Technology Descriptions for Web Survey on Multi-Criteria Analysis

Research Stream 2b

This series of slides gives general descriptions of the 26 generation technologies contained in the NEEDS database for multi-criteria evaluation. It includes 2 nuclear, 16 fossil (10 coal & lignite, and 6 natural gas) and 8 renewable (biomass, solar and wind) technologies.

The intent is to introduce these technologies to readers who are not familiar with them by presenting pictures, a table of technical data and a brief description of the technology and related social factors.

Some technologies are also illustrated separately (i.e. CO_2 separation and sequestration, and biomass gasification) that in practice must be combined combined with a power plant (as shown in the data tables). These descriptions follow the plants to which they are attached.

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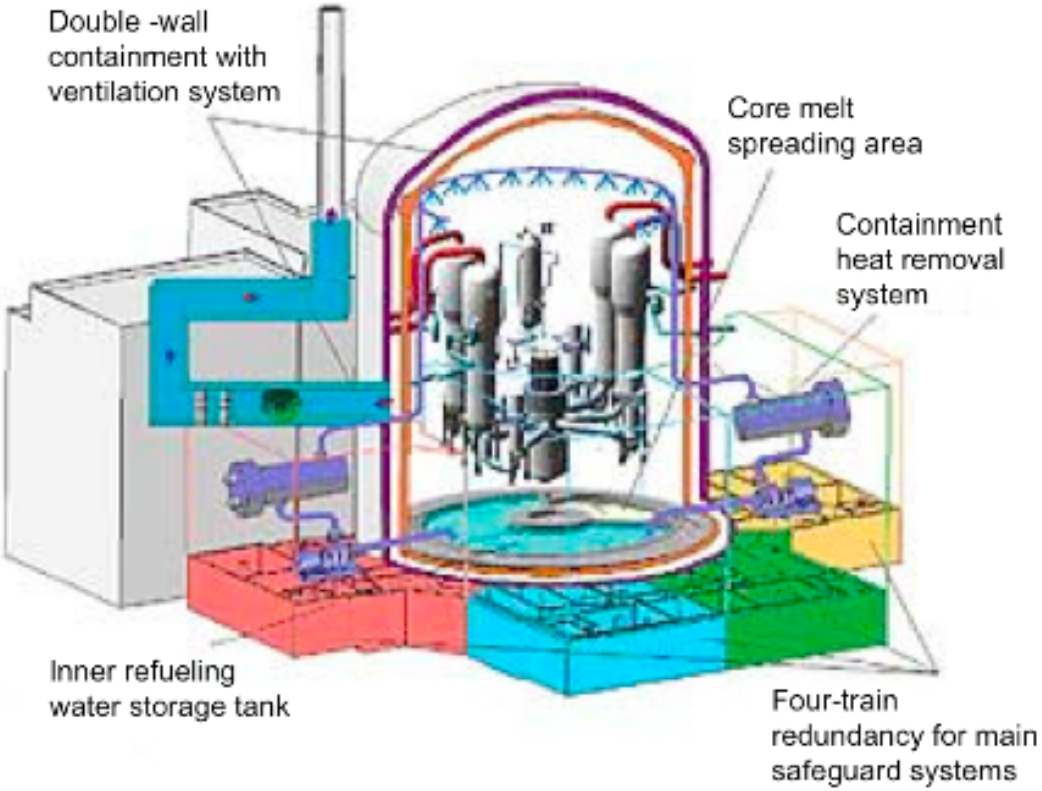
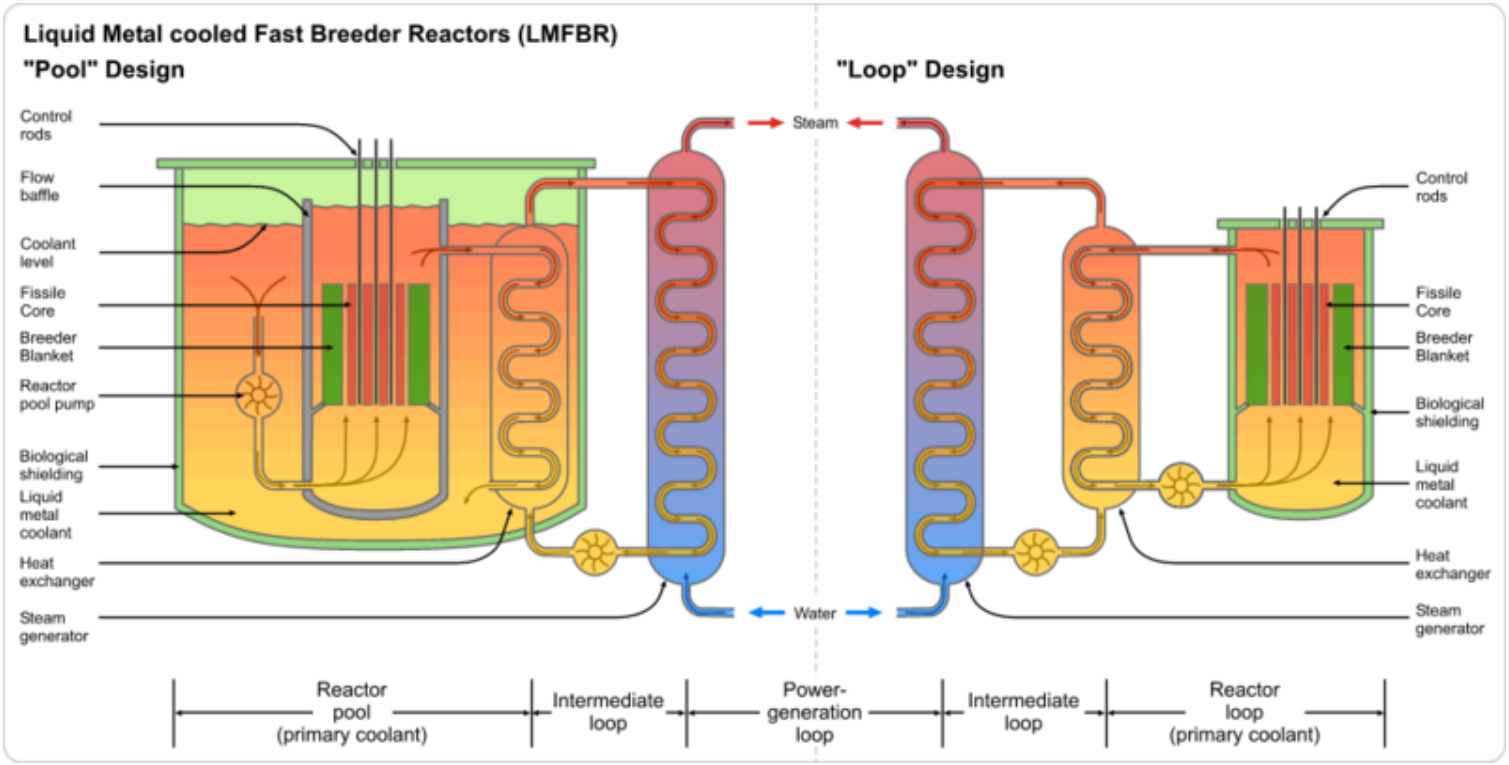
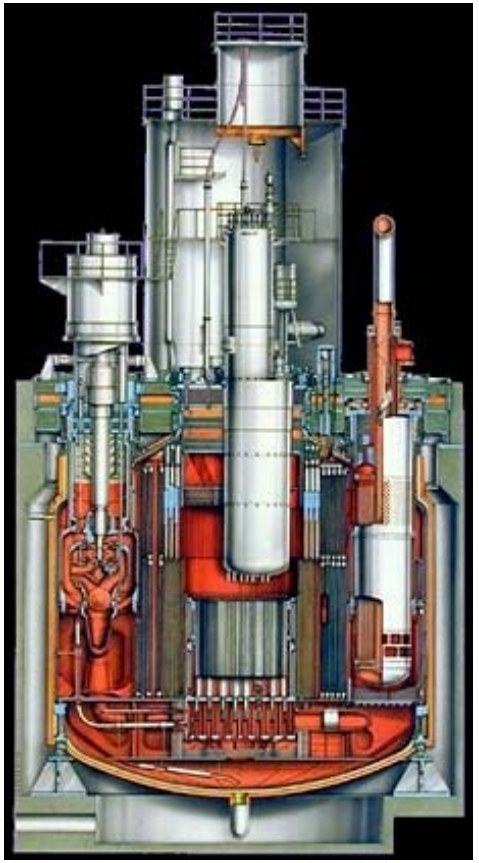
Nuclear, European Pressurized Reactor (EPR) - Illustrations



