Hydrogen – a fuel of the future?

Hydrogen has been widely advocated as a potential 'energy carrier' for the future. Its use as a fuel has a number of advantages:

- it can act as a store of renewable energy from season to season
- it can provide a transport fuel not dependent on the world's declining reserves of oil
- the only by-products of its combustion are water and a very small amount of nitrogen oxides, and even these emissions can be reduced to zero if fuel cells (see Box 10.4 below) are used.

Fossil-fuel-based hydrogen

The production and use of hydrogen as a fuel is well understood. Before the arrival of natural gas, 'town gas' produced from coal in the 19th century consisted mainly of a mixture of hydrogen and carbon monoxide. Hydrogen is already used in large quantities as a feedstock for the chemical industry, mainly in the manufacture of fertilizers. Currently, it is mainly produced by steam 're-forming' of natural gas (methane), a process that necessarily also produces carbon dioxide:

$$2H_2O + CH_4 \rightarrow CO_2 + 4H_2$$

Steam + Methane → Carbon dioxide + Hydrogen

Although technicall

Renewably based hydrogen

There also are a number of ways that renewable or 'solar' hydrogen can be produced without CO_2 by-products:

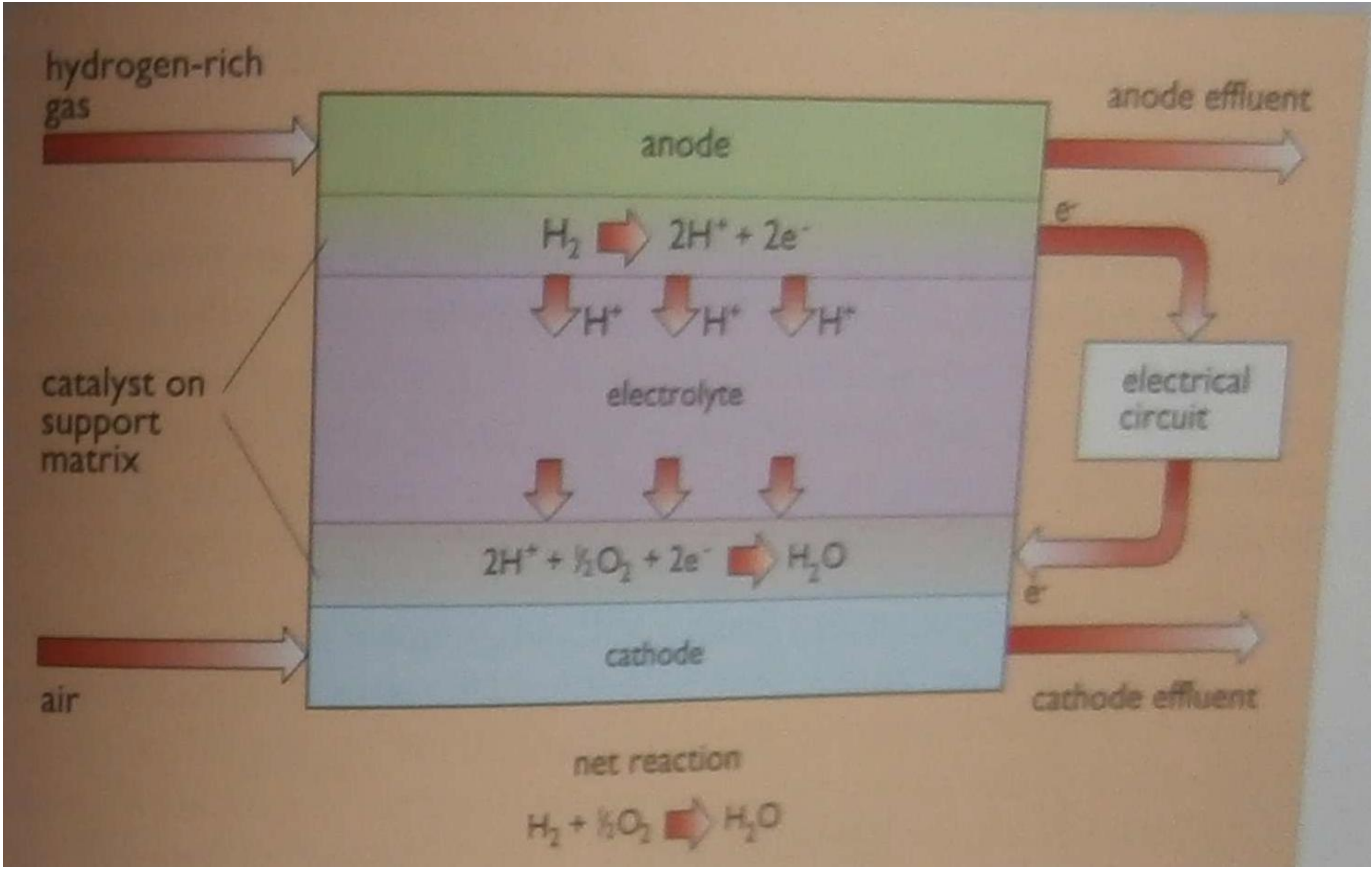
- by the electrolysis of water using electricity from non-fossil sources
- by the **thermal dissociation** of water into hydrogen and oxygen using concentrating solar collectors (probably in desert areas). To do this directly would require very high temperatures, over 2000 °C, but with more complex processes using extra chemical compounds the same result may be achievable at temperatures of under 700 °C. These processes have not yet been developed on a commercial scale
- by the gasification of biomass in a similar manner to that for coal, converting the carbon content of the biomass into CO_2. If the biomass has been sustainably grown then this CO_2 should be re-absorbed in new biomass as it is grown. The use of this technology coupled with CCS raises the interesting possibility of producing hydrogen with *negative* overall CO_2 emissions.

