	145	30.1	62	62	4.7	16%	-0.7	5.6	5.0		2.65	1062
CNG (pipeline 4000 km / LNG)			200	145	30.1										
	PISI (BF)	353				-36	-36	4.3	14%	0.2	1.7	1.9	238	1.01	444
	PISI (ded.)	351				-33	-33	4.4	15%	0.1	1.2	1.4	169	0.72	305
	Hybrid	261				76	76	10.9	36%	-0.6	6.1	5.5	692	2.95	508
CBG (mixed sources)	PISI (BF)	353				-291	376	50.4	167%	3.5	1.7	5.2	655	2.79	104
LPG (remote)	PISI (BF)	356	356		30.1	-1	-1	3.8	12%	1.1	1.4	2.6	322	1.37	684
Ethanol	PISI	200	200		17.3										
Sugar beet															
Pulp to fodder						-343	54	5.6	32%	1.2		1.2	250	1.10	207
Pulp to heat						-231	166	11.1	65%	1.1		1.1	234	1.03	97
Ex wheat															
DDGS to animal feed															
Conv. Boiler						-328	50	5.3	30%	1.3		1.3	272	1.19	239
NG GT + CHP						-278	98	7.8	45%	0.8		0.8	182	0.80	108
Lignite CHP						-321	55	-1.4	-8%	1.1		1.1	234	1.03	
Straw CHP						-310	172	12.1	70%	1.2		1.2	253	1.11	97
DDGS to energy															
Conv. Boiler						-233	140	7.0	40%	1.6		1.6	349	1.53	231
NG CCGT						-184	187	9.5	55%	1.2		1.2	259	1.14	126
Lignite CHP						-226	145	0.3	2%	1.4		1.4	311	1.37	5110
Straw CHP						-216	261	13.8	80%	1.5		1.5	330	1.45	110
Ex straw						-236	206	15.3	89%	2.0		2.0	431	1.89	130
Ex wood						-361	173	12.9	75%	2.9		2.9	621	2.73	223
Bio-diesel	CIDI+DPF	145		145	12.8										
Glycerine as chemical															
RME						-150	102	5.8	45%	0.8		0.8	241	0.99	140
REE						-158	109	6.3	49%	0.8		0.8	246	1.01	131
SME						-118	115	9.0	70%	0.9		0.9	273	1.12	102
Glycerine as animal feed															
RME						-157	94	5.1	39%	0.8		0.8	229	0.94	152
REE						-165	102	5.6	44%	0.8		0.8	234	0.96	141
SME						-126	108	8.2	64%	0.9		0.9	260	1.07	107
Synthetic diesel fuels		145		145	12.8										
Syn-diesel ex NG (remote) CIDI+DPF						-75	-75	-1.2	-9%	0.3		0.3	102	0.42	
Syn-diesel ex coal CIDI+DPF						-118	-118	-16.3	-127%	0.1		0.1	20	0.08	
Syn-diesel ex wood CIDI+DPF						-150	159	11.7	91%	2.2		2.2	654	2.68	188
Syn-diesel ex wood via BL CIDI+DPF						-109	163	12.3	96%	0.6		0.6	187	0.77	51
DME ex NG (remote) CIDI						-48	-48	0.2	2%	0.5	0.3	0.8	230	0.94	
DME ex coal CIDI						-104	-104	-15.0	-117%	0.5	0.3	0.8	250	1.02	
DME ex wood CIDI						-124	160	11.8	92%	1.6	0.3	1.9	568	2.33	162
DME wood via BL CIDI						-51	164	12.4	96%	0.1	0.3	0.4	116	0.48	32

