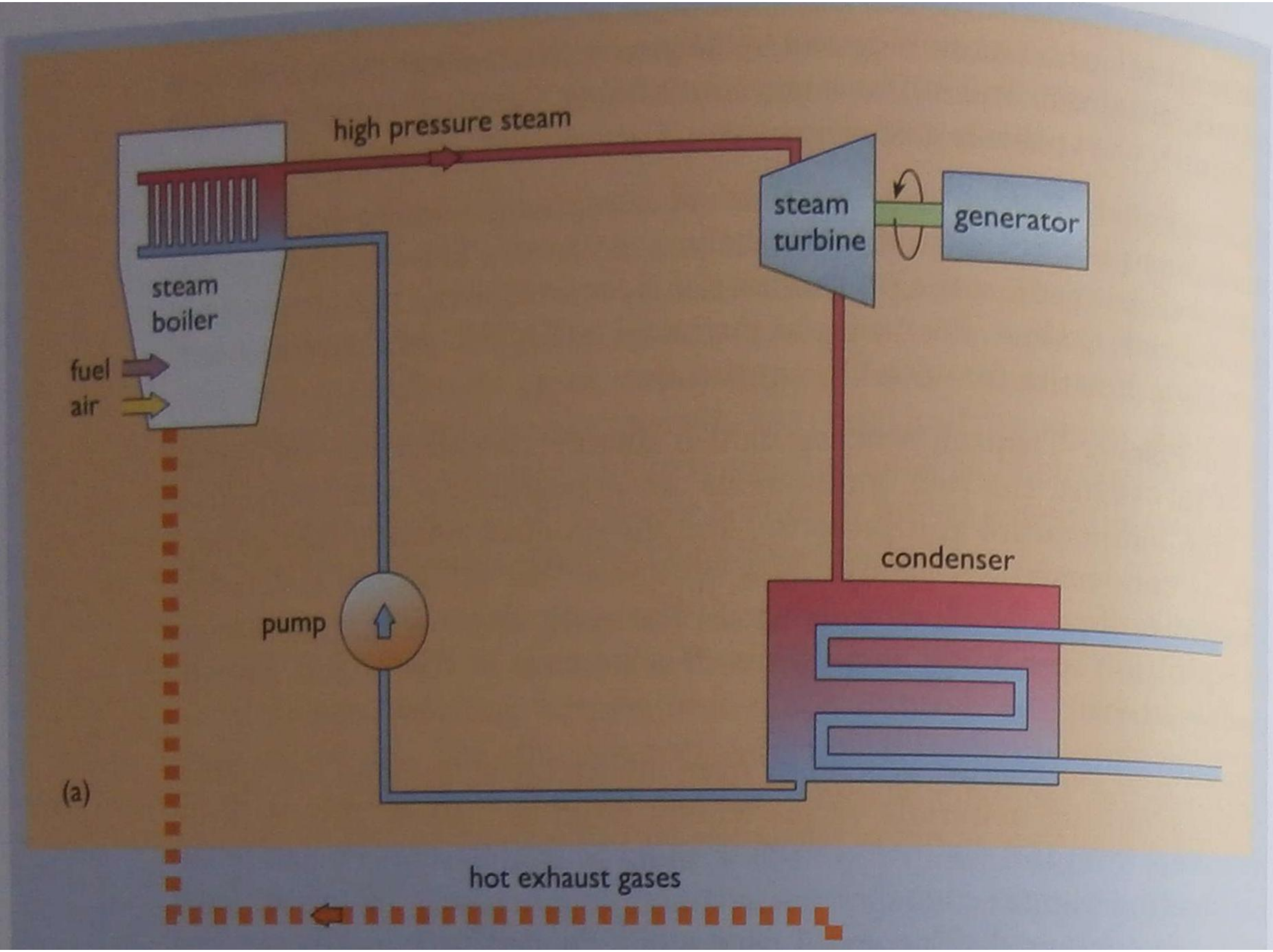

high pressure steam
steam
turbine
generator
steam
boiler
fuel
air
pump
condenser
(a)
hot exhaust gases

