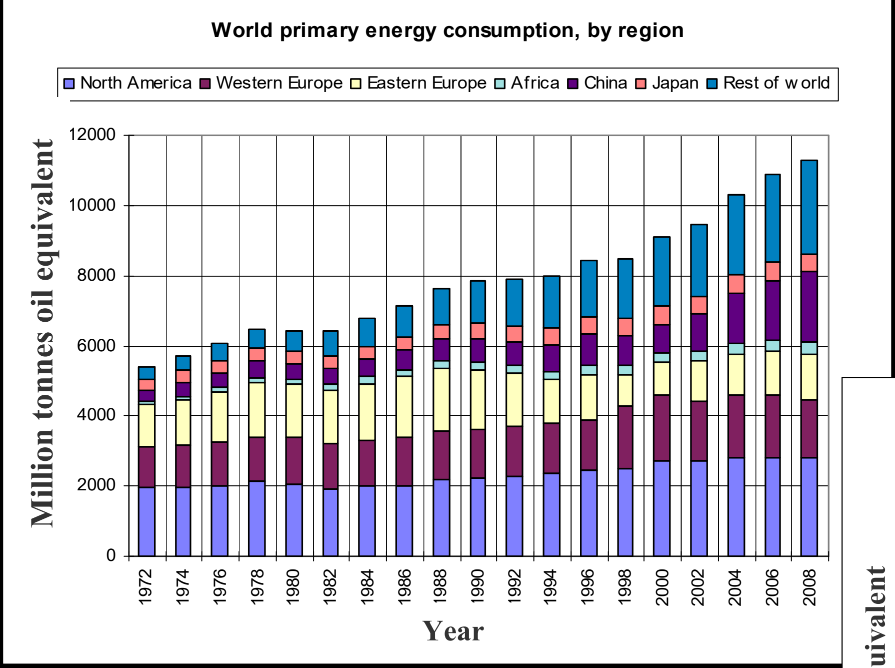
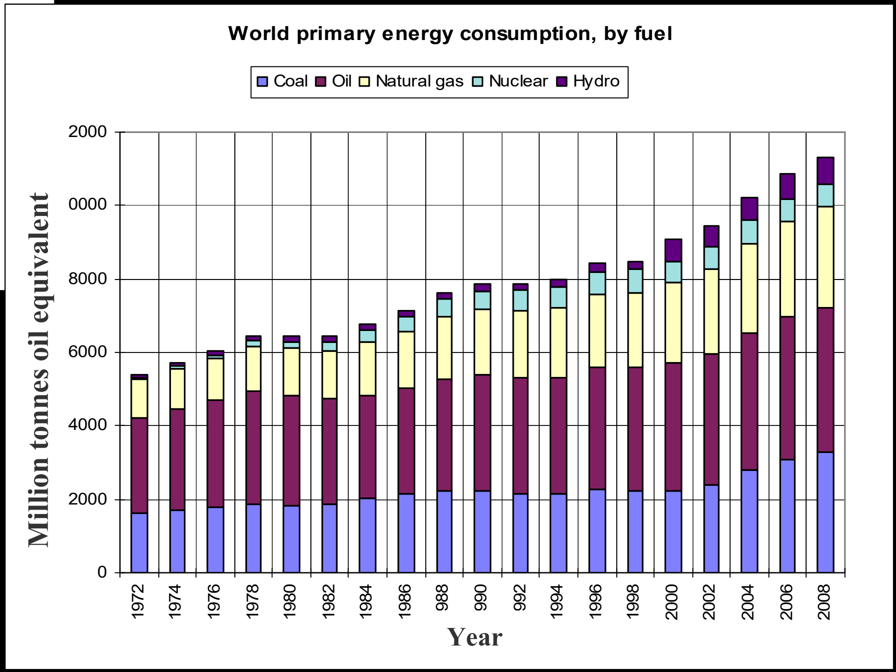
Thermal power plant

87% of the world's energy
comes from fossil fuels:
coal, oil & natural gas.

World primary energy consumption by region and fuel type



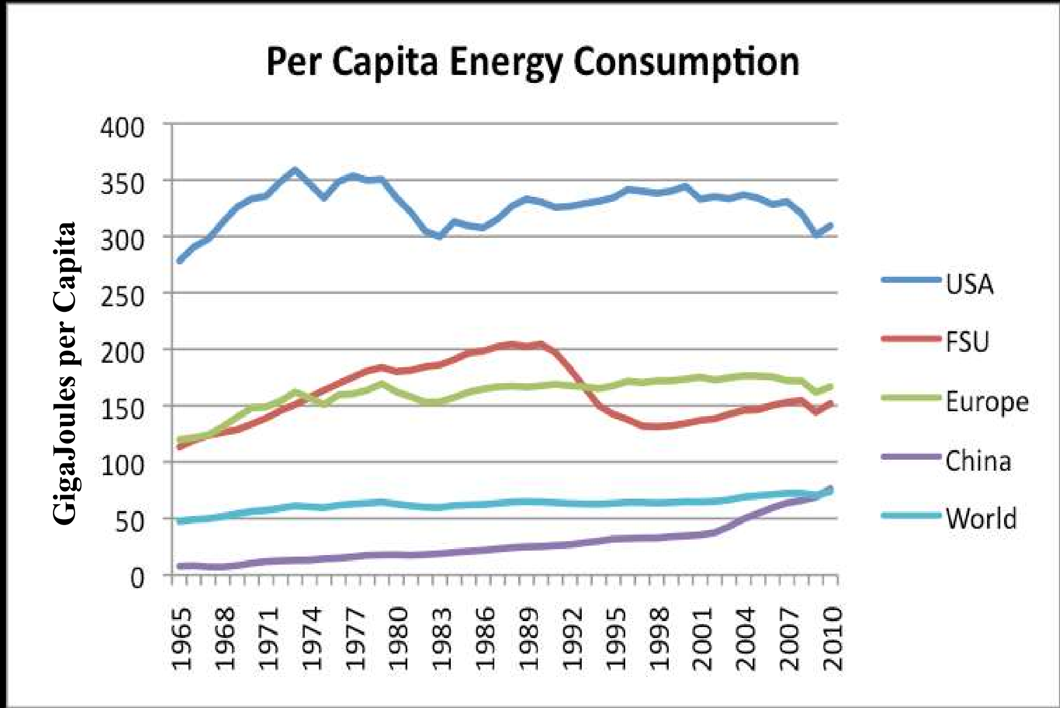
- Average 2% rise per year over period; ~5% in recent years.
- Developed nations stable.
- China & rest of the world growing.