Nuclear, European Fast Reactor (EFR) – Illustrations





Nuclear, EPR and EFR – Technical Characteristics

Research Stream 2b

Characteristics	Units	1 **Nuclear Plants** **EPR** European Pressurized Reactor	2 **EFR** Sodium Fast Reactor (Gen IV Fast Breeder Reactor
Type of fuel		U235, 4.9%	Mixed Oxide
Electric efficiency	%	0.37	0.4
Electric generation capacity	MW	1590	1450
Load factor (expected hours/yr)	hours/year	7916	7889
Annual generation (expected)	kWh/year	1.26E+10	1.14E+10
Construction time	years	4.8	5.5
Capital cost (net present value)	€/kWe	1498	1900
Total capital cost (net present value)	M€	2383	2756
Plant life	years	60	40
Average cost of electricity	€cents/kWhe	3.01	2.68

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Nuclear, European Pressurized Reactor – Description and social factors

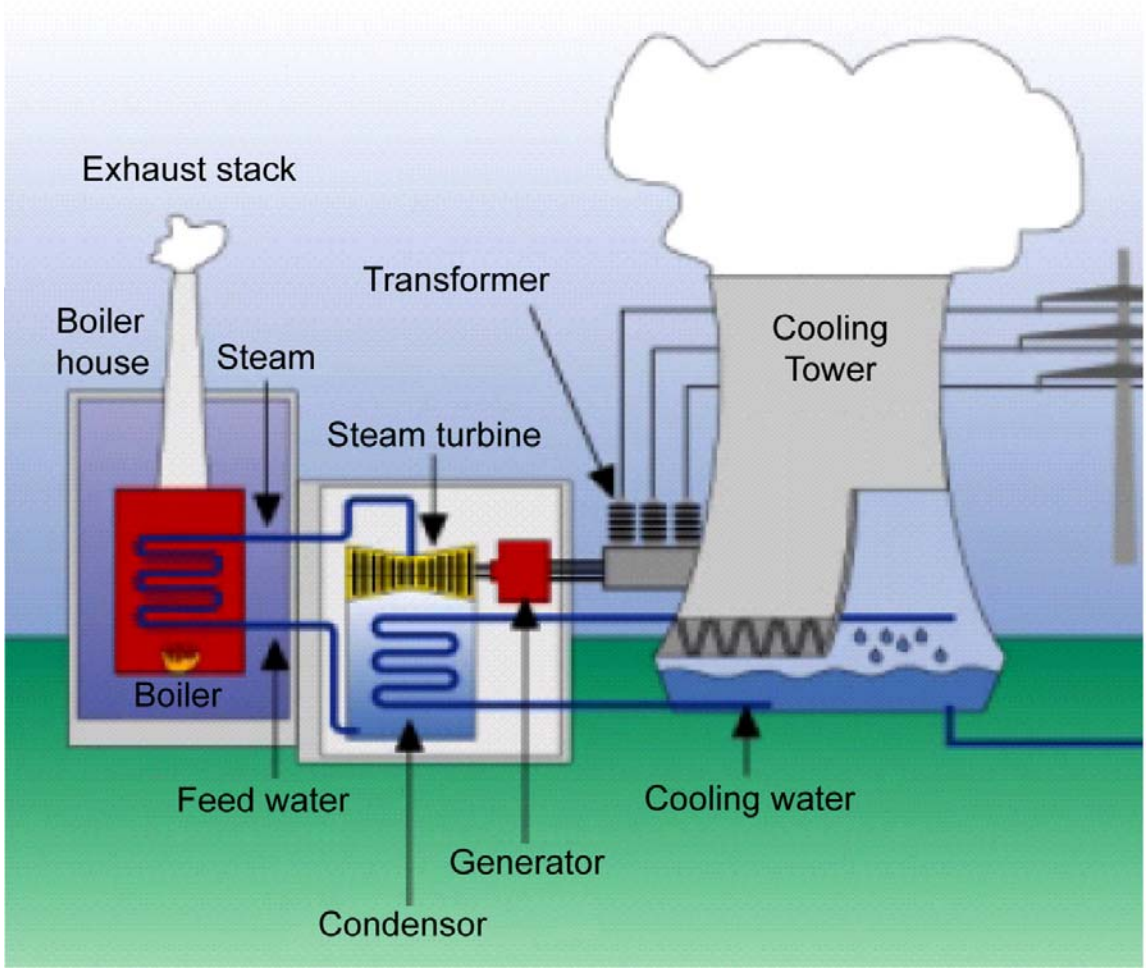
Research Stream 2b

Generation Technology	Nuclear Power, EPR
Technical description	European Pressurized Reactor. Generation 3 pressurized water reactor (PWR) with enhanced reliability & safety.
Primary energy source	Uranium.
Form of waste requiring storage	Low to high level radioactive waste (spent fuel depends on fuel cycle and reprocessing). Low chemical waste from full technology chain.
Record of past public acceptance	No EPRs yet in service, so acceptance is limited to a few construction permits. Past nuclear acceptance in general has been mixed to poor. Accident risks, waste storage & proliferation may remain controversial.
Possible proliferation or misuse	Possible misuse of fissile materials for making weapons.
Labor mix for technology chain	Fuel cycle, plant operation construction & demolition, waste storage.
Visual disturbance	Low to moderate, mainly dependent on whether or not cooling tower is present.
Noise	Low.