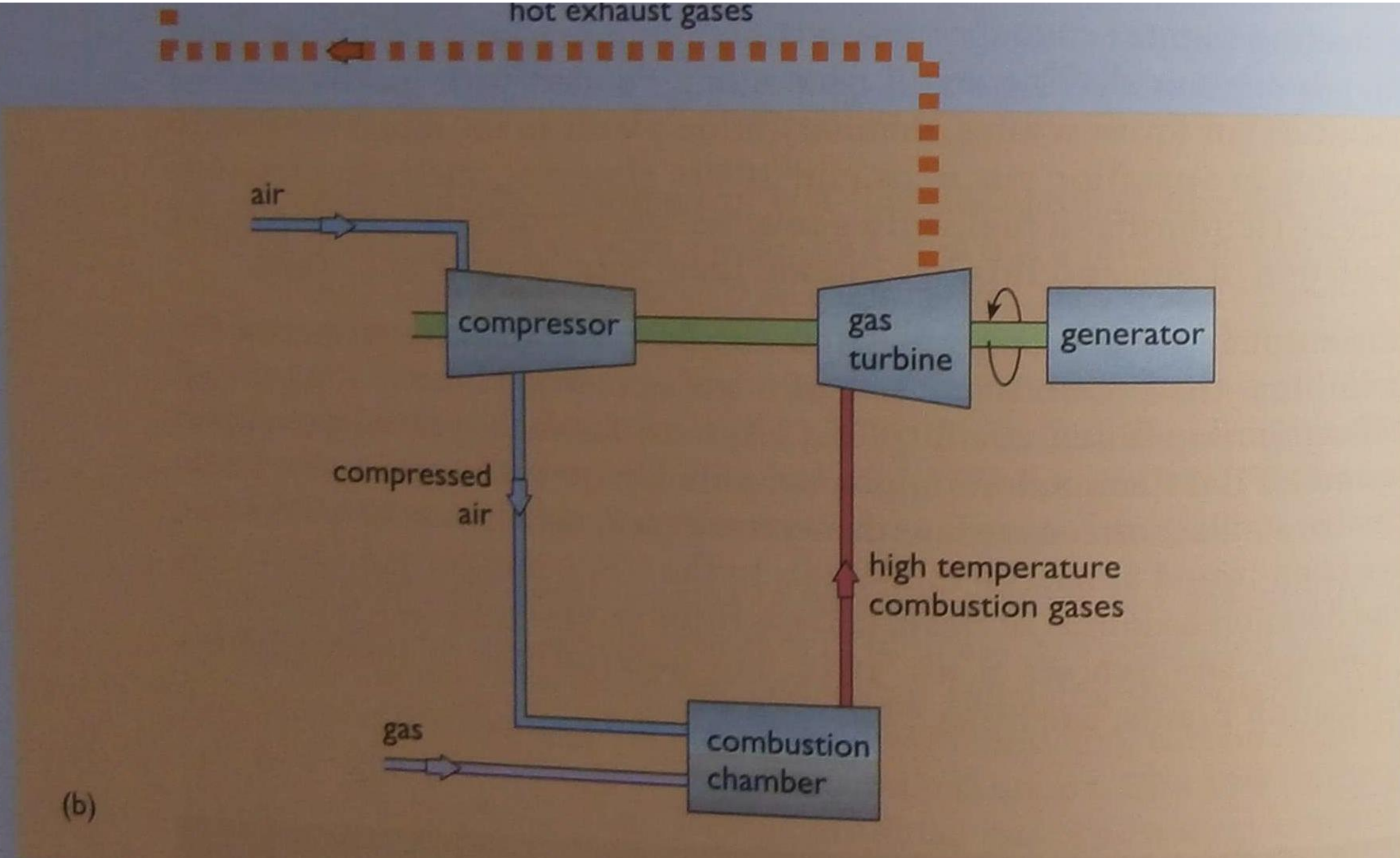


Figure 4.16 Types of generating system (a) conventional steam turbine, (b) simple gas turbine. In a CCGT plant the gas turbine exhaust gases (dotted line) replace the fuel/air input as the heat source for the boiler of the steam turbine

Transesterification

Following his invention of the compression ignition engine that bears his name, Dr Rudolf Diesel demonstrated the use of a variety of vegetable oils. More have been tried since, but as in other cases, cheap crude oil came to dominate the market.

After extraction from the parent plant as outlined above, certain vegetable oils can be burned directly in some modern diesel engines, either pure or blended with diesel fuel, but most applications require minor modifications to the engine and fuel system. Upgrading of vegetable oils to **biodiesel** results in a fuel that can blend with or replace petroleum diesel in unmodified engines.

4.9 Biochemical processing

Biochemical processes rely on the use of microorganisms to convert biomass into more useful forms for bioenergy. The processes may also involve some conventional chemical and physical stages, but the essential stage is biological.

Anaerobic digestion

The process of anaerobic digestion (AD) is complex, but in outline, bacteria break down organic material into sugars and then into various organic acids which are further decomposed to produce **biogas**, a mixture of methane, carbon dioxide and trace gases, including hydrogen sulfide. The feedstock used may include dung or sewage, food processing wastes or discarded food, agricultural residues or specially grown silage crops that are harvested green. Digestion can take place in either wet or dry systems. In **wet** systems, the raw feedstock is usually converted to a slurry with up to 80–95% water, and fed into a purpose-built **digester** whose temperature can be controlled. The high throughput of water in wet anaerobic digestion systems may be a disadvantage, and in '**dry**' digestion systems the moisture content in the digester is much lower. This requires a higher input of energy to mix the material, but avoids the need to dispose of large volumes of water.

The natural digestion process in a landfill (Figure 4.20(a)) takes place over years, rather than the days or weeks of in-vessel systems. In developing a landfill gas site, each area is covered with a layer of impervious material after it is filled, and the gas is collected by an array of interconnected perforated pipes placed at depths of up to 20 metres in the refuse (Figure 4.20(b)). In a large well-established landfill there can be several kilometres of pipes, with as much as 1000 m^3 per hour of gas being pumped out.