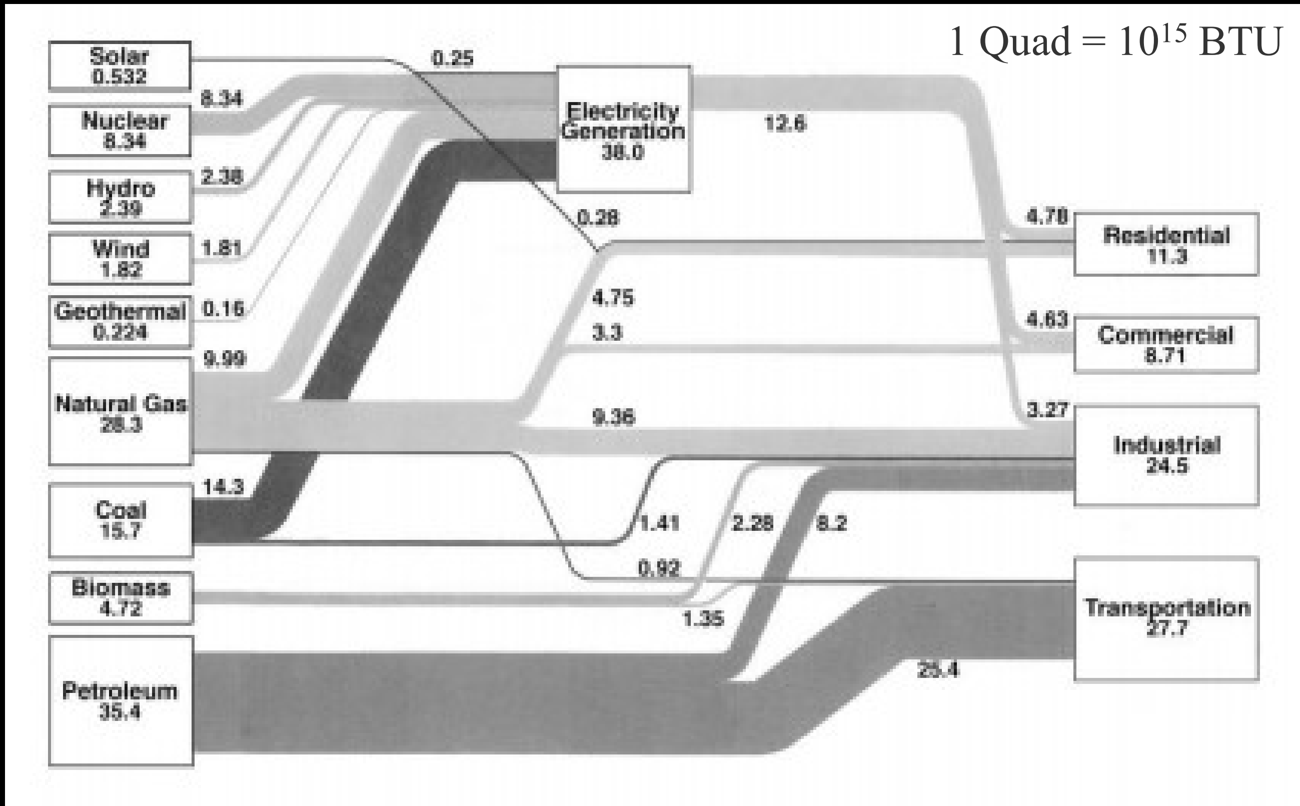
- Coal, gas and oil consumption dominant and in balance.
- Hydro & nuclear less but stable.

World primary energy consumption per capita

- Energy consumption per capita remains fairly static in developed countries but is rising steadily elsewhere.
- Eastern and Western Europe have converged.
- Accelerating growth in rest of world (~1% per year).



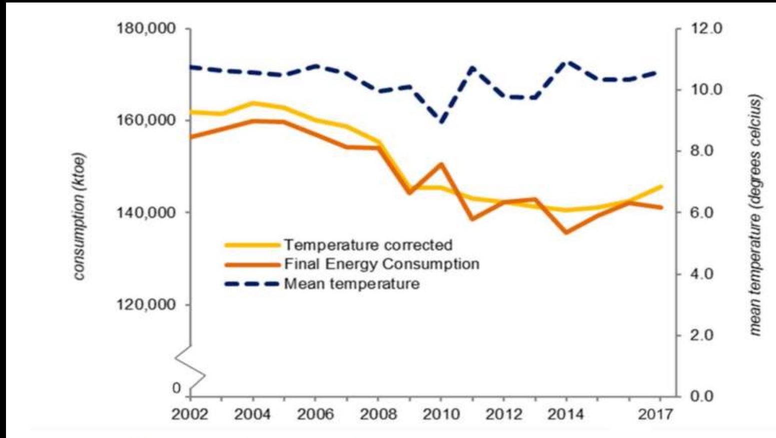
US energy consumption, 2015 (quadrillion BTU)



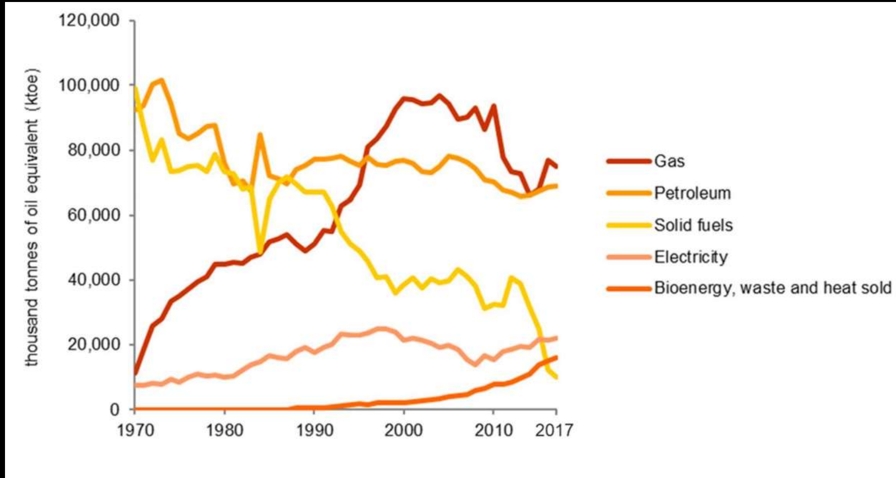
97.5 Quads: solar 0.5%, nuclear 9%, hydro 2.5%, wind 2%, geothermal 0.2%, natural gas 29%, coal 16% (with natural gas 64% of electricity), biomass 5%, petroleum 36% (92% of transport)

UK energy consumption

- Energy consumption has downward trend since 2005 until 2016.
- Mainly due to improving energy efficiency in the built environment and continued de-industrialisation.
- Note volatility in demand due to temperature fluctuation.