Nuclear, European Fast Reactor – Description and social factors

Generation Technology	Nuclear Power, EFR
Technical description	European Fast Reactor. Generation IV sodium-cooled liquid metal fast breeder reactor (LMFBR). Also called Sodium Fast Reactor, or SFR. Uses fast neutrons to produce new fuel as well as electricity via steam driven turbogenerator.
Primary energy source	Uranium.
Form of waste requiring storage	Low to high level radioactive waste (spent fuel reprocessing is required to extract new fuel bred). Low chemical waste from full technology chain.
Record of past public acceptance	Limited prior acceptance in some countries for some examples (Phenix, Superphenix). Past nuclear acceptance in general has been mixed to poor. Accident risks, waste storage & proliferation may remain controversial.
Possible proliferation or misuse	Misuse of enrichment technologies for weapons proliferation. Diversion of bred fuel for chemical processing to obtain plutonium. Possible misuse of diverted spent fuel for dirty bomb.
Labor mix for technology chain	Fuel cycle, plant construction, operation & demolition, waste storage.
Visual disturbance	Low to moderate, mainly dependent on whether or not cooling tower is present.
Noise	Low.

Coal & Lignite Steam Power Plants – Illustrations



Lignite Open Pit Mining – Illustrations

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Coal & Lignite Steam Power Plants – Technical Characteristics

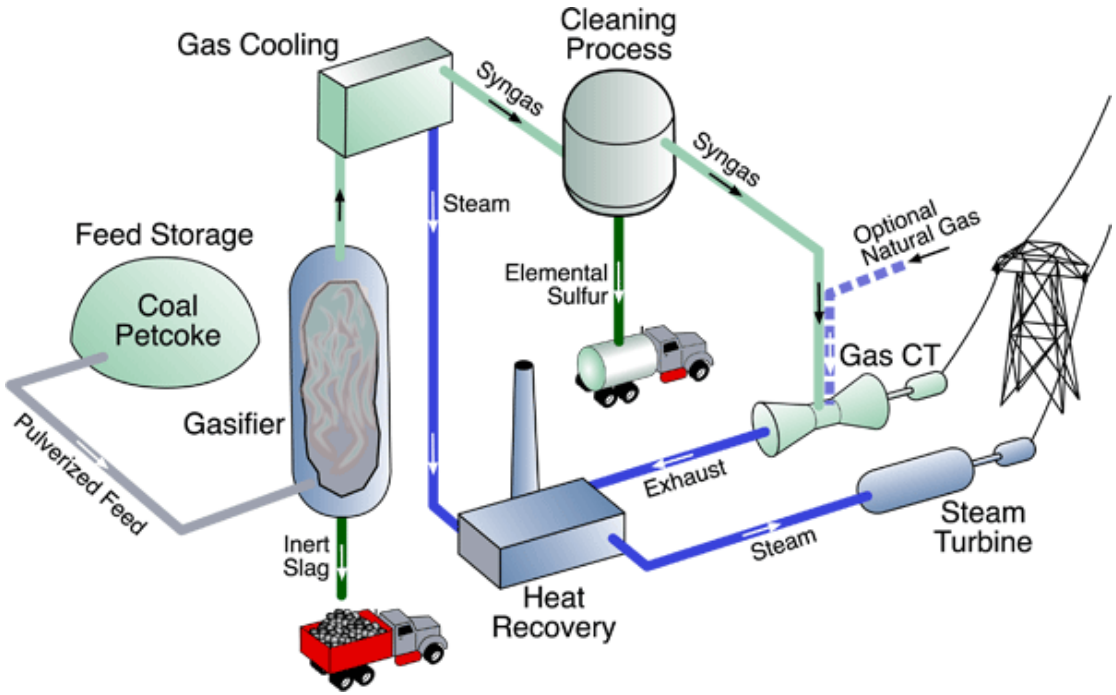
Research Stream 2b

Characteristics	Units	3 **Advanced Fossil** **PC** Pulverized Coal (PC) steam plant	4 **PC-post CCS** Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	5 **PC-oxyfuel CCS** Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	6 **PL** Pulverized Lignite (PL) steam plant	7 **PL-post CCS** Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	8 **PL-oxyfuel CCS** Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion
Type of fuel		hard coal	hard coal	hard coal	lignite	lignite	lignite
Electric efficiency	%	0.54	0.49	0.47	0.54	0.49	0.47
Electric generation capacity	MW	600	500	500	950	800	800
Load factor (expected hours/yr)	hours/year	7600	7600	7600	7760	7760	7760
Annual generation (expected)	kWh/year	4.56E+09	3.80E+09	3.80E+09	7.37E+09	6.21E+09	6.21E+09
Construction time	years	3	3	3	3	3	3
Capital cost (net present value)	€/kWe	983	1560	1560	989	1560	1560
Total capital cost (net present value)	M€	590	780	780	939	1248	1248
Plant life	years	35	35	35	35	35	35
Average cost of electricity	€cents/kWhe	2.96	3.94	4.00	3.01	4.08	4.16

Coal & Lignite Steam Power Plants – Description and social factors

Generation Technology	Coal & Lignite Steam Plants
Technical description	Coal or lignite is pulverized and then burned in a tall boiler with watertube walls. The steam produced is used to drive a turbine generator. Polluting SO2 and particulate emissions are filtered by chemical scrubbers, fabric filters and/or electrostatic precipitators. Coal ash and scrubber by-products are recycled or landfilled. Higher boiler temperatures and pressures continue to produce higher efficiencies. CO2 separation and sequestration can be combined with technology chain.
Primary energy source	Coal or lignite.
Form of waste requiring storage	Direct waste is flyash and scrubber byproducts (gypsum). Total chemical waste for full technology chain is high, relative to other technologies.
Record of past public acceptance	Acceptance dependent on tradition, emissions controls and growing concerns about CO2. Energy chain has also required acceptance of coal mining and related health burdens.
Possible proliferation or misuse	None.
Labor mix for technology chain	Mining, transport, plant construction, generation.
Visual disturbance	Mining and generation can be visually objectionable.
Noise	Locally significant at mine and plant.

Coal & Lignite IGCC Power Plants – Illustrations



Coal & Lignite IGCC Power Plants – Technical Characteristics

Research Stream 2b

Characteristics	Units	9 **Integrated Gasification Combined Cycle** **IGCC coal** Integrated Gasification Combined Cycle (IGCC)	10 **IGCC coal** Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	11 **IGCC lig** Integrated Gasification Combined Cycle (IGCC)	12 **IGCC lig** Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
Type of fuel		hard coal	hard coal	lignite	lignite
Electric efficiency	%	0.545	0.485	0.525	0.465
Electric generation capacity	MW	450	400	450	400
Load factor (expected hours/yr)	hours/year	7500	7500	7500	7500
Annual generation (expected)	kWh/year	3.38E+09	3.00E+09	3.38E+09	3.00E+09
Construction time	years	3	3	3	3
Capital cost (net present value)	€/kWe	1209	1505	1209	1209
Total capital cost (net present value)	M€	544	602	544	483
Plant life	years	35	35	35	35
Average cost of electricity	€cents/kWhe	6.17	7.26	6.57	6.78

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Coal & Lignite IGCC Power Plants – Description and social factors

