Appendix A

Table A1.

- Energy:

	PEMFC	AFC	PAFC	MCFC	SOFC
1) Range of unit size and project size [MW]	0.001-0.250 [1]	0.001-0.100 [1]	0.050-upwards [1]	0.300- upwards [1]	0.300- upwards [1]
2) Nominal efficiency					
i) For electricity generation only [%]	28-40 [2]	30-40	37 [2]	50-55 [2]	28-55 [2]
ii) For combined heat and power [%]	80-90 [2]	70-80	80-90 [2]	80-90 [2]	80-90 [2]
3) Efficiency at partial load	Assume same as nominal efficiency	Assume same as nominal efficiency	Assume same as nominal efficiency	Assume same as nominal efficiency	Assume same as nominal efficiency
4) Flexibility towards fuel, fuel resource availability, plant siting and infrastructures (e.g. cooling water needs, high voltage, grid gas pipes, etc.)	Pure hydrogen [3]	Hydrogen [4]	Hydrogen or reformate fuel (natural gas, methanol, naphtha, LPG[1], propane, landfill gas) [5]	Hydrogen, Natural gas, CO [6], any hydrocarbon	Hydrogen, CH_4, CO_2+H_2O, CO [3], methanol, any hydrocarbon
5) Flexibility towards exploitation:					
i) Cold start [minutes from 0% to 90% of nominal power]	10-60	10-60	180-240 [7]	60-1200 (1 to 20 hours)	60-1440 (1 to 24 hours)
ii) Warm/lukewarm start [minutes from 0% to 90% of nominal power]	≈4.3 s from 293.15 K and ≈8.3 s from 253.15 K	<1	<5	<10	<10 (electrochemical response in milliseconds, thermal transient in minutes)
iii) Uncontrollable variation in load [% from nominal power]	negligible	negligible	negligible	negligible	negligible

[1] LPG is usually a mixture of propane (C_3H_8) and butane (C_4H_{10})

Total energetic score					

- Ecology and resource use:

1) Exhaust[2] [average in lifetime, including construction & transport]:					
i) CO_2 [kg/kWh$_{electricity}$]	0.601 [2]	No data	0.649 [2]	0.481 [2]	0.511 [2]
ii) SO_2 [kg/kWh$_{electricity}$]	3.0e-4 [2]	No data	3.8e-4 [2]	3.2e-4 [2]	2.5e-4 [2]
iii) NO_x [kg/kWh$_{electricity}$]	8.8e-5[3] [8]	No data	6.12e-6[4] [2]	3.19e-4[5] [9]	4.44e-5[3] [1,10] (73% operation including fuel chain, 27% manufacturing and disposal)
iv) PM_{10} [kg/kWh$_{electricity}$]	1.1e-5[3] [8]	No data	No data	4.86e-6[5] [9]	7.58e-6[3] [1,10] (100% manufacturing and disposal)
v) NMVOC [kg/kWh$_{electricity}$]	1.875e-9[6] [8]	No data	2.16e-6[4] [2]		7.094e-8[6] [8]
vi) Methane [kg/kWh$_{electricity}$]	6.4e-4[7] [8]	No data	0[4] [2]	5.83e-6[5] [9]	2.38e-4[7] [1, 9] (100% operation including fuel chain)

[2] Assuming 80% load factor, and 40 000 hours lifetime. Fuel chain assumed is UK continental shelf natural gas to UK NG network.
[3] Fuel chain and transport emissions not included
[4] Only for operation stage
[5] From processing and transport
[6] Only for the manufacturing stage
[7] Transport emissions not included, Hydrocarbons in total

	vii) N_2O [kg/kWh$_{electricity}$]	5.938e-7 [11]	No data	No data	No data	No data
	viii) C_{14} [kg/kWh$_{electricity}$]		No data	No data	No data	No data
	ix) Heavy metals [most important ones, g/kWh$_{electricity}$]	1.1625e-7[8] [8]	No data	No data	No data	3.3313e-7[8] [8]
2)	Thermal exhaust [TJ/GWh$_{electricity}$]					
	i) Into air	No data	No data	No data	No data	No data
	ii) Into water source	No data	No data	No data	No data	No data
3)	Liquid waste					
	i) Total liquid waste [kg/kWh$_{electricity}$]	No data	No data	No data	1.114-1.263 [8, 9]	3.125e-5[9] [8]
	ii) Total nitrogen into water source [kg/kWh$_{electricity}$]	4.136e-9[8] [8]	No data	No data	No data	9.206e-7[8]
	iii) Total phosphor into water source [kg/kWh$_{electricity}$]	2.156e-8[8] [8]	No data	No data	No data	1.21e-7[8]
	iv) Total chlorides into water source [kg/kWh$_{electricity}$]	2.914e-6[8] [8]	No data	No data	No data	3.716e-5[8]
	v) Total sulfates into water source [kg/kWh$_{electricity}$]	1.881e-6[8] [8] [8]	No data	No data	No data	1.352e-5[8]
	vi) Others ($KMnO_4$, iron, organic materials, solid materials)[Separately]	Suspended solids: 3.682e-6[8] [8] Metals: 1.787e-6[8] [8]	No data	No data	No data	Suspended solids: 2.2501e-4[8] [8] Metals: 1.216e-4[8] [8] Dissolved solids: 2.252e-6[8]
4)	Solid waste [tons/MWh$_{electricity}$]					
	i) Flue dust	8.835e-6[10] [8]	No data	No data	No data	8.455e-4[10] [8]
	ii) Slurry	No data	No data	No data	No data	No data
	iii) Hazardous waste	No data	No data	No data	No data	No data
	iv) Radioactive waste	No data	No data	No data	No data	No data
	v) Other solid waste	5.32e-5[8] [8] Total:	Total:	Total:	3.6e-3[11] [9] Total:	Total:

[8] Transport and in-use emissions not included
[9] Only for manufacturing and operation
[10] Manufacture and disposal only, Slag and ash

5)	Safety and health impacts					
	i) Population affected by worst perceived accident during operation [nr of persons]	No data	No data	No data	No data	No data
	ii) Number of deaths over the fuel cycle [persons/MWh$_{electricity}$]	No data. Same as CNG	No data. Same as CNG	No data. Same as CNG	No data. Same as CNG	No data. Same as CNG
	iii) Other effects					
6)	Visual impact and noise	60 dBA at 10 m	60 dBA at 10 m	60 dBA at 10 m	65 dBA at 10 m	65 dBA at 10 m
7)	Footprint and use of resources					
	i) Primary material moved for construction [kg/kW$_p$ of nominal power	Steel (0.916 kg/kW$_p$) [8]	No data	No data	No data	Steel (87.5 kg/kW$_p$ for Planar Systems and 59.005 kg/kW$_p$ for Tubular Systems) [8]
	ii) Secondary material moved for construction [kg/kW$_p$ of nominal power	Carbon Polymer (0.769 kg/kW$_p$) [8]	No data	No data	No data	Cr Alloy (13.413 kg/kW$_p$) [8]
	iii) Main materials uses for construction (five) [kg/kW$_p$ of nominal power]	1. Steel (0.916 kg/kW$_p$) 2. Carbon Polymer (0.769 kg/kW$_p$) 3. Aluminium Alloy (0.340 kg/kW$_p$) 4. AlO_3 (0.264 kg/kW$_p$) 5. Polypropylene (0.100 kg/kW$_p$) [8]	No data	No data	No data	1. Steel (87.5 kg/kW$_p$ for Planar Systems and 59.005 kg/kW$_p$ for Tubular Systems) 2. Cr Alloy (13.413 kg/kW$_p$) 3. Sr-doped $LaMnO_3$ (4.26 kg/kW$_p$) 4. Alumina (4.2 kg/kW$_p$) 5. ZrO_2 (4.05 kg/kW$_p$) [8]
	iv) Primarily material moved for	CNG	CNG	CNG	CNG	CNG

[11] Mainly steel from machinery used for the stack production process and from the plant structure

usage e.g. fuel [tons/ $MWh_{electricity}$]				Water	Water
v) Secondary material moved for usage e.g. fuel [tons/ $MWh_{electricity}$]	No data	No data	No data	No data	No data
vi) Critical materials in construction and usage (materials that may become a limiting factor for the technology) [kg/kW_p of nominal power]	Platinum (0.009 kg/kW_p) Ruthinium (0.001 kg/kW_p)	1. PTFE 2. Pt 3. Graphite [8]	1. PTFE 2. Pt 3. Graphite 4. H_3PO_4 [8]	1. Lithium potassium carbonate 2. Li_2CO_3/K_2CO_3 3. Molten carbonate/$LiAlO_2$ 4. Ni-Cr/Ni-Al alloy 5. NiO (lithiated in state-of-the art cathodes) [8]	No data
Total ecological score					

- Economy (without subsidies, price level for 2003):

1) Investment cost [euro/MW_e]	1 000 000 - 70 000 000 [12]	1 900 000 [13]	4 500 000[12] [3]	2 800 000 - 5 000 000[13] [7]	15 000 000 – 30 000 000 [13]
2) Availability [hours per year]	No data	No data	8410 (96%) [14]	No data	No data
3) Operational time [hours of nominal power/year]	No data	No data	No data	No data	No data
4) Reliability [%]	No data	No data	No data	No data	No data
5) Technical life span [years]	2.3 years for mobile and 11 years for stationary applications (at full load) [8]	2-4 years (at full load) [12, 14]	11 (for the stack)-20 (for the plant) (at full load) [5]	3-4 years [12]	8-11 (for the stack)-20 (for the plant) (at full load) [8]

[12] Based on 200KW system. 2002 1:1 exchange rates of US$ and Euro
[13] Based on 250KW and 2MW system. 2002 1:1 exchange rates of US$ and Euro

6) Construction time [years]	No data. Assume faster than large centralized plant due to modularity.	No data. Assume faster than large centralized plant due to modularity.	No data. Assume faster than large centralized plant due to modularity.	No data. Assume faster than large centralized plant due to modularity.	No data. Assume faster than large centralized plant due to modularity.
7) Fuel cost [euro/MJ]	As per CNG plus reformer	As per CNG plus reformer	As per CNG plus reformer	As per CNG	As per CNG
8) Operation and Maintenance (O&M) cost [euro/$MWh_{electricity}$]	0.019-0.027 [4]	No data	0.024 [4]	0.027-0.036 [4]	0.021 [4]
9) Waste handling and dismantling [euro/ $MWh_{electricity}$]					
Total economic score					

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