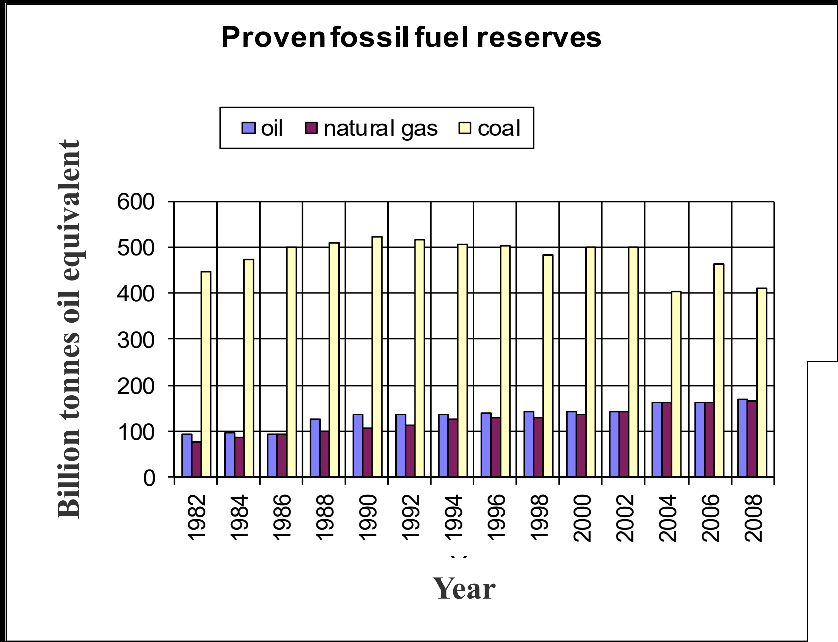


Source; BEIS ECUK Table 1.01

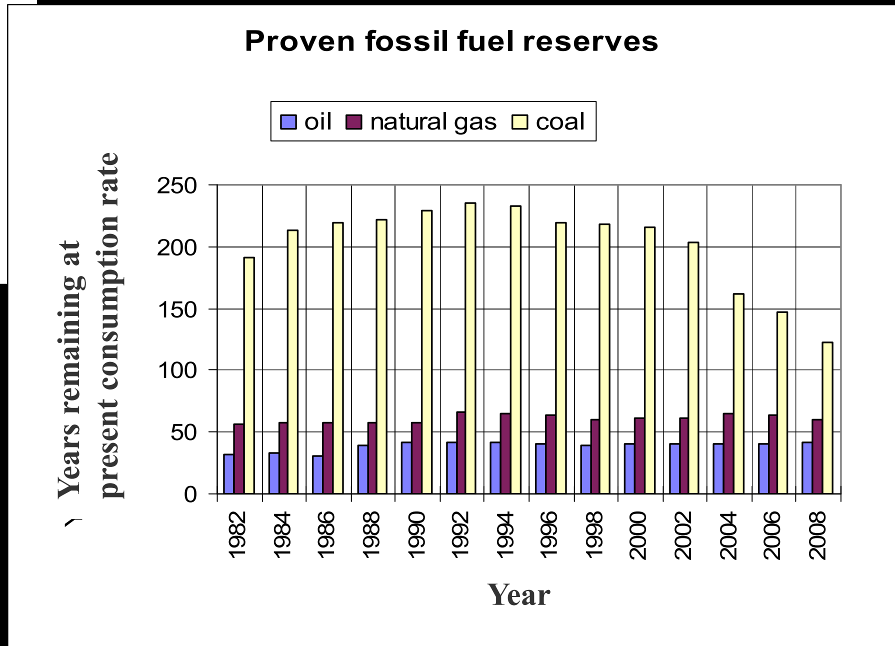


Source; BEIS ECUK Table 1.10

World fossil fuel reserves



- Coal dominant.
- Gas overtaking oil.
- New exploration and extraction technology could significantly increase reserves.



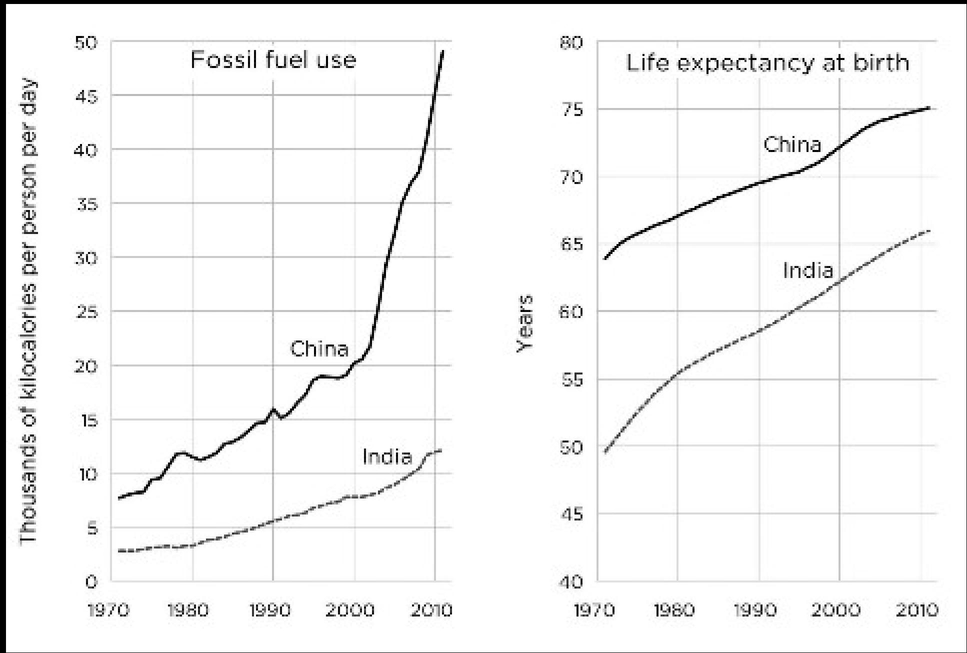
Natural gas reserves

- Remaining resource greater that previously extracted.