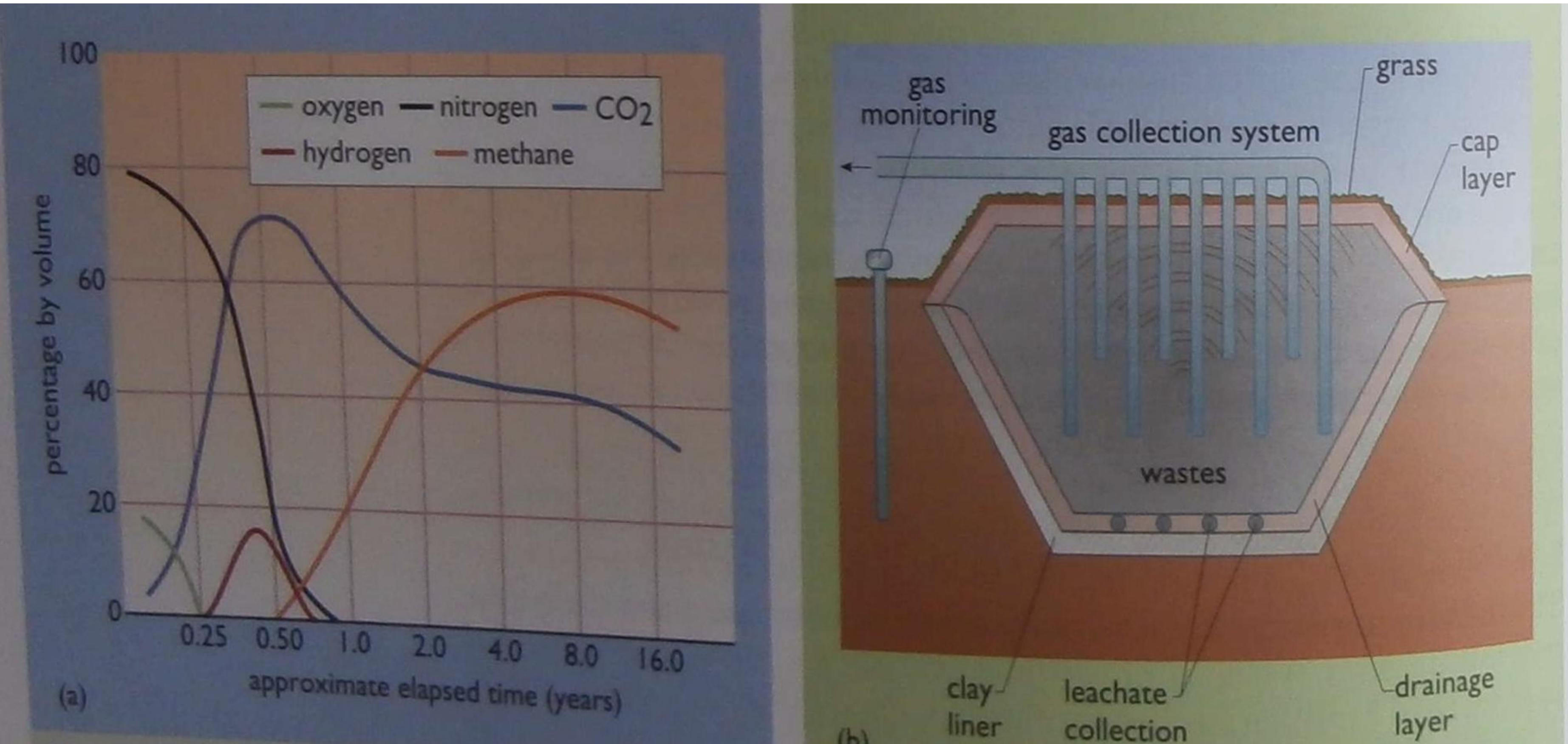
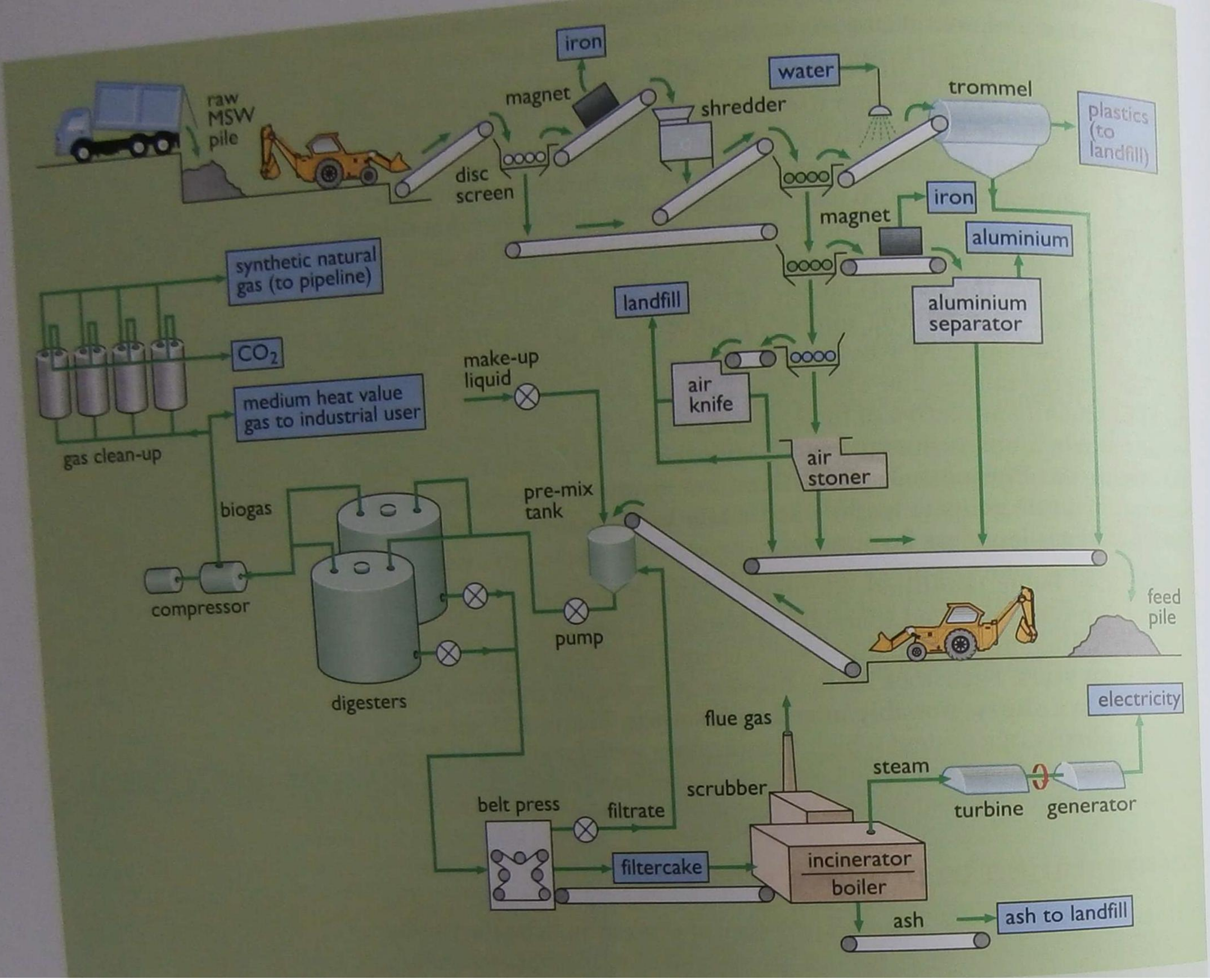