of photoelectrochemical

BOX 10.4 Fuel cells

In Chapter 2 it was explained that all heat engines are inherently limited in the efficiency with which they can convert heat into motive power, and hence into electricity if the engine is driving a generator. Normally, most of the energy in the input fuel emerges as 'waste' heat (although of course this can often be harnessed and put to good use).

The fuel cell (see Figure 10.22) enables hydrogen and oxygen fuel to be converted to electricity at potentially a higher efficiency than could be achieved by burning them in a heat engine. A fuel cell is in principle a battery in which the active elements are not solids (such as the lead and lead dioxide in a car battery) or liquids (as in the flow battery plant mentioned above) but gases. Indeed, when the fuel cell was first invented by Sir William Grove in 1839 he called it a 'gas battery'.


hydrogen-rich gas
anode
anode effluent
$H_2 \rightarrow 2H^+ + 2e^-$
e^-
H^+
H^+
H^+
catalyst on support matrix
electrolyte
electrical circuit
$2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$
e^-
air
cathode
cathode effluent
net reaction
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

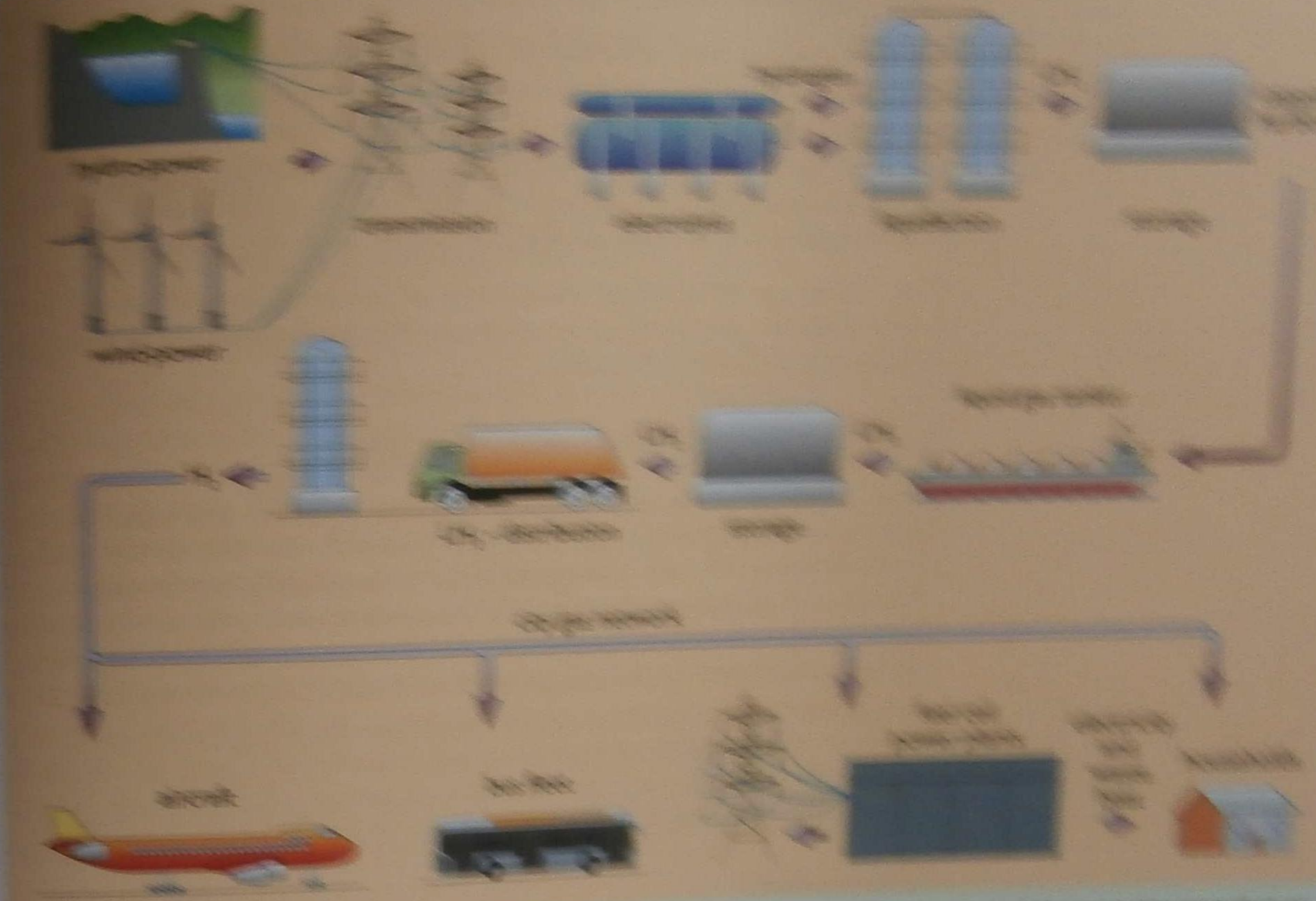


Figure 18.23 A possible future hydrogen economy. Two possible sources of renewable energy could be tapped to manufacture hydrogen, which could be shipped to consumers and used in a variety of ways.