Benefits of fossil fuel

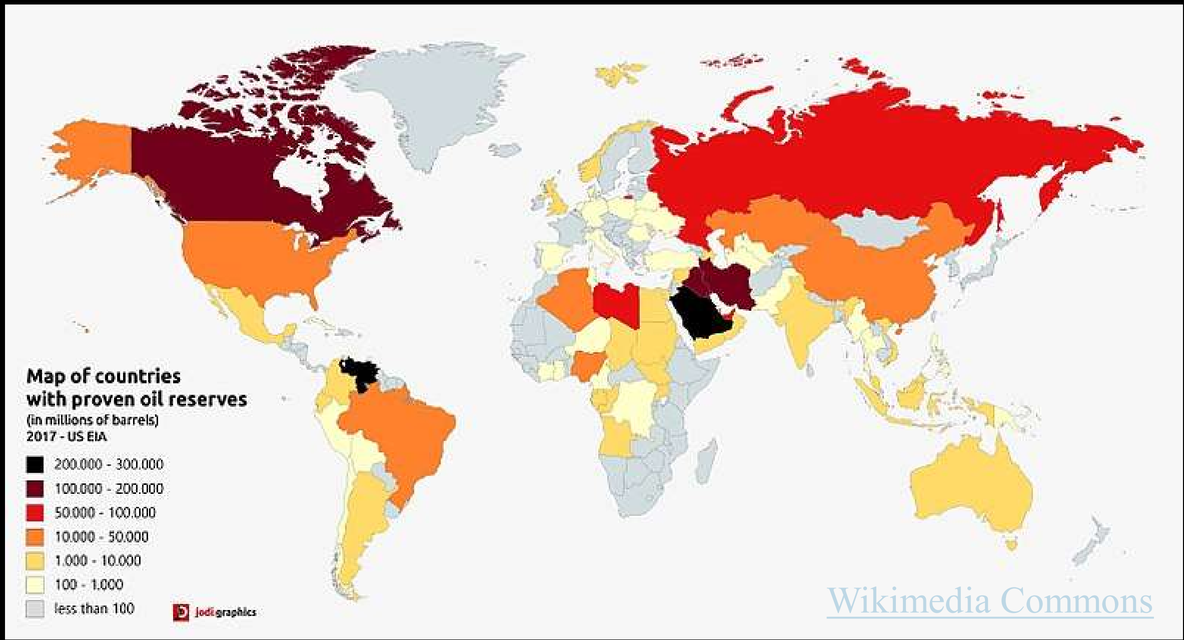
- Despite dire warnings throughout the latter half of the 20th century, fossil fuel use increased dramatically because of the perceived benefits and absence of an alternative.

Fossil fuel use and life expectancy in China and India



Source: BP Statistical Review of World Energy (2013) and World Development Indicators Online Data (2014).

Opportunities and challenges



Wikimedia Commons

Reserves:

- ❑ Coal 230-1500 yrs;
- ❑ Oil 40-250 yrs;
- ❑ Gas 75-250 yrs (conventional reserves)

Outlook:

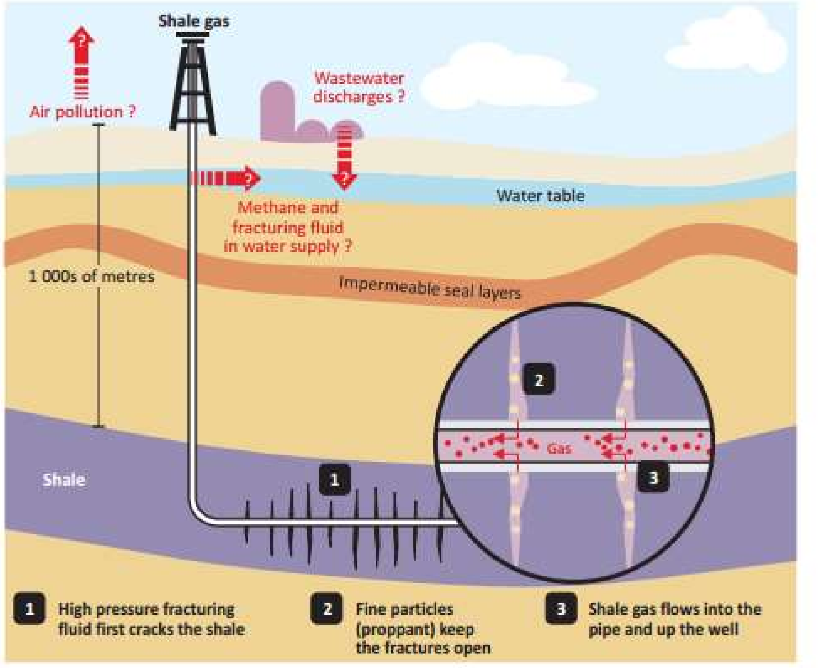
- ❑ global energy spend <2% of GDP;
- ❑ UK spend 6% of GDP (£75b/y; c.f. £10b/y spent on discarded food);
- ❑ will dominate the world economy for 30 years or more.