Figure 4.20 (a) The changing gas composition in a landfill site, (b) Extraction of landfill gas

Fermentation to produce ethanol

Since fermentation requires sugars, an obvious starting point is sugar-cane, and this is the basis of Brazil's PRO-ALCOOL gasohol programme. Cereals, where the main carbohydrate is starch, require initial processing (**malting**) to convert the starch to sugar. This conversion occurs naturally when seeds germinate, so the seed is dampened to start germination and sugar formation, then dried rapidly to prevent decomposition.

The liquid resulting from fermentation contains about 10% ethanol. Distillation to increase the concentration requires a considerable heat input, usually supplied by crop residues. The energy content of ethanol is about 30 GJ t^{-1}, or 0.024 GJ per litre. The 360 litres of ethanol produced from a tonne of maize (Table 4.4) therefore has an energy content of 8.6 GJ. Comparing this with the 19 GJ t^{-1} gross energy present in the grain (Table 4.2) shows that the conversion efficiency of fermentation is relatively poor, but the technology is well developed and can be adapted to convert a range of inputs into a useful product. The only gaseous by-product is pure carbon dioxide which can be captured and stored for use in products such as carbonated drinks. It can also be used in greenhouses to stimulate the production of horticultural crops or even new sources of biomass.



iron
water
raw MSW pile
magnet
shredder
trommel
plastics (to landfill)
disc screen
iron
magnet
aluminium
synthetic natural gas (to pipeline)
landfill
aluminium separator
CO_2
make-up liquid
air knife
medium heat value gas to industrial user
gas clean-up
air stoner
biogas
pre-mix tank
compressor
pump
feed pile
digesters
electricity
flue gas
steam
scrubber
belt press
filtrate
turbine
generator
filtercake
incinerator
boiler
ash
ash to landfill