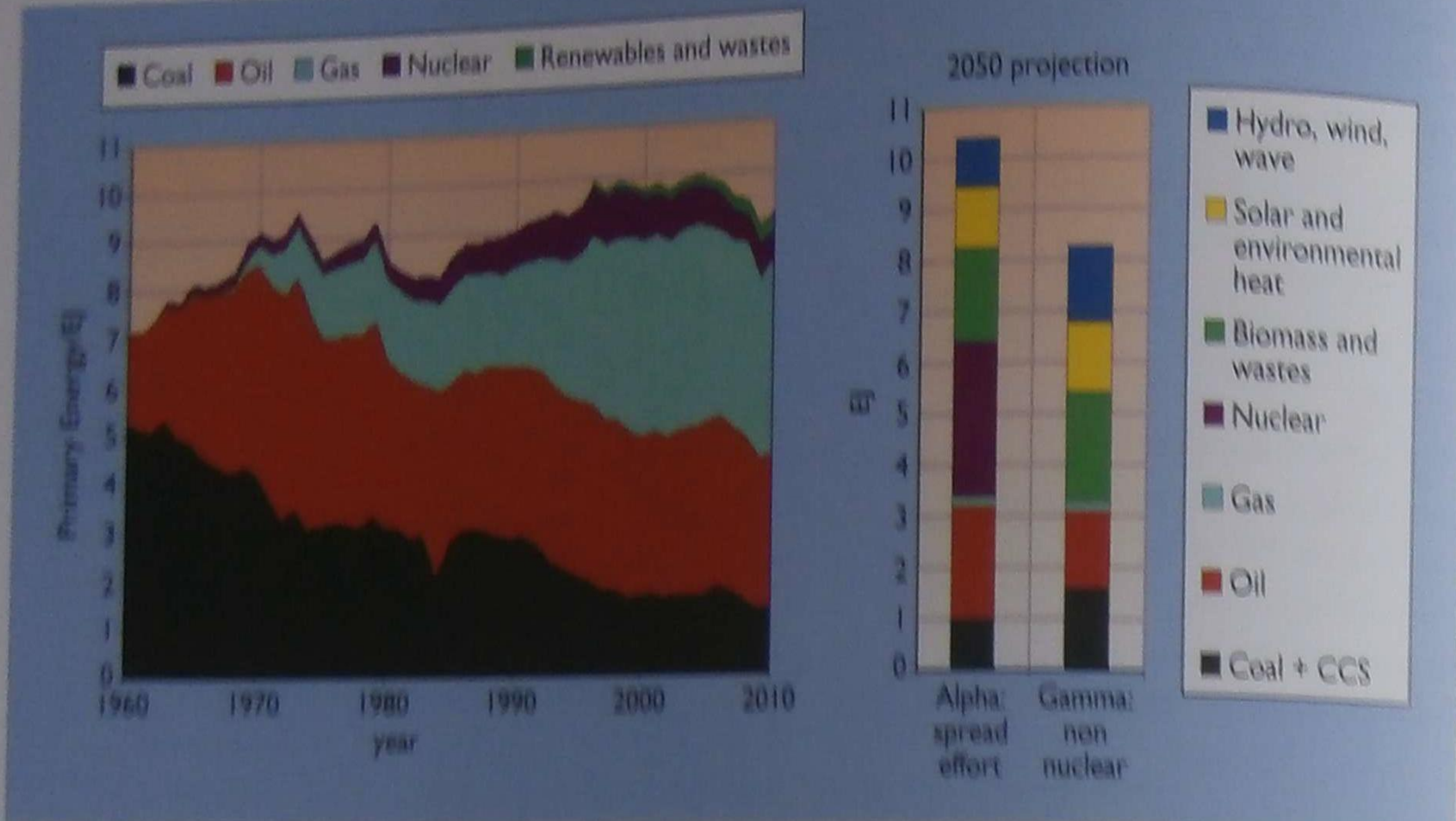


Figure 10.24 The UK primary energy supply mix 1960 to 2010, alongside two DECC projections (Alpha and Gamma) of possible energy supply mixes in 2050