Research Stream 2b

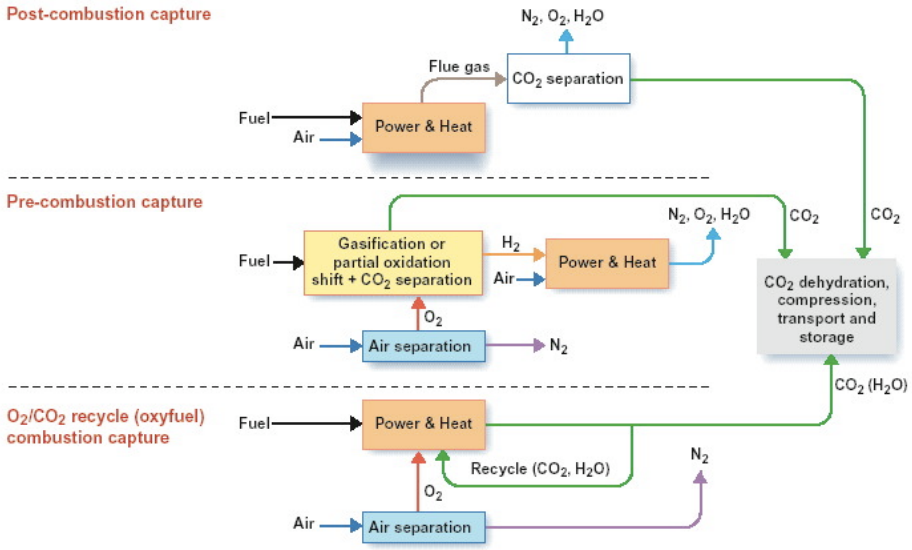
Generation Technology	Coal & Lignite IGCC Plants
Technical description	Integrated gasification combined cycle. Coal is transformed to a syngas fuel that is burned directly in a combustion turbine generator. The recovered waste heat is then used to drive a steam turbine generator. CO2 separation and sequestration can be combined with technology chain.
Primary energy source	Coal or lignite.
Form of waste requiring storage	Ash and other waste. Some byproducts (i.e. sulfur) are sold. Chemical waste for full technology chain is low, relative to other technologies.
Record of past public acceptance	IGCC still under development, but higher acceptance can be expected than for conventional coal plants, given fewer impacts. Energy chain has also required acceptance of coal mining and related health burdens.
Possible proliferation or misuse	None.
Labor mix for technology chain	Mining, transport, plant construction, generation.
Visual disturbance	Mining and generation can be visually objectionable.
Noise	Locally significant at mine and plant.

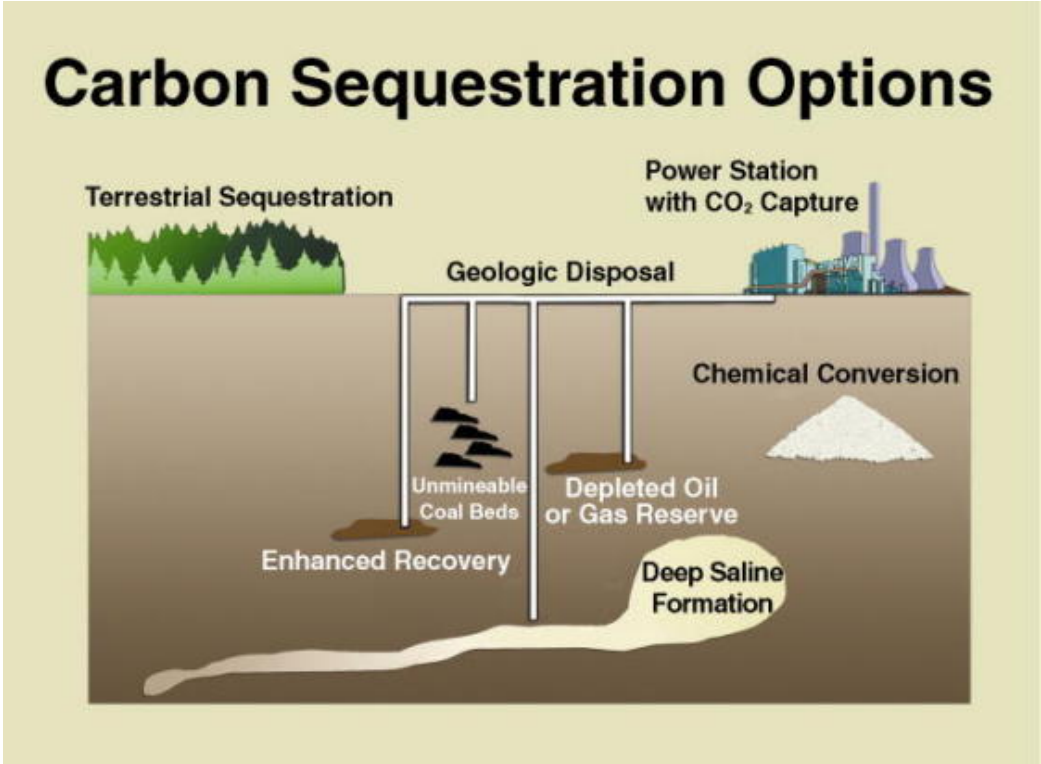
Carbon Capture & Sequestration (CCS) – Illustrations

Research Stream 2b

CO_2 may be separated by:

- pre-combustion capture,
- oxyfuel combustion capture, or
- post-combustion capture.



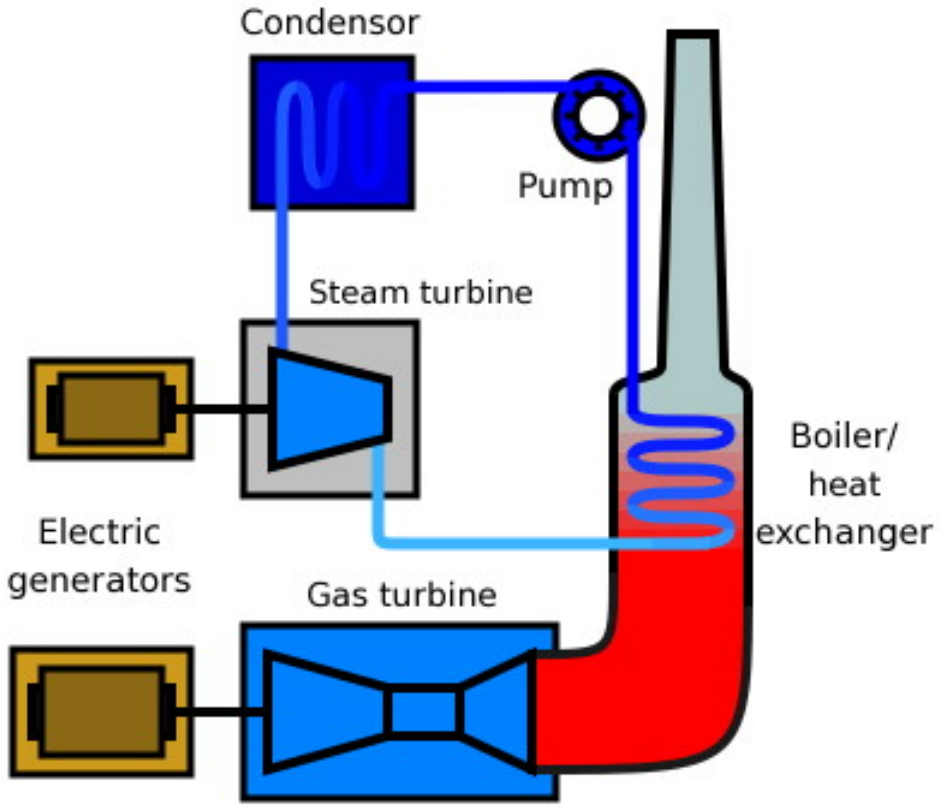


CO_2 may be sequestered in a variety of repositories.