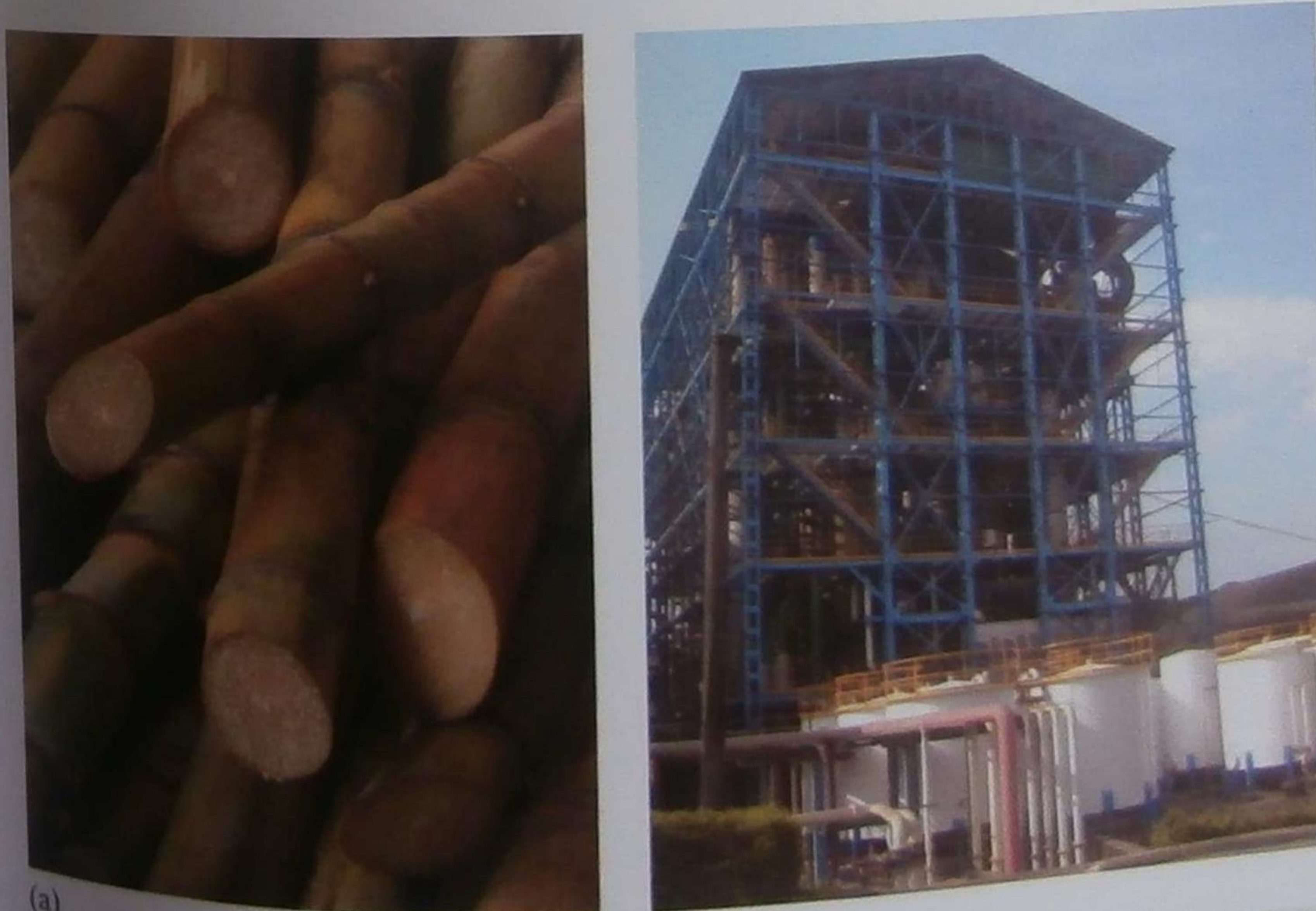
Table 4.4 Ethanol yields from a range of crops

Raw material	Litres per tonne[1]	Litres per hectare per year[2]
Sugar cane (harvested stalks)	70	400–12 000
Maize (grain)	360	250–2000
Cassava (roots)	180	500–4000
Sweet potatoes (roots)	120	1000–4500
Wood	160	160–4000[3]

[1] This depends mainly on the proportion of the raw material that can be fermented

[2] The ranges reflect worldwide differences in yield

[3] The upper figure is a theoretical maximum



(a)

(b)

Figure 4.22 (a) Sugar cane, (b) Brazilian ethanol production plant

Bioethanol can be used to produce **ethanol gel**, a clean-burning fuel that consists of bioethanol bound in a hydrated cellulose thickening agent. Cooking stoves specially designed for use with ethanol gel have been developed for sale both in developing countries and in European leisure/camping applications (there are also ethanol gel burners that can be retrofitted into several kinds of traditional African cooking stoves). In such appliances, ethanol gel is a highly controllable, easily lit cooking fuel with a heating efficiency of roughly 40%. Initial market penetration has taken place in several African countries, including Nigeria, Zimbabwe, Malawi and South Africa. Ethanol gel can act as a substitute for wood fuels and kerosene, reducing CO_2 emissions and indoor air pollution, thereby addressing the serious problem of clean, controllable, renewable heat for cooking in the developing world (UN Foundation, 2008). It is ironic, but perhaps industrially and economically necessary, that ethanol stoves are simultaneously growing in popularity as aspirational focal points for Western homes.