Challenges:

- ❑ refine exploration techniques;
- ❑ make less ‘polluting’ (e.g. decarbonise);
- ❑ enhanced extraction (e.g. sequestrate C);
- ❑ new resources (e.g. coal bed methane, oil shale, tar sand)
- ❑ new uses (e.g. methanol production)

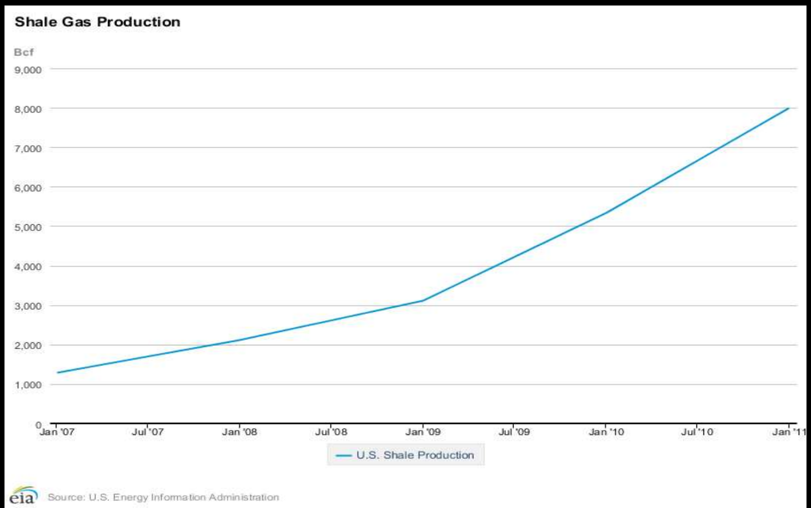
Unconventional reserves

- Shale, 'tight' gas or oil in low permeability, low yield rock (10x less than conventional reserves)
- Coal bed methane
- Hydraulic fracturing of rock required
- Estimated potential gas resource 650 x 10^{12} m^3
- Equivalent of an extra 50% on top of conventional hydrocarbon reserves
- In the US 'fracked' gas accounts for 40% of total gas production (2.5 x 10^{11} m^3/yr)



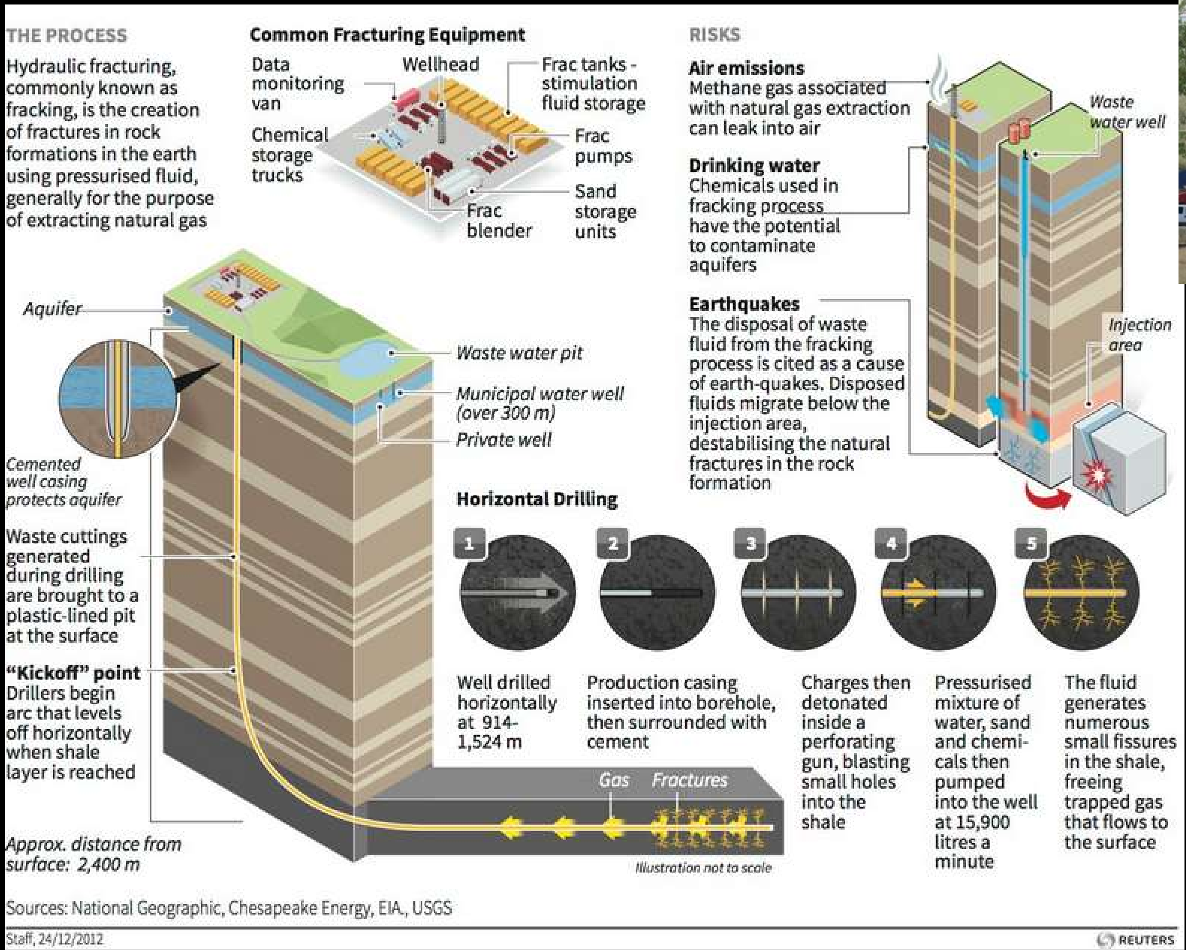
Source: Adapted from Aldhous (2012).

Note: The possible environmental hazards discussed in the text are shown with red arrows. Although the figure illustrates a shale gas well with multi-stage hydraulic fracturing, some similar hazards are present with conventional gas wells, and with tight gas developments.



Challenges:
(similar to conventional)
- refine exploration techniques;
- make less 'polluting' (e.g. decarbonise, water pollution);
- enhanced extraction (e.g. sequestrate C);
- possible increased seismic activity

Fracking process



Thermal power plant operation

- These use the heat of fossil fuel combustion to boil water, generate steam, drive a multi-stage turbine and finally a generator.
- The generator is grid-connected, so its rotational speed must be carefully controlled.
- In the UK, the largest standard turbo-generator units are rated at 660 MWe.
- Substantial amounts of heat are rejected from the boiler exhaust stack (high temperature) and at the condenser (low temperature).
- Efficiency is limited by the laws of thermodynamics, with an upper limit given by the Carnot efficiency:

$$\eta_c = 1 - T_2 / T_1$$

where T_1 is the temperature at which heat is supplied and T_2 the temperature at which heat is rejected to the surroundings.