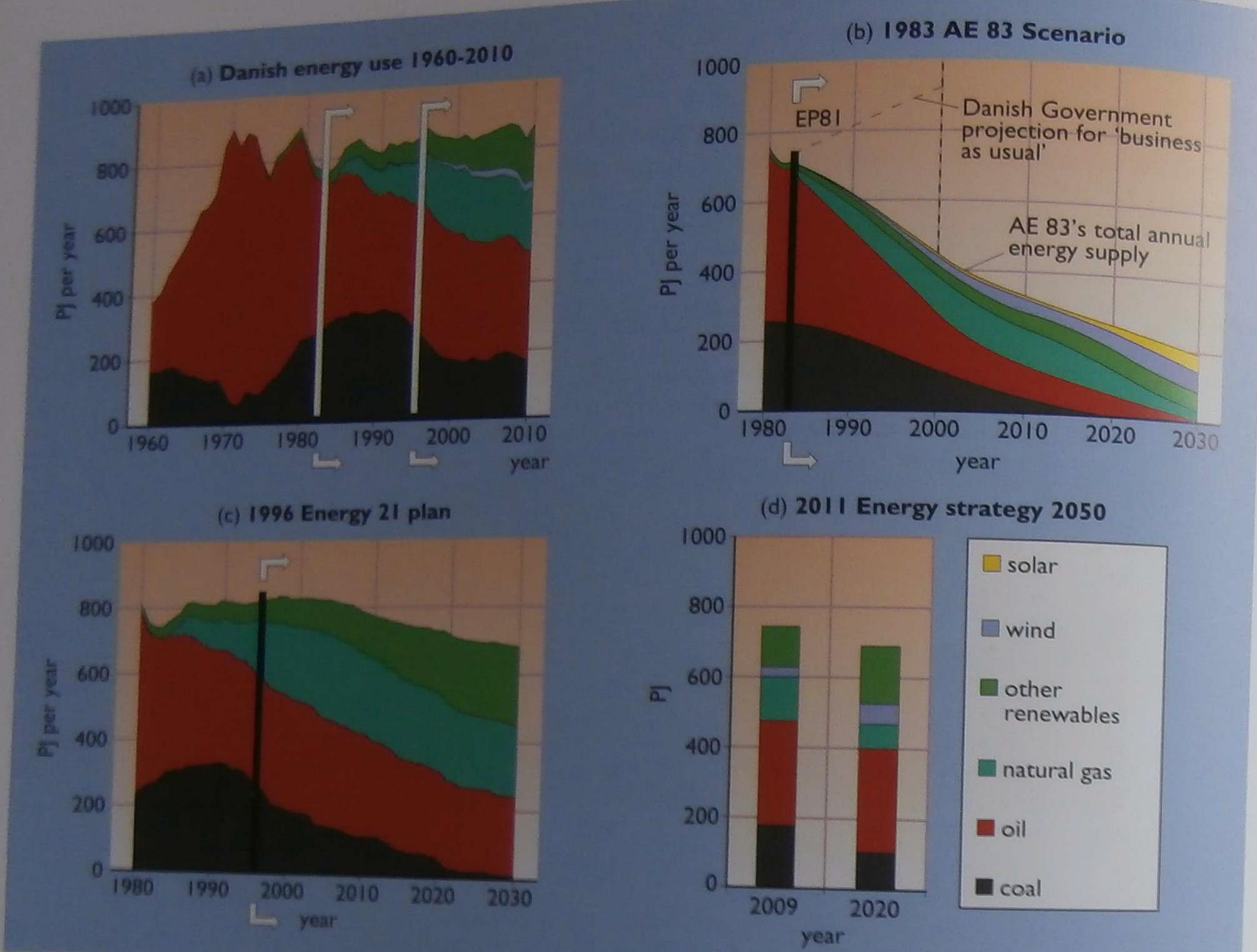


Figure 10.26 (a) Primary energy consumption in Denmark 1960–2010

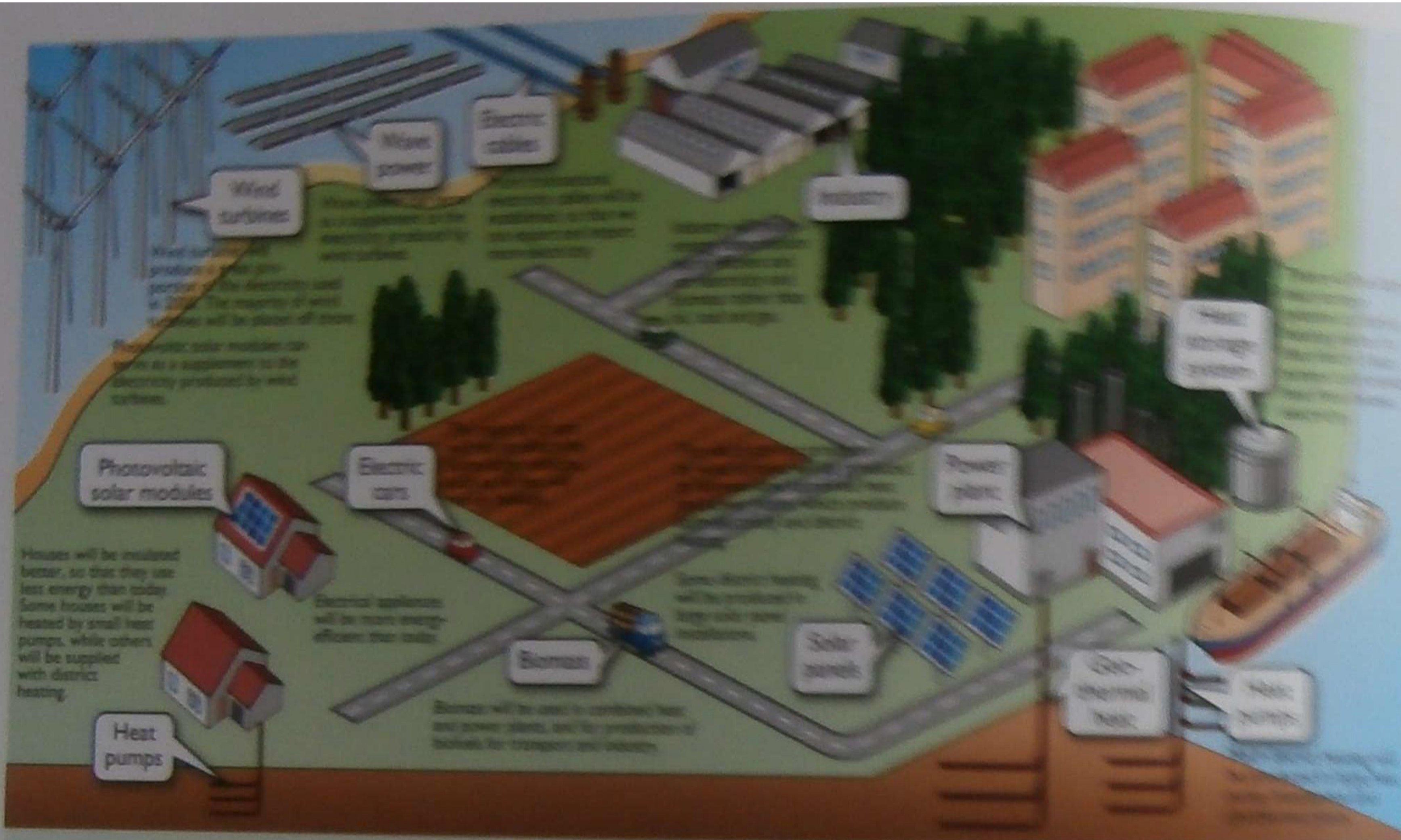


Figure 10.27 A vision of how Denmark sees it energy future in 2050, from the Danish Government's Climate Change Committee (2011) – backed up by an earlier study from the Danish Society of Engineers (2010). All fossil fuel use has been phased out, and the country runs on 100% renewable power, from a mixture of onshore and offshore wind, solar PV and thermal panels, biomass fuels (some imported), electric heat pumps, geothermal energy, CHP plants and large heat stores. International electricity links enable Denmark to export and import electricity when there are surpluses or deficits.

Table 10.8 Eight scenarios for a wholly renewable electricity supply for Germany in 2050. In the first four scenarios, German energy demand is some 500 TWh per year (SV500). In the second four scenarios, electricity demand rises to 700 TWh per year (SV700). The four variants involve different assumptions about the extent of self-sufficiency in Germany and the strength of interconnections to neighbouring countries

Assumptions	German electricity demand in 2050: 500TWh	German electricity demand in 2050: 700TWh
Self sufficiency	Scenario 1.a: DE 100% SV-500	Scenario 1.b: DE 100% SV-700
Net self sufficiency, interchange with Denmark and Norway	Scenario 2.1.a: DE-DK-NO 100% SV-500	Scenario 2.1.b: DE-DK-NO 100% SV-700
Maximum 15% net import from Denmark and Norway	Scenario 2.2.a: DE-DK-NO 85% SV-500	Scenario 2.2.b: DE-DK-NO 85% SV-700
Maximum 15% net import from the Europe-North Africa region (EUNA)	Scenario 3.a: DE-EUNA 85% SV-500	Scenario 3.b: DE-EUNA 85% SV-700

DE: Germany; DK: Denmark; NO: Norway; EUNA: Europe and North Africa; SV: self sufficiency