Another

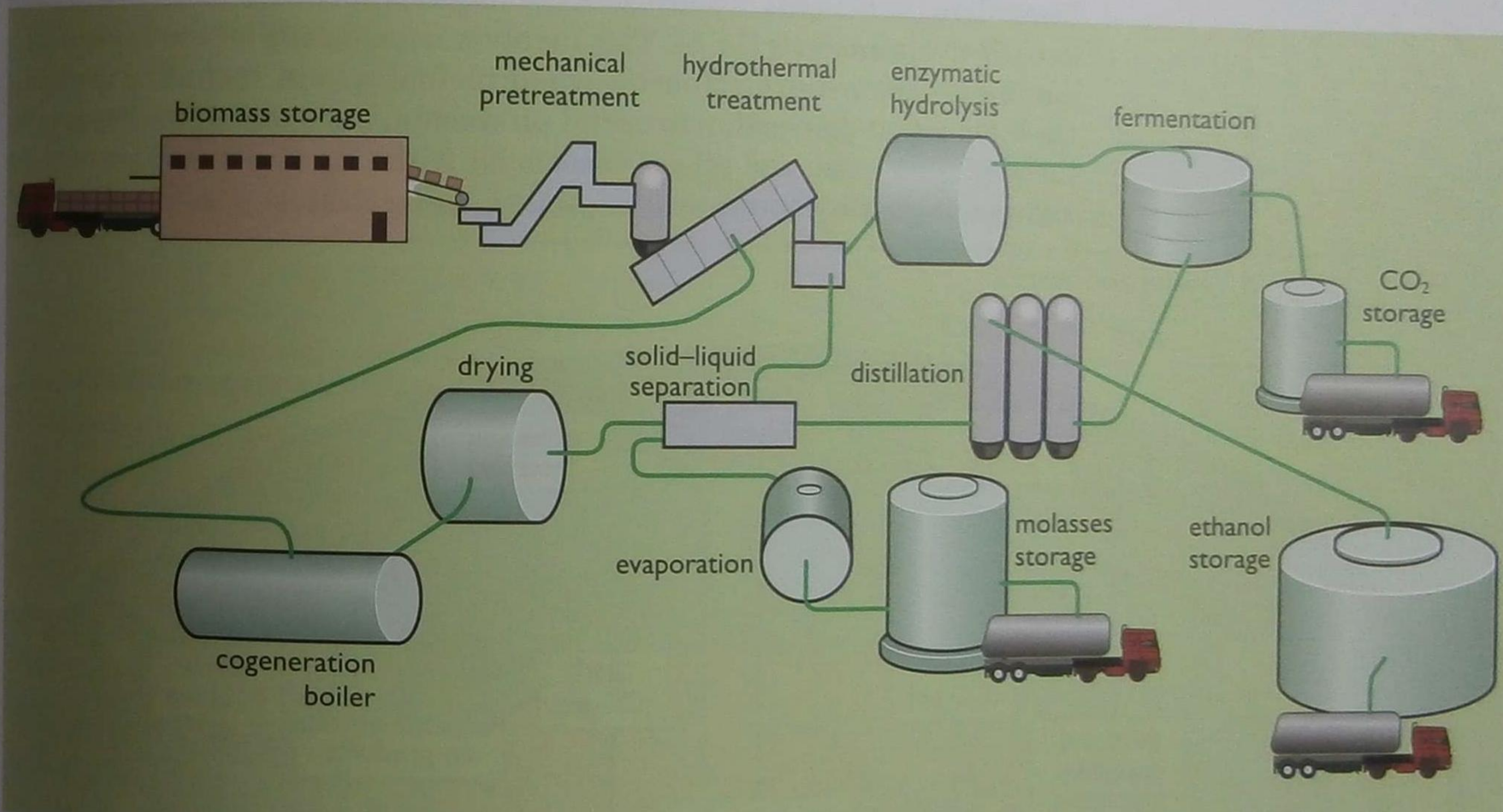


Figure 4.23 Schematic of the Inbicon integrated process for ethanol production from straw. The cogeneration boiler supplies steam to the hydrothermal treatment.