Thermal power plant operation

- A more realistic calculation of power plant efficiency comes from the endo-reversible efficiency equation:

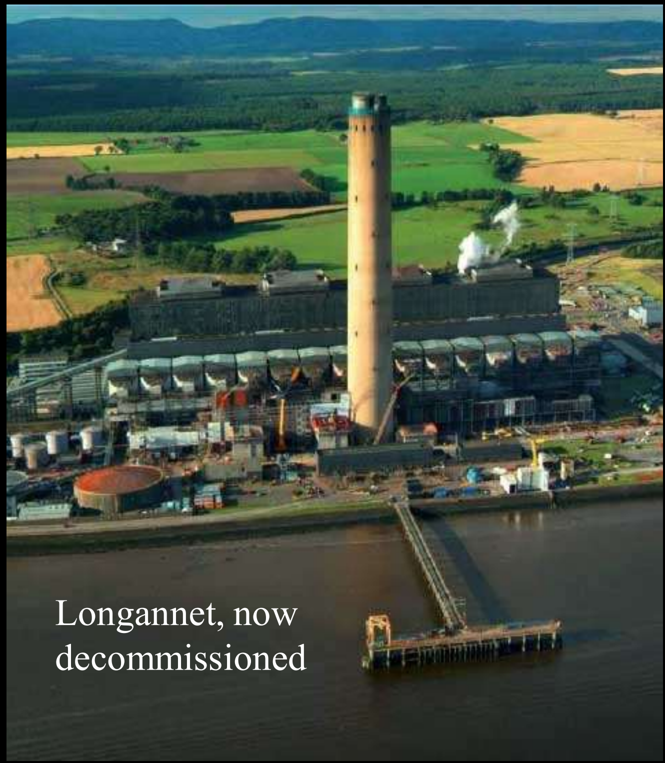
$$\eta_e = 1 - \sqrt{\frac{T_2}{T_1}}$$

- For example Longannet power station produced steam at 568°C (841K) and rejects heat to the environment at ~10°C (283K)

