Energy Resources and Policy
Handout:
Electricity generation from thermal power plant

1. Large-scale operations

All large thermal power generating plant operate in the same way: the heat of combustion (of coal, oil, gas, industrial, agricultural or domestic waste or various forms of biomass) is used to boil water and generate steam. (A nuclear power station also works in this way.) The steam then drives a steam turbine, which may have a number of stages, and finally a generator. The generator is normally grid-connected, so its rotational speed (and that of the turbines) must be carefully controlled. In the UK, the largest standard turbo-generator units are rated at 660 MW of electrical output.

On exhaust from the turbine, the steam is cooled and condensed to water, after which it is pumped back into the boiler to begin the cycle once more. Substantial amounts of heat are rejected in the exhaust stack from the boiler; this is at a fairly high temperature. Major heat rejection also takes place in the condenser: temperatures here are lower and it is not so easy to find a use for it. Some energy may be recovered by warming the water in a heat exchanger on its way into the boiler.

The efficiency of the plant (as with all thermal processes) is limited by the laws of thermodynamics. An absolute limit is given by the Carnot efficiency:

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

where T_1 is the upper temperature of the working fluid (i.e. in a power plant this will be the superheated steam) and T_2 is the temperature at which heat is rejected to the surroundings (the temperature in the condenser). For plant of the type shown in Figure 1, efficiency is unlikely to exceed 35%.

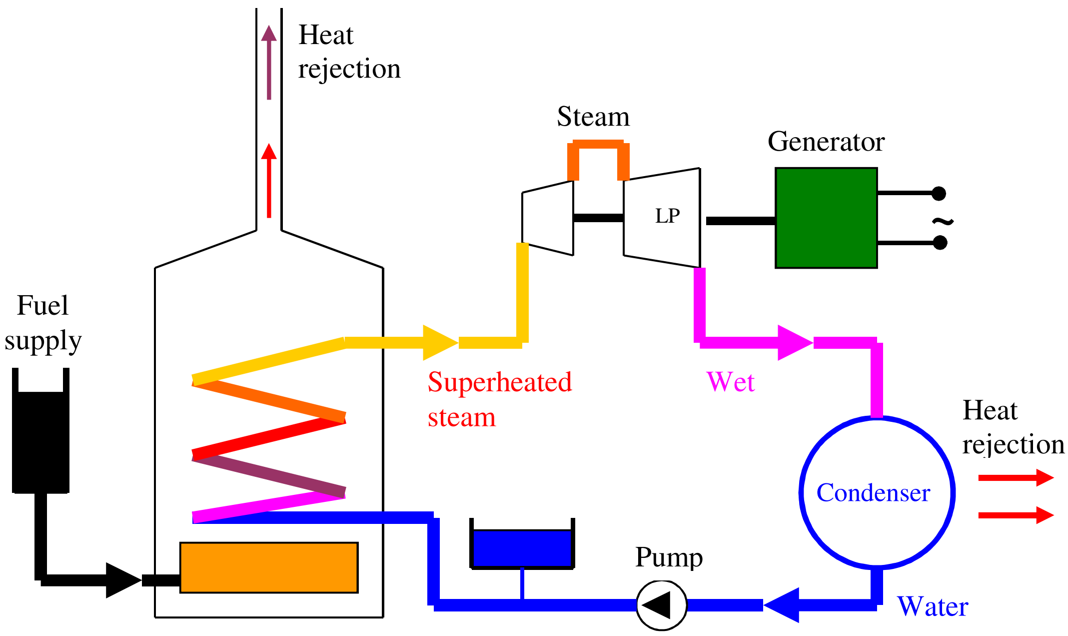

Figure 1: thermal power plant schematic.

A more realistic value of efficiency is given by the *endoreversible* efficiency:

$$\eta = 1 - \sqrt{(T_2 / T_1)}$$

Take the example of Longannet power station. The combustion process produces superheated steam at 568°C and heat is rejected at 10°C. So the heat supply temperature is 568 + 273 = 841K; and the heat rejection temperature us 10 + 273 = 283K.