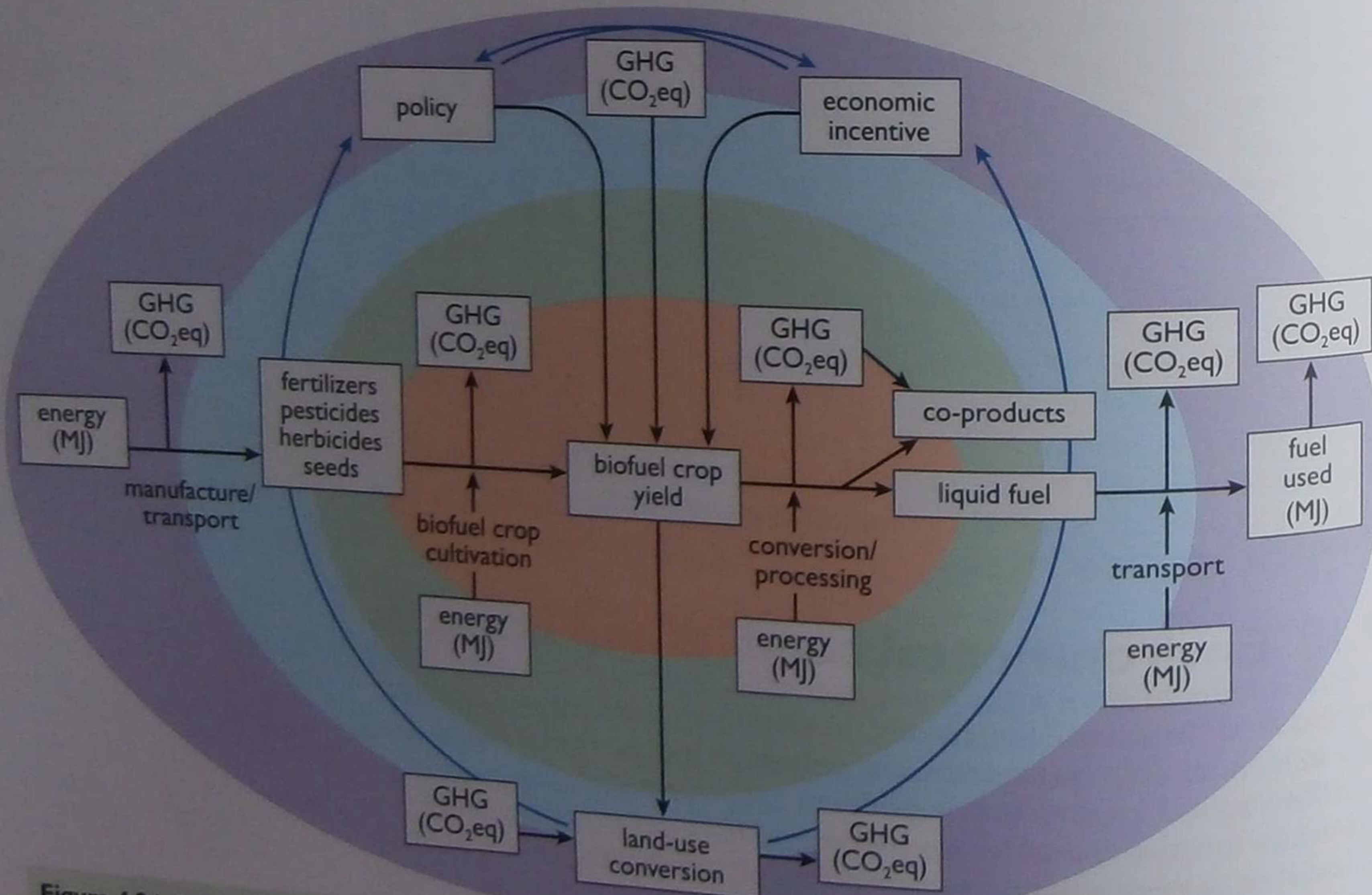


Figure 4.24 Different system boundaries for the life-cycle analysis (LCA) of biomass energy systems (Davies et al., 2009) (GHG = Greenhouse Gases, measured in terms of the amount of CO_2 that would have an equivalent greenhouse effect, CO_2eq)

Table 4.5 Net life cycle gaseous emissions from electricity generation systems in the UK

	Emissions[1]/t GW h^{-1}		
	CO_2	SO_2	NO_x
Combustion, steam turbine			
Poultry litter	10	2.42	3.90
Straw	13	0.88	1.55
Forestry residues	29	0.11	1.95
MSW (EfW)	364	2.54	3.30
Anaerobic digestion, gas engine			
Sewage gas	4	1.13	2.01
Animal slurry	31	1.12	2.38
Landfill gas	49	0.34	2.60
Gasification, BIGCC[2]			
Energy crops	14	0.06	0.43
Forestry residues	24	0.06	0.57
Fossil fuels			
Natural gas: CCGT[2]	446	0.0	0.5
Coal: with minimal pollution abatement	955	11.8	4.3
Coal: Flue Gas Desulfurization and low NO_x [3] burner	987	1.5	2.9

[1] Note that 1 g kWh

Methane

Methane is a powerful greenhouse gas and is produced from the anaerobic breakdown of biomass (either naturally or by human intent). A molecule of CH_4 is about 22 times as effective as a molecule of CO_2 in trapping the Earth's radiated heat. Collection of the methane released from anaerobic manure and slurry stores, and from landfills, and subsequent combustion effectively replaces each CH_4 molecule by a CO_2 molecule. The combustion of landfill gas was estimated to have reduced UK greenhouse gas emissions by the equivalent of

Energy balance

The terms **energy balance, energy payback ratio**, or **fuel energy ratio** are used to describe the relationship between the energy output of a system and the energy inputs needed to operate it (usually from fossil fuels). The concept came to the fore when doubts arose concerning some of the early fuel-from-biomass projects introduced following the oil price increases of the 1970s. There were claims that, when a full life-cycle analysis was undertaken, the fossil-fuel energy input for some schemes was actually greater than their bioenergy output.

The ratio of output to input will of course depend on the type of system, and the extent of the processing involved. In particular, ratios will normally be lower if the final 'output' is electricity, because of the inherent limit on the Carnot efficiency (see Box 2.4) of heat engines used in generation.

Table 4.6 The range of fuel energy ratios for selected bioenergy systems reported in the literature to 2008

	Fuel energy ratio	
	Lowest	Highest
Lignocellulosic crops (generalized)	1.8	5.6
Switchgrass	0.44	4.43
Corn	0.69	1.95
Miscanthus (combustion)	1.16	1.16
Miscanthus (gasification)	0.99	0.99

Only one set of data for miscanthus systems was available.
Source: derived from Davies et al., 2009

Costing bioenergy

The four main factors that determine the cost of energy from any system are described in Appendix B. For most renewable energy systems, the initial *capital cost* (including the cost of borrowing the money) is a major component. Unlike many other renewable energy technologies, bioenergy systems can also have significant *fuel* costs. Energy crops, for example, must be planted, fertilized, protected against weeds and pests, harvested and transported. On the other hand, EfW may have *negative fuel costs* in the form of savings in payments for disposal of wastes.

Electricity from wastes

The economics of electric power from **landfill gas** are relatively simple. The gas itself is a waste product that must in any case be collected and flared off to protect the environment and prevent explosions. So the marginal additional cost of piping it to a gas engine is likely to be small. The main costs are thus the capital cost of the engine and generator and connection to the grid, together with a modest allowance for O&M.