- Carnot (ideal efficiency) **66.3%**

- Endoreversible efficiency **42.0%**

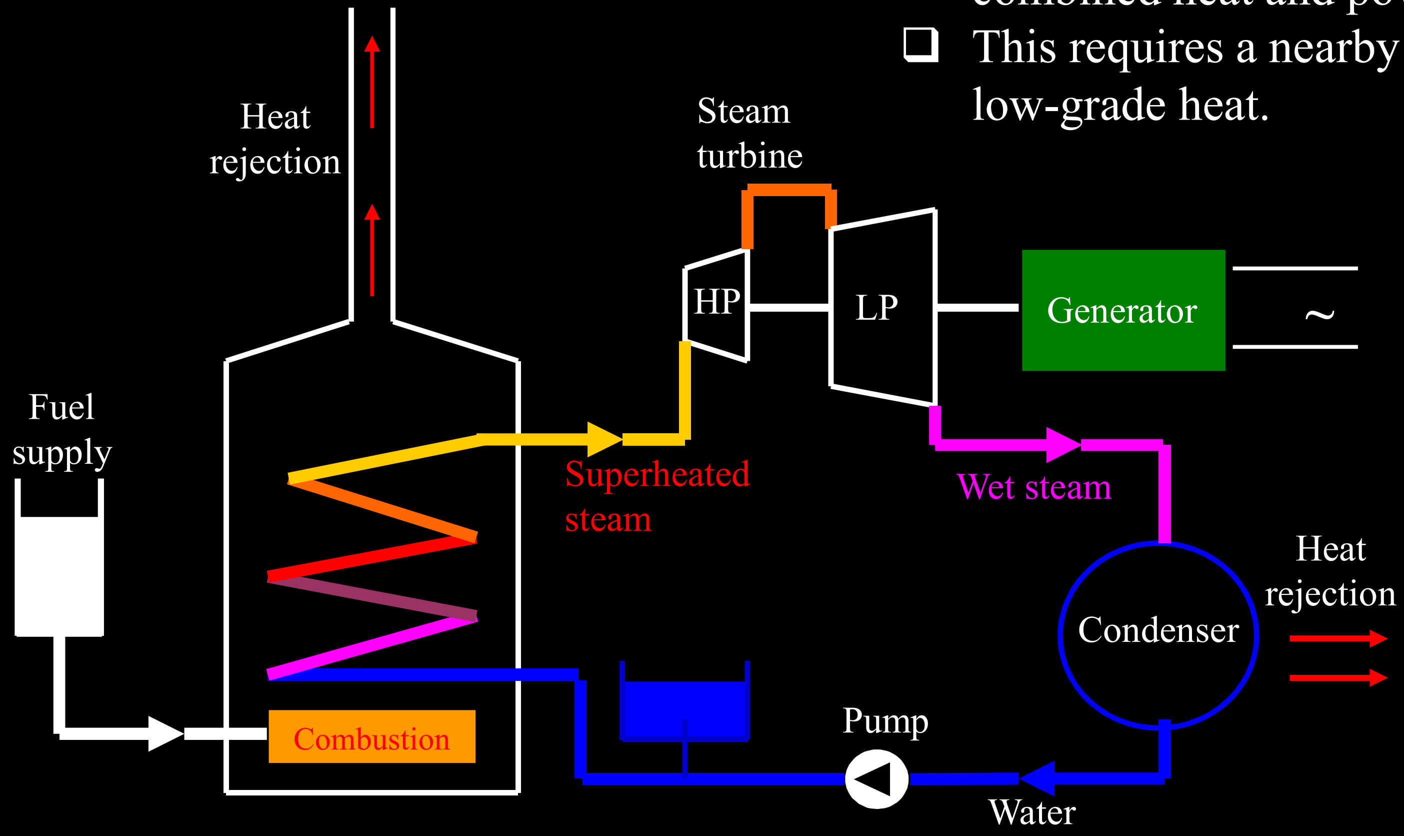
- Actual efficiency achieved **37%**



Longannet, now decommissioned

Fossil fuel electricity generating plant

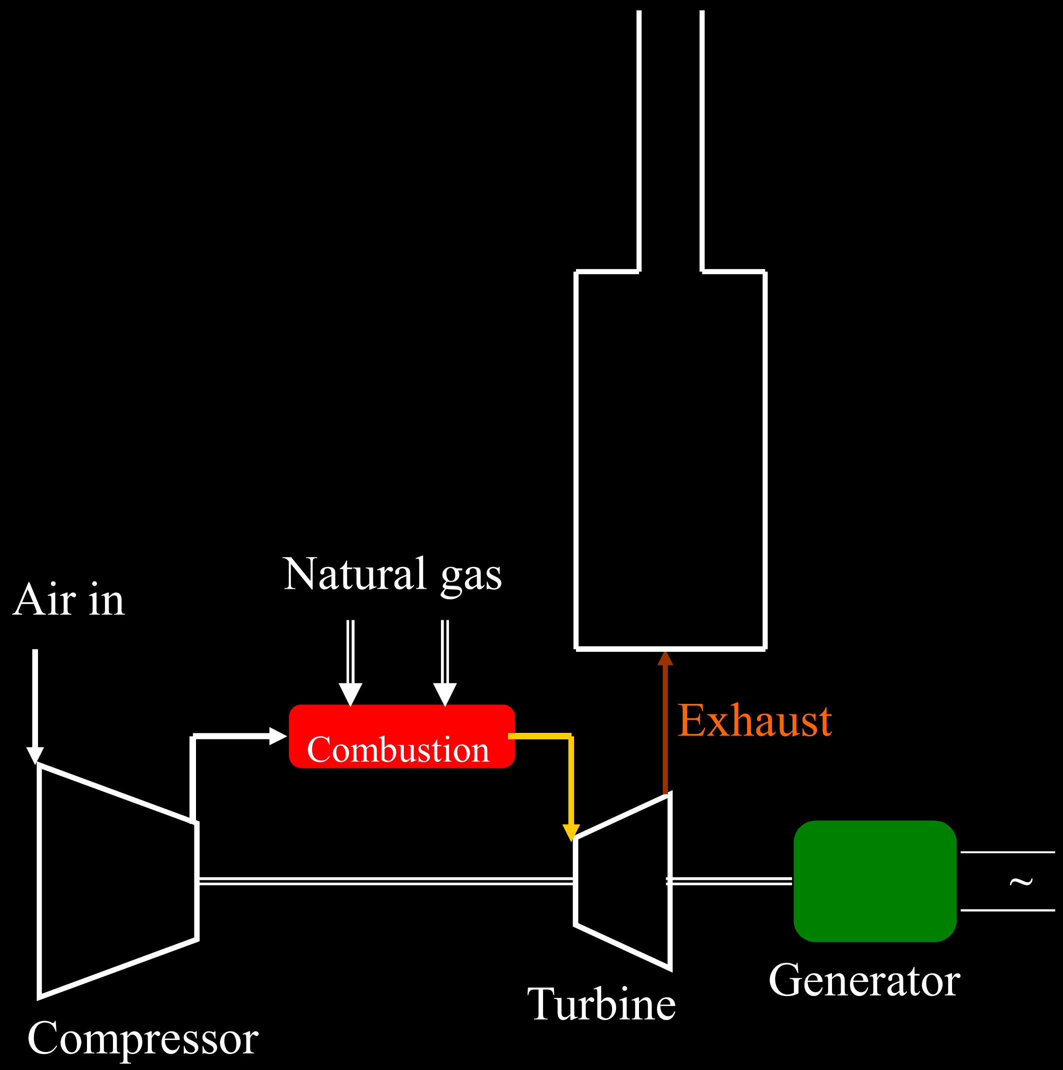
- Efficiency is unlikely to exceed ~40%.
- May be improved by providing combined heat and power.
- This requires a nearby market for the low-grade heat.



Drax power station

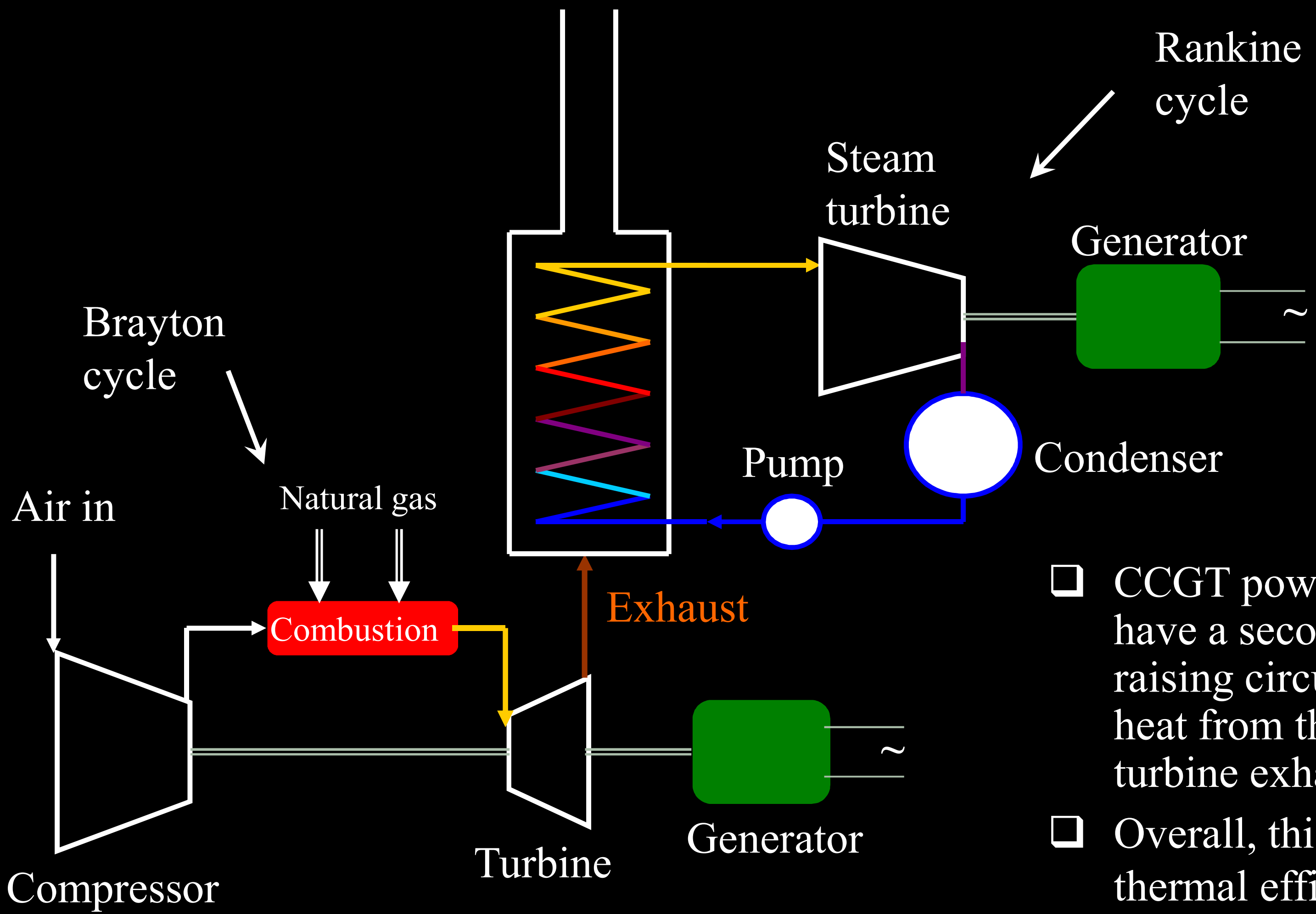
- Largest in the UK.
- 6 turbine-generators rated at ~3.9 GW electrical output.
- Subject of regular protests from environmental groups.
- 4 Units now burn mixed biomass 2 units burn coal - 2.6 GW Biomass/1.3 GW Coal.
- Biomass imported from US and Canada.
- Plans to convert final two coal to closed cycle gas turbine.