SRU/SG 2011-1/Table 10-1

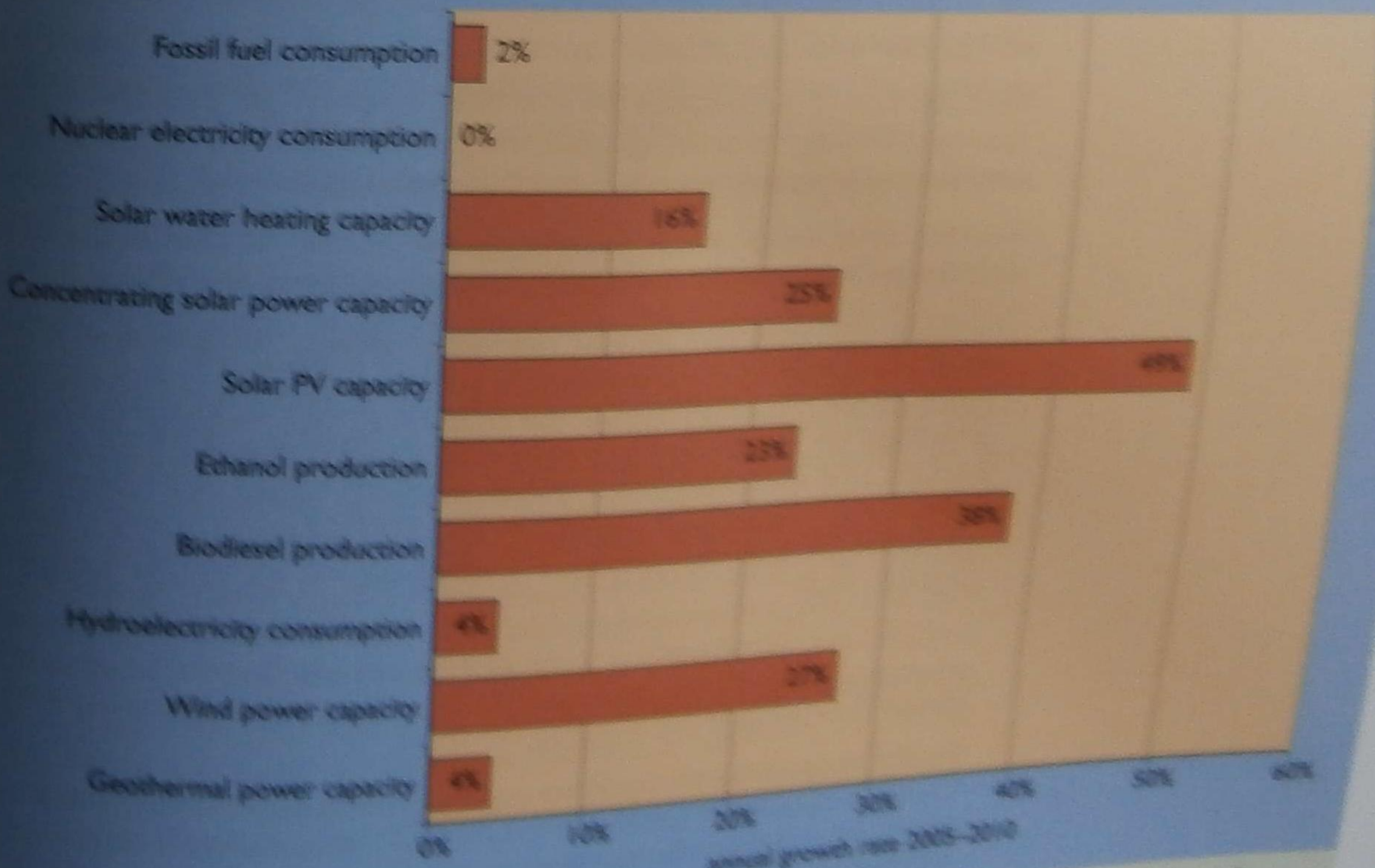
Source: SRU, 2011

Table 10.5 World-wide levelized cost estimates for renewable electricity generation

Technology	Cost /US cents kWh^{-1}
Concentrating solar power	20–31
PV (residential rooftop)	23–86
PV (utility-scale fixed tilt)	15–62
Biomass co-firing	2.9–7.1
Hydro (all sizes)	2.4–15
Geothermal	4.5–13
Tidal range	23–32
Onshore wind (large turbines)	5.2–17
Offshore wind (large turbines)	12–23

Notes: 2008 data, 10% discount rate, 1 US cent ≈ 0.65 p

Source: IPCC, 2011



... electricity and hydroelectricity consumptions plus those of
... 2011)