Carbon Capture & Sequestration – Description and social factors

Generation Technology	Carbon Capture & Sequestration, CCS
Technical description	CO2 can be separated by using pure O2 to preprocess the fuel before final combustion, using pure O2 and recycling some of the combustion exhaust, or by separating the CO2 from the exhaust gases from normal combustion. The separated CO2 can be sequestered in geological formations, in the deep ocean, or by conversion to solid mineral form.
Primary energy source	Dependent upon base plant technology. Decreases net generation efficiency and raises primary energy required.
Form of waste requiring storage	CO2 sequestered. Type of CSS can increase or decrease total chemical waste from entire technology chain.
Record of past public acceptance	Process(es) still under development; local acceptance problems expected.
Possible proliferation or misuse	None expected.
Labor mix for technology chain	Separation plant, pipeline transport and well or conversion.
Visual disturbance	Little extra disturbance at plant. May cause disturbance at sequestration site.
Noise	Little extra noise at generation plant. Local noise at sequestration site.

Gas Turbine Combined Cycle (GTCC) – Illustrations



Gas Turbine Combined Cycle – Technical Characteristics

Research Stream 2b

Characteristics	Units	13 **GTCC** Combined Cycle	14 **GTCC CCS** Combined Cycle with Carbon Capture & Storage (CCS), post combustion
Type of fuel		natural gas	natural gas
Electric efficiency	%	0.65	0.61
Electric generation capacity	MW	1000	1000
Load factor (expected hours/yr)	hours/year	7200	7200
Annual generation (expected)	kWh/year	7.20E+09	7.20E+09
Construction time	years	3	3
Capital cost (net present value)	€/kWe	440	615
Total capital cost (net present value)	M€	440	615
Plant life	years	25	25
Average cost of electricity	€cents/kWhe	5.99	8.69

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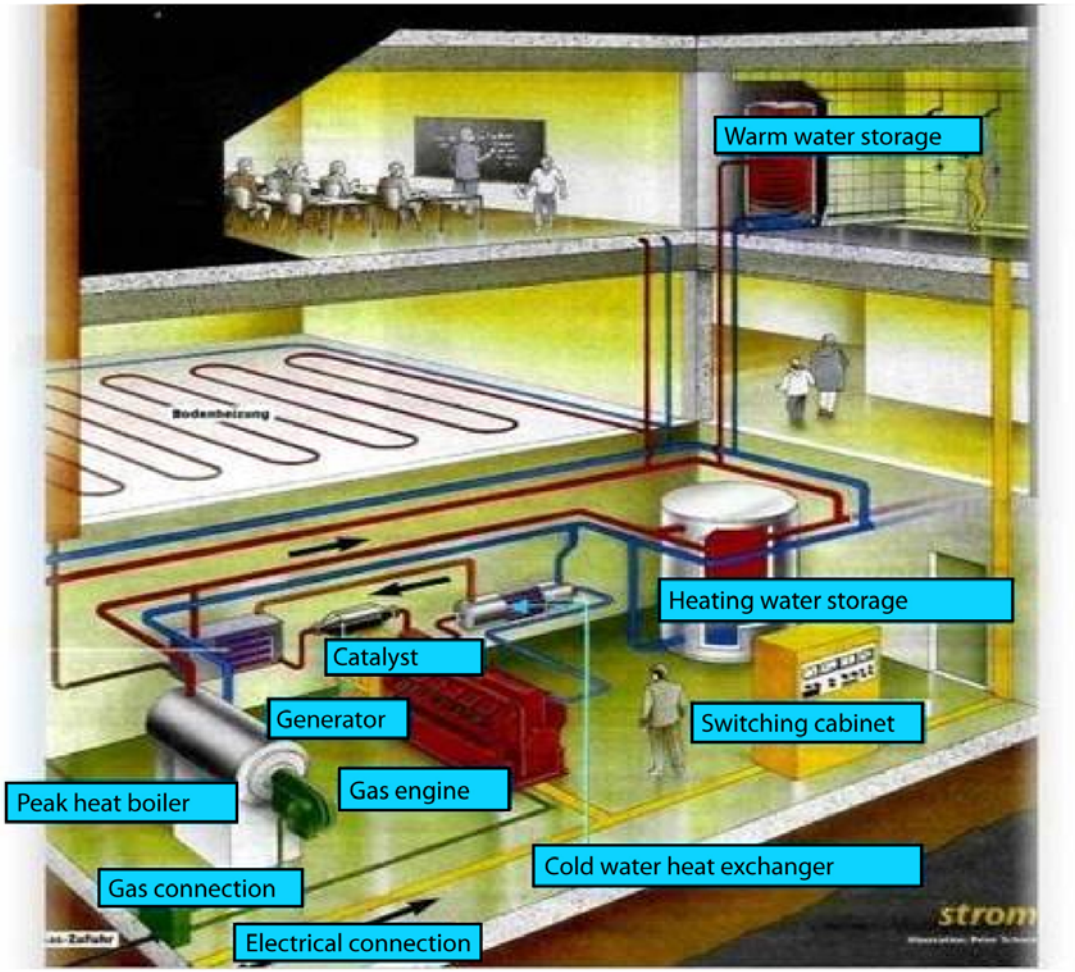
Gas Turbine Combined Cycle – Description and social factors

Generation Technology	Gas Turbine Combined Cycle, GTCC
Technical description	Gas turbine combined cycle. Natural gas is burned directly in a combustion turbine generator, and the recovered waste heat is then used to also drive a steam turbine generator.
Primary energy source	Natural gas.
Form of waste requiring storage	Moderate chemical waste for full technology chain.
Record of past public acceptance	Moderate for generating plant. Growing concerns about CO2 emissions. Also requires acceptance of natural gas pipeline network.
Possible proliferation or misuse	None.
Labor mix for technology chain	Drilling, pipeline transport, plant construction & operation.
Visual disturbance	Low local disturbance. Pipeline networks largely underground.
Noise	Low local noise levels.