<u>**Gas turbine electricity generating plant**</u>



- Gas turbine is frequently based on civil aircraft jet engine designs.
- Light in weight and easy to transport, but a very low thermal efficiency (25% to 30%) with massive heat rejection via exhaust gases.
- Used to generate small quantities of electricity (e.g. on offshore oil platforms).

Combined cycle gas turbine generating plant (CCGT)



- CCGT power stations have a secondary steam raising circuit using the heat from the gas turbine exhaust.
- Overall, this raises the thermal efficiency to between 55 and 60%.

Small scale generating plant

- In the form of an IC engine, fuelled by gas or liquid fuel, with direct drive to a generator.
- Peak efficiencies ~35% and much less at part load.
- A Stirling engine might be used, in which case solid fuels or solar energy could provide the heat source.
- Hydrogen fuel is another possibility, but for producing electricity it is better to use it in a Fuel Cell (efficiency of around 60%).
- Small-scale operations generally provide opportunities for CHP production.
- Arrangements for autonomous operation or cooperation with the local electricity grid are required.

Emissions

- Particles (soot), unburnt hydrocarbons, SO_2 (arising from the sulphur content of the fuel), NO_x (arising from high-temperature combustion in air).

- These pollutants can be reduced by careful control of the combustion process, and by treatment of exhaust gases by chemical action or filtration. Such processes have a significant economic implication.

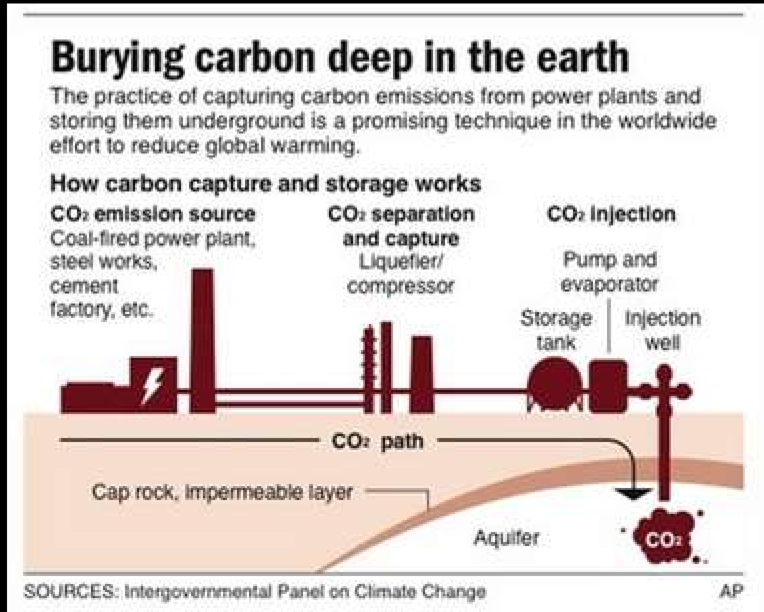
- CO_2 emissions from the combustion of fossil fuels for electricity production can be characterised as follows.

Fuel	CO_2 emission (kg/kWh)
Coal	0.9
Oil	0.7
Natural Gas	0.2

- It is often asserted that biofuels can be used in a sustainable manner (i.e. by replanting as consumed) so that the net emissions of CO_2 will be zero. However, production typically uses more energy that is delivered and arable land is displaced.

Carbon capture and storage

- Technical and economic viability unknown; estimates for a coal fired plant:
  - 80-90% CO_2 emission reduction;
  - costing 10-55% of the total carbon mitigation effort until 2100;
  - 25-40% increase in fuel needs to capture and compress CO_2;
  - cost of energy increased by 21-91% (for new plant with nearby storage, otherwise greater).



- CO_2 storage in deep geological formations (most promising), in deep ocean masses, or in the form of mineral carbonates.

- North America has enough storage capacity at its current rate of production for more than 900 years worth of CO_2.

Food for thought

- Is it possible that the benefits of fossil fuels might outweigh the downsides?
- Can the world exist without them in the foreseeable future?
- Can their impacts be mitigated?
- Is there a prejudice in the way society processes information about fossil fuels?
- If fossil fuels created no waste, were cheap, and had no resource depletion concerns, would the green movement still oppose them?
- Might we consider the possibility that fossil fuel use could bring benefit by fertilizing the planet while mitigating climate risk?