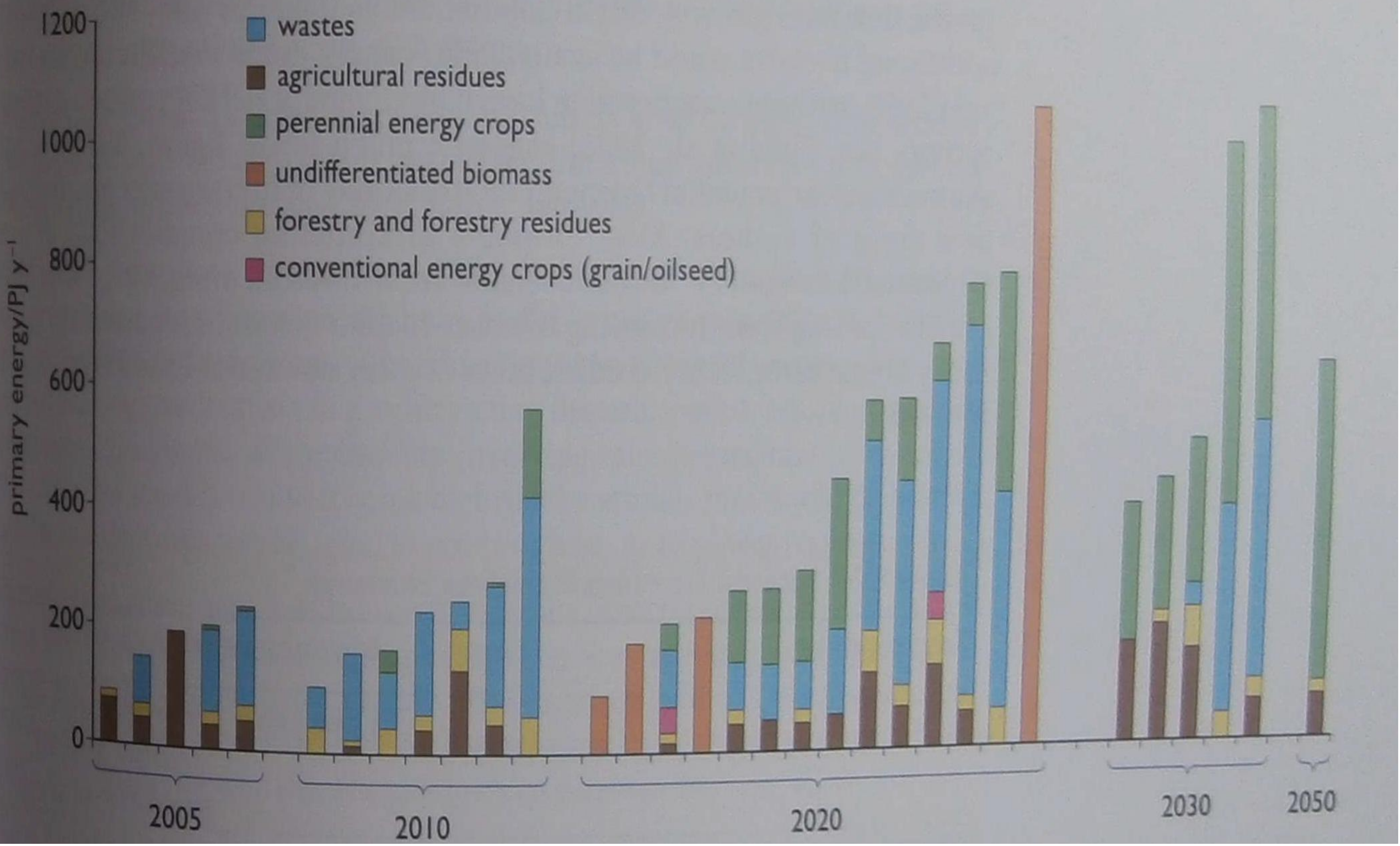
Owners of sites can charge increasingly high **gate fees** to accept waste, particularly near large cities, which operators can offset against the additional costs of generating electricity from landfill gas.

With landfill sites in ever-shorter suppl[illegible]
sites is also risin[illegible]

Table 4.8 Cost of production at seven Midwest corn ethanol plants, 2006/07 ($ per US gallon)

Item	Cost/$
Electricity	0.025
Natural gas	0.190
Denaturant	0.070
Enzymes etc.	0.063
Labour and management	0.051
Maintenance and repair	0.019
Miscellaneous	0.037
Total processing	0.450
Feedstock	1.063
Distillers grains (for animal feed)	–0.229
Operating costs	1.288
Estimated capital cost	0.350
Estimated total cost	1.640

Source: Perrin, 2009



wastes
agricultural residues
perennial energy crops
undifferentiated biomass
forestry and forestry residues
conventional energy crops (grain/oilseed)
primary energy/PJ y⁻¹
1200
1000
800
600
400
200
0
2005
2010
2020
2030
2050

Geothermal energy – heat from the Earth – is one of the less well recognized forms of renewable energy. This chapter explains the nature of geothermal energy, why it is treated as renewable even though locally heat is being mined, its usage over the past hundred years and its probable future. It is one of the few renewables that is constantly available. Although it used to be thought the preserve of regions prone to volcanic activity, that has now changed; new technologies are making this energy source available almost everywhere and it is realistic to think that geothermal energy could meet a significant fraction of energy demand within the twenty-first century. This chapter documents its current usage and outlines the steps that are being taken to make this forecast a reality.