Cogeneration, Small Engine – Illustrations

Source: COMUNA-metall/ASUE



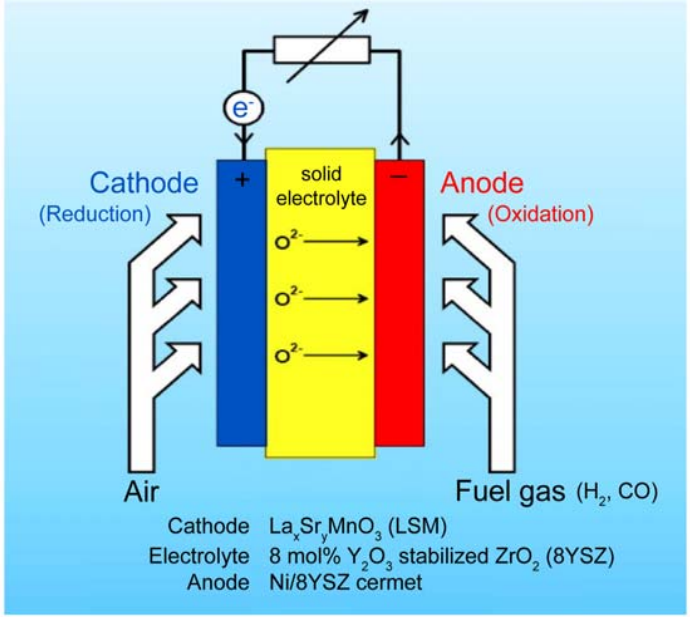
Cogeneration, Small Engine – Technical Characteristics

Characteristics	Units	15 **IC CHP** IC engine cogeneration
Type of fuel		natural gas
Electric efficiency	%	0.44
Electric generation capacity	MW	0.2
Load factor (expected hours/yr)	hours/year	5000
Annual generation (expected)	kWh/year	1.00E+06
Construction time	years	1
Capital cost (net present value)	€/kWe	879
Total capital cost (net present value)	M€	0
Plant life	years	20
Average cost of electricity	€cents/kWhe	11.10

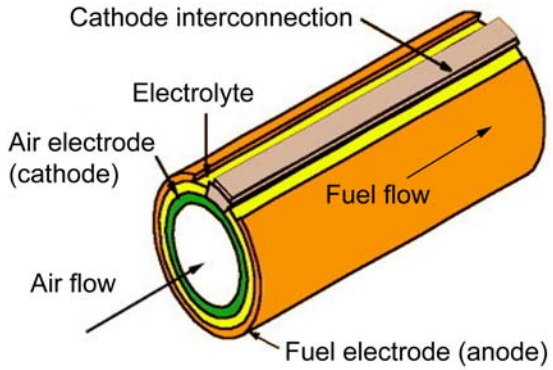
Cogeneration, Small Engine – Description and social factors

Generation Technology	Small Internal Combustion Engine Cogeneration, Distributed
Technical description	Small internal combustion engine drives generator and provides heat. Used in distributed residental & commercial applications.
Primary energy source	Natural gas, wood (synthesized gas) or biomass (digester gas).
Form of waste requiring storage	Moderate chemical waste for full technology chain.
Record of past public acceptance	Distributed nature means public acceptance is not a critical issue. Natural gas fuel requires acceptance of drilling & pipeline transport. Biogas requires acceptance of biomass harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacturing, installation.
Visual disturbance	None (inside buildings).
Noise	Minimal, local.

Fuel Cells, Cogeneration – Illustrations



Cylindrical Geometry



Fuel Cells, Cogeneration – Technical Characteristics

Characteristics	Units	16 **Fuel Cells MCFC NG** Molten Carbonate Fuel Cells, natural gas	17 **MCFC wood gas** Molten Carbonate Fuel Cells, wood gas	18 **MCFC NG** Molten Carbonate Fuel Cells, natural gas	19 **SOFC NG** Solid Oxide Fuel Cells (tubular, natural gas
Type of fuel		natural gas	wood gas	natural gas	natural gas
Electric efficiency	%	0.5	0.5	0.55	0.58
Electric generation capacity	MW	0.25	0.25	2	0.3
Load factor (expected hours/yr)	hours/year	5000	5000	5000	5000
Annual generation (expected)	kWh/year	1.25E+06	1.25E+06	1.00E+07	1.50E+06
Construction time	years	0.83	0.83	0.83	0.83
Capital cost (net present value)	€/kWe	1544	1544	1235	1030
Total capital cost (net present value)	M€	0	0	2	0
Plant life	years	5	5	5	5
Average cost of electricity	€cents/kWhe	8.74	8.44	7.29	6.73

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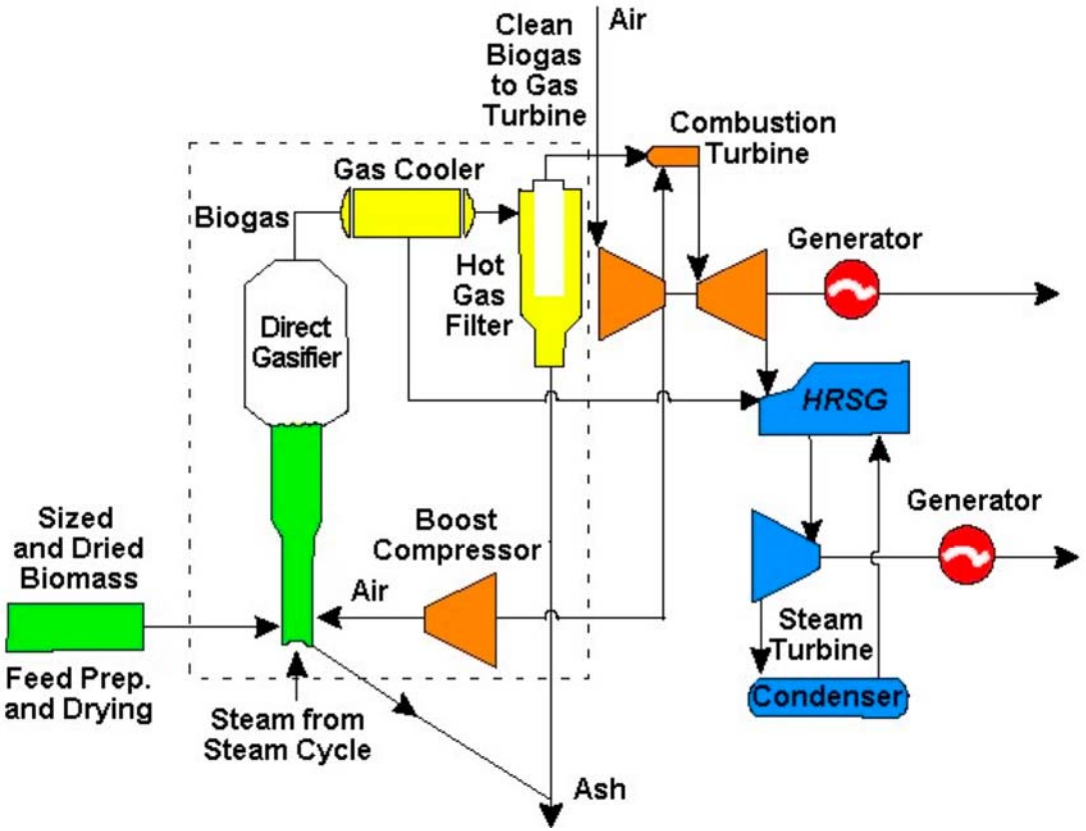
Fuel Cells, Cogeneration – Description and social factors

Generation Technology	Fuel Cell Cogeneration, Distributed
Technical description	Polymer electrolyte, molten carbonate and solid oxide fuel cells. Direct conversion of chemical energy to electricity, and use of heat in distributed residential and commercial applications.
Primary energy source	Natural gas or wood (synthesized gas).
Form of waste requiring storage	Moderate chemical wastes for full technology chain, with relatively less for wood gas.
Record of past public acceptance	Distributed nature means public acceptance is not a critical issue. Natural gas fuel requires acceptance of drilling & pipeline transport. Syngas requires acceptance of wood harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacturing, installation for plant. Gas-drilling & pipelines. Syngas-logging & transport.
Visual disturbance	None (inside buildings).
Noise	Minimal, local.