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Fuel	Powertrain	Alt. fuel consumed PJ/a	Fuel substituted		Base case GHG Mt CO _{2eq} /a	WTW savings ^(1,2)				Incremental cost over ref. scenario G€ /a			Cost of substitution		Cost of CO ₂ avoided €/t CO _{2eq}
			Gasoline	Diesel		Energy (PJ/a)		GHG					€/t fossil fuel	€/ 100 km	
			PJ/a		Total	Fossil	Mt CO _{2eq} /a	% of base	WTT	Vehicles	Total				
Oil price @50 €/bbl															
Hydrogen from thermal processes			200	145	30.1										
Ex NG reforming	ICE PISI	314				-232	-232	-6.2	-21%	5.9	3.7	9.6	1206	5.14	1351
	ICE hybrid	278				-154	-154	-1.7	-6%	5.1	8.7	13.8	1725	7.36	
	FC	176				44	44	9.8	33%	3.3	10.0	13.2	1657	7.07	
	FC hybrid	157				82	82	12.0	40%	2.9	12.9	15.8	1978	8.44	
Ex coal gasification	ICE PISI	314				-422	-421	-29.4	-98%	6.3	3.7	10.1	1259	5.37	1315
	ICE hybrid	278				-329	-328	-22.7	-76%	5.5	8.7	14.2	1772	7.56	
	FC	176				-63	-62	-13.3	-44%	3.1	10.0	13.0	1629	6.95	
	FC hybrid	157				-12	-12	-8.6	-28%	2.6	12.9	15.6	1947	8.31	
Ex wood gasification	ICE PISI	314				-288	346	26.6	88%	5.7	3.7	9.4	1181	5.04	355
	ICE hybrid	278				-198	352	27.0	90%	5.0	8.7	13.6	1707	7.29	
	FC	176				12	368	28.2	94%	2.9	10.0	12.8	1604	6.85	
	FC hybrid	157				55	371	28.4	94%	2.5	12.9	15.4	1929	8.23	
Hydrogen from electrolysis															
Electricity ex NG	ICE PISI	314	200	145	30.1	-760	-760	-38.1	-127%	9.6	3.7	13.4	1672	7.13	
	ICE hybrid	278				-616	-616	-29.6	-98%	8.4	8.7	17.1	2142	9.14	
	FC	176				-252	-252	-8.1	-27%	5.1	10.0	15.0	1880	8.02	
	FC hybrid	157				-181	-181	-3.9	-13%	4.4	12.9	17.4	2174	9.28	
Coal	ICE PISI	314				-974	-974	-108.4	-360%	7.7	3.7	11.4	1431	6.11	
	ICE hybrid	278				-796	-796	-90.5	-300%	6.7	8.7	15.4	1929	8.23	
	FC	176				-373	-373	-47.6	-158%	4.0	10.0	13.9	1745	7.44	
	FC hybrid	157				-288	-288	-39.0	-130%	3.5	12.9	16.4	2054	8.76	
Nuclear	ICE PISI	314				-1551	-1549	24.8	82%	10.4	3.7	14.2	1776	7.58	572
	ICE hybrid	278				-1329	-1328	25.4	84%	9.2	8.7	17.9	2234	9.53	
	FC	176				-696	-695	27.2	90%	5.5	10.0	15.5	1938	8.27	
	FC hybrid	157				-576	-576	27.5	91%	4.8	12.9	17.8	2226	9.50	
Wind	ICE PISI	314				-221	327	24.4	81%	10.2	3.7	14.0	1750	7.47	573
	ICE hybrid	278				-150	335	25.0	83%	9.0	8.7	17.7	2211	9.43	
	FC	176				50	357	26.9	89%	5.4	10.0	15.4	1923	8.21	
	FC hybrid	157				88	362	27.3	91%	4.7	12.9	17.7	2213	9.44	
Indirect hydrogen															
Ref + FC	Gasoline	304	200	145	30.1	50	50	3.8	13%	-0.5	21.4	20.9	2619	11.18	5488
	Naphtha					59	59	5.1	17%	-0.5	21.4	20.9	2619	11.18	
	Diesel					44	44	3.1	10%	-0.5	21.4	20.9	2619	11.18	
	Methanol ex NG	277													
Remote/import 4000 km NG						-50	-50	3.0	10%	0.5	21.4	21.9	2739	11.69	7313
						-71	-71	1.3	4%	0.6	21.4	22.1	2760	11.78	
Methanol ex coal						-139	-139	-25.5	-85%	0.5	21.4	21.9	2739	11.69	856
Methanol ex wood						-177	-177	26.9	89%	1.6	21.4	23.0	2846	12.30	
Methanol ex wood via BL						-44	-44	28.1	93%	0.0	21.4	21.4	2761	11.44	

⁽¹⁾ i.e. a negative number denotes an increase

⁽²⁾ Relative to the "business-as-usual" scenario: gasoline PISI for ethanol, diesel CIDI for diesel fuels and combined scenario for other fuels