Table 10.4 Levelized costs of heat from different sources for domestic use

Heating type	Cost / p kWh^{-1}
Natural gas boiler	6.8–10.5
Air-source heat pump	10.9–16.5
Ground-source heat pump	12.8–18.6
Biomass boiler	15.3–23.7
Solar thermal water heating	26.6

Note: Based on 2011 costs, 15 year equipment life and 8% discount rate

Source: CCC, 2011a

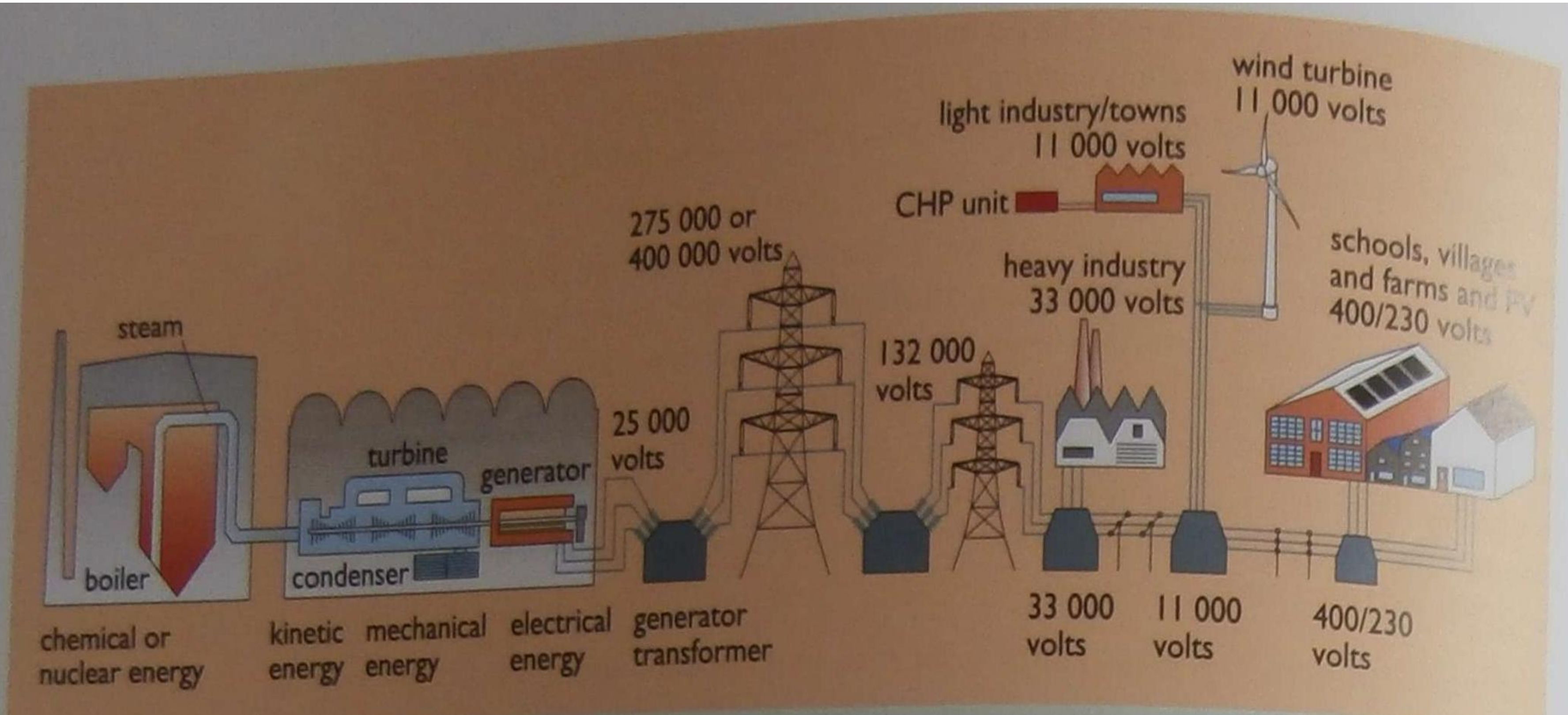


Figure 10.14 A schematic of the basic UK electricity system