Biomass Gasification, Heat & Power – Illustrations



Biomass Gasification, Heat & Power – Technical Characteristics

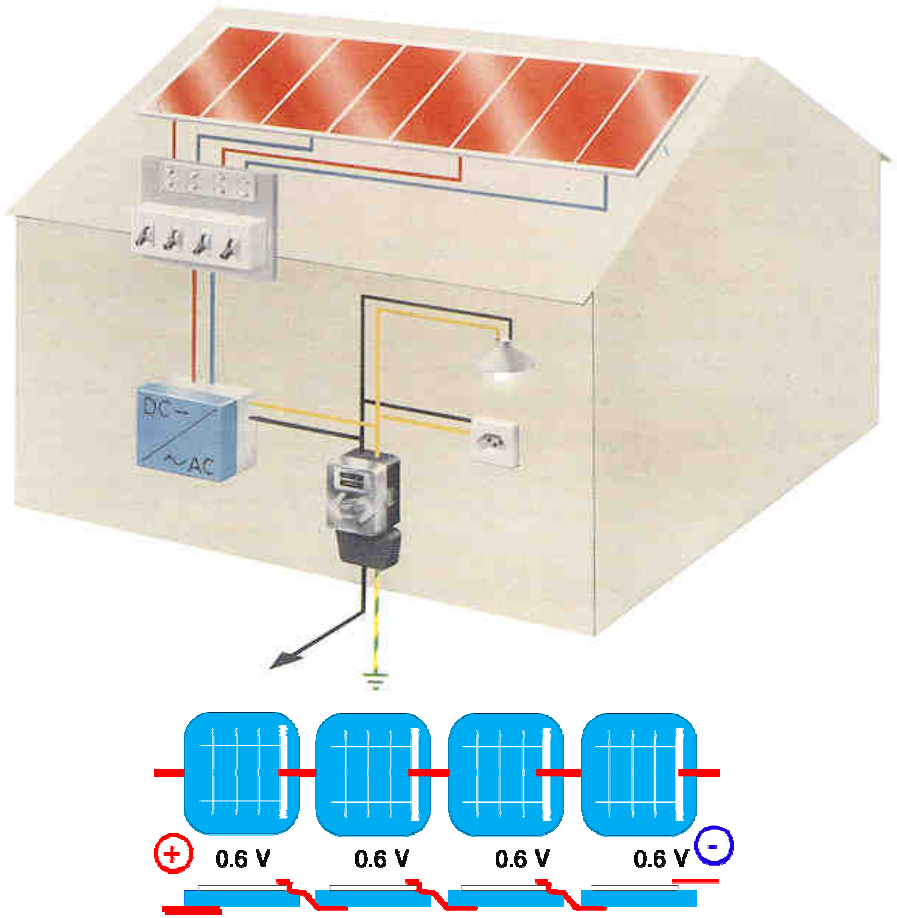
Research Stream 2b

Characteristics	Units	20 **Biomass CHP** **CHP poplar** Steam turbine cogeneration, short rotation forestry poplar	21 **CHP straw** Steam turbine cogeneration, agricultural waste wheat straw
Type of fuel		SRF poplar	waste straw
Electric efficiency	%	0.3	0.3
Electric generation capacity	MW	9	9
Load factor (expected hours/yr)	hours/year	8000	8000
Annual generation (expected)	kWh/year	7.20E+07	7.20E+07
Construction time	years	2	2
Capital cost (net present value)	€/kWe	2280	2280
Total capital cost (net present value)	M€	21	21
Plant life	years	15	15
Average cost of electricity	€cents/kWhe	7.29	6.51

Biomass Gasification, Heat & Power – Description and social factors

Generation Technology	Biomass Gasification, Heat & Power
Technical description	Wood or crop waste biomass is gasified and burned in a boiler and the steam used to drive a turbine generator. The waste heat is recovered and used.
Primary energy source	Wood (poplar) from short rotation forestry, and crop waste (wheat straw). Forestry requires land use and wood transport. Crop waste requires no additional land use, but requires transport and depletes soil of crop nutrients.
Form of waste requiring storage	Low chemical waste for full technology chain.
Record of past public acceptance	Moderate for gasification and generation plant. Requires acceptance of biomass harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Forestry, harvest, transport, plant construction & operation.
Visual disturbance	Periodic clear cutting for wood, truck traffic for transport.
Noise	Local plant noise. Traffic noise, if through populated areas.

Solar Power, PV – Illustrations



Solar Power, PV – Technical Characteristics

Characteristics	Units	22 **Solar PV-Si plant** PV, Mono-crystalline Si, Plant Size	23 **PV-Si building** PV, Mono-crystalline Si, Building Integrated	24 **PV-CdTe building** CdTe, Building Integrated
Type of fuel		sun	sun	sun
Electric efficiency	%	0	0	0
Electric generation capacity	MW	46.6375	0.4197375	0.839475
Load factor (expected hours/yr)	hours/year	984	984	984
Annual generation (expected)	kWh/year	4.59E+07	4.13E+05	8.26E+05
Construction time	years	2	0.5	0.5
Capital cost (net present value)	€/kWe	848	927	927
Total capital cost (net present value)	M€	40	0	1
Plant life	years	40	40	35
Average cost of electricity	€cents/kWhe	6.30	6.92	7.15