The Carnot cycle efficiency is therefore 66.3%

The endoreversible efficiency is 42%, much closer to the actual efficiency of 37%!

The most effective way to improve η is to provide combined heat and power (CHP): to design (and locate) the plant to produce useful electricity and useful heat. Obviously, a market for the low-grade heat (e.g. space heating or some industrial processes) must be available on or near the site.

2. Combined cycle gas turbine (CCGT) plant

Here, natural gas is used to fuel a gas turbine engine (probably a modified aircraft power unit). The turbine drives a generator, producing electricity (Figure 2a). The turbine exhaust temperature is high and contains a great deal of energy; the gases are passed through a heat exchanger to boil water and produce steam, in a similar way to the thermal power plant described previously. This steam then passes through a turbine (driving a second generator), travelling around a circuit as shown in Figure 2a.

In this 2-stage process, overall efficiency is increased to perhaps 55%. The technology is only effective in large-scale operations; gas turbines without the secondary steam-raising stage are used to generate smaller quantities of electricity (e.g. on offshore oil platforms), but efficiency is then below 30%.

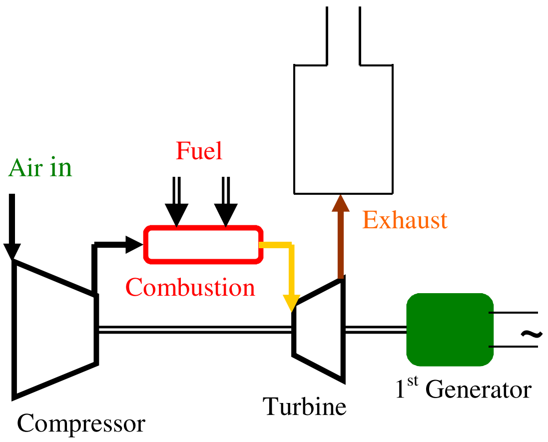

Figure 2a: gas turbine electricity generating plant.

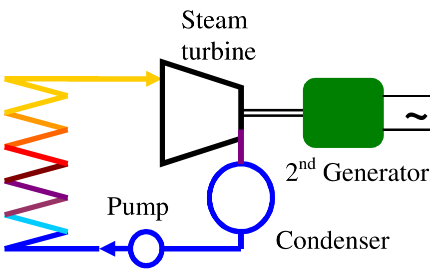

Figure 2b: steam-raising second stage for combined cycle plant.

3. Small-scale generating plant

This generally takes the form of an engine, fuelled by gas or liquid fuel, with direct drive to a generator. Conventional internal combustion (IC) engines are commonly used and Carnot efficiency limitations again apply, with peak efficiencies expected to be around 35% (and much less at part load). A Stirling engine might be used as the prime mover, in which case solid fuels or even 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 (giving an efficiency of around 60%).

Small-scale operations generally provide opportunities for CHP production, as there is likely to be a local demand for the thermal output in the form of a space heating or hot water demand. Depending on the circumstances, it may even be economic at the domestic scale. Arrangements for autonomous operation or cooperation with the local electricity grid (import/export) need to be properly developed before this concept of 'embedded generation' can be effectively adopted.

4. **Emissions**

These can take the form of particles (soot), unburnt hydrocarbons, sulphur dioxide (SO_2) and oxides of nitrogen (NO_x). SO_2 arises from the sulphur content of certain fuels, principally coal and oil. NO_x arises from high-temperature combustion in air. These and other pollutants can be reduced (but not entirely eliminated) by careful control of the combustion process, and by treatment of exhaust gases by chemical action or filtration. Such processed has a significant economic implication.

Finally, there is carbon dioxide, CO_2, emissions of which from the combustion of fossil fuels for electricity production can be characterized as follows.

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

Emissions from the combustion of waste materials or biofuels depend on their composition. If biofuels are used in a sustainable manner (i.e. by replanting as consumed), the carbon cycle at least is closed, and net emissions of CO_2 will be zero.