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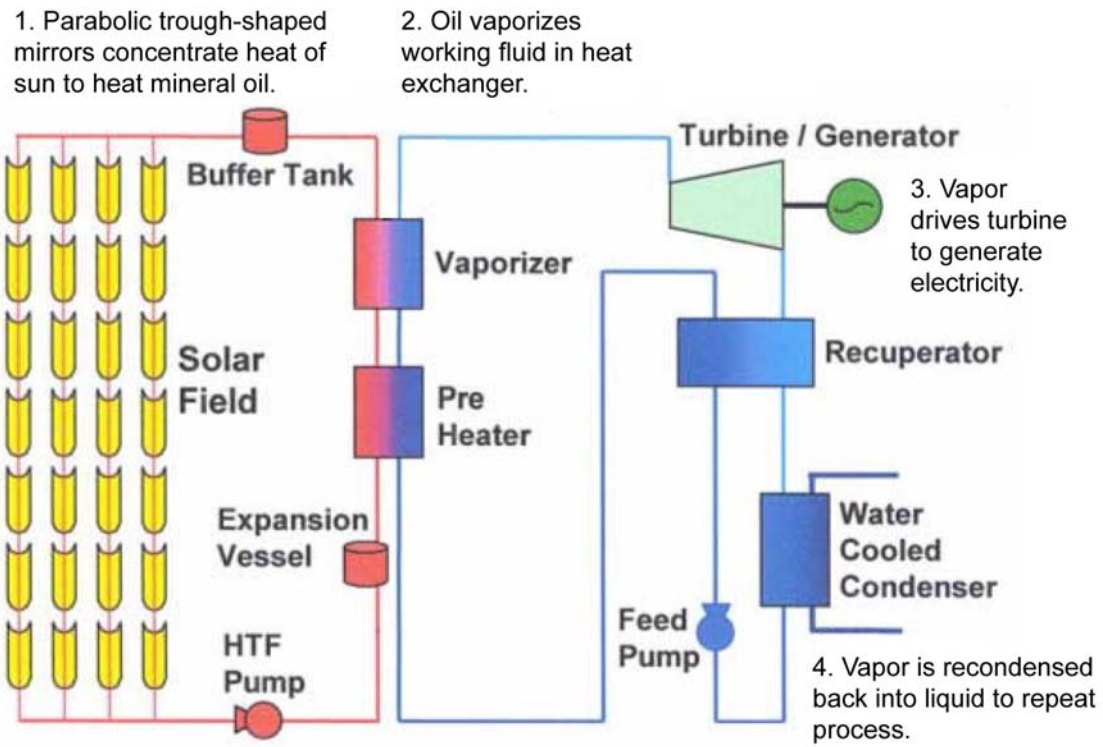
Solar Power, PV – Description and social factors

Generation Technology	Solar, PV
Technical description	Direct photovoltaic generation. Different possible cell types. Location may be dedicated site, or on existing rooftops.
Primary energy source	Sun.
Form of waste requiring storage	No direct wastes for panels. Medium to medium low chemical wastes for full technnology chain.
Record of past public acceptance	Generally very good for roof-mounted installations. Possible local opposition to dedicated site installations.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacture & fabrication, transport & installation.
Visual disturbance	Significant (self standing) to low (rooftop).
Noise	None.

Solar Power, Thermal Trough – Illustrations



Solar Power, Thermal Trough – Technical Characteristics

Characteristics	Units	25 **Solar thermal** Concentrating solar thermal power plant
Type of fuel		sun
Electric efficiency	%	0.185
Electric generation capacity	MW	400
Load factor (expected hours/yr)	hours/year	4518
Annual generation (expected)	kWh/year	1.81E+09
Construction time	years	3
Capital cost (net present value)	€/kWe	3044
Total capital cost (net present value)	M€	1217
Plant life	years	40
Average cost of electricity	€cents/kWhe	6.31

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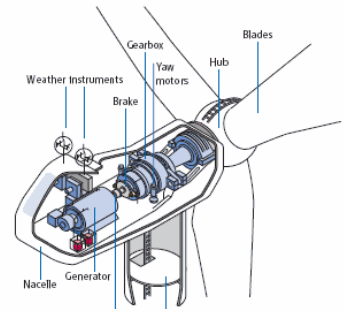
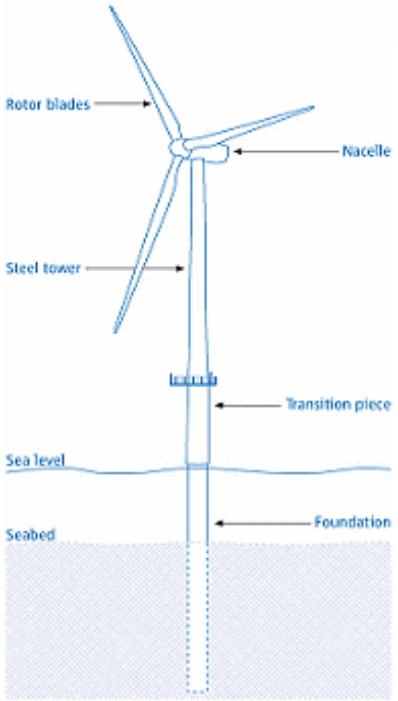
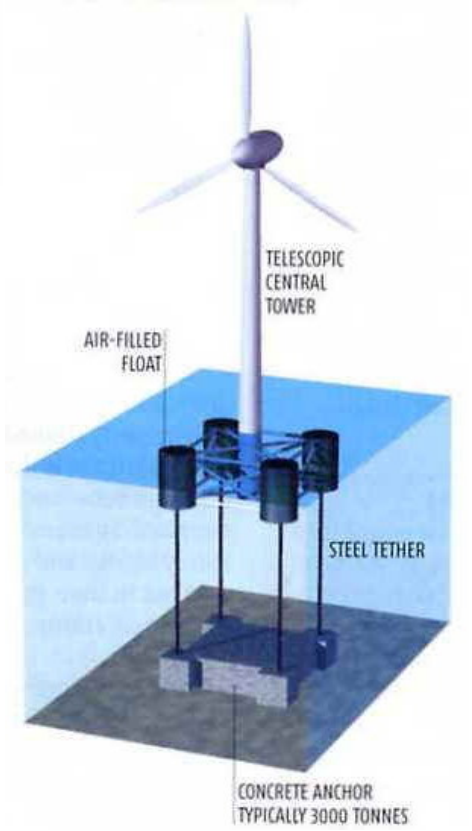
Solar Power, Thermal – Description and social factors

Generation Technology	Solar, Thermal Trough
Technical description	Parabolic trough concentrates sun to heat oil in pipe. Oil is used to drive rankine cycle generator, which may be steam or an organic working fluid depending upon temperature. Some heat storage may be used.
Primary energy source	Sun.
Form of waste requiring storage	Medium level of chemical waste from full technology chain.
Record of past public acceptance	Generally good, but limited historic experience.
Possible proliferation or misuse	None.
Labor mix for technology chain	Plant construction.
Visual disturbance	Significant, but in generally remote location.
Noise	Minimal local noise.

Wind Power, Offshore – Illustrations







Wind Power, Offshore – Technical Characteristics

Characteristics	Units	26 **Wind** **Wind-offshore** Wind
Type of fuel		wind
Electric efficiency	%	0
Electric generation capacity	MW	24
Load factor (expected hours/yr)	hours/year	4000
Annual generation (expected)	kWh/year	9.60E+07
Construction time	years	2
Capital cost (net present value)	€/kWe	1130
Total capital cost (net present value)	M€	27
Plant life	years	30
Average cost of electricity	€cents/kWhe	7.27

Wind Power, Offshore – Description and social factors

Generation Technology	Wind, Offshore
Technical description	Offshore park of large, moored wind turbines.
Primary energy source	Wind.
Form of waste requiring storage	No direct waste from turbines. Medium low chemical waste from full technology chain.
Record of past public acceptance	Quite good, local opposition.
Possible proliferation or misuse	None.
Labor mix for technology chain	Turbine manufacture, towing, cable laying.
Visual disturbance	Remote, depends on distance offshore.
Noise	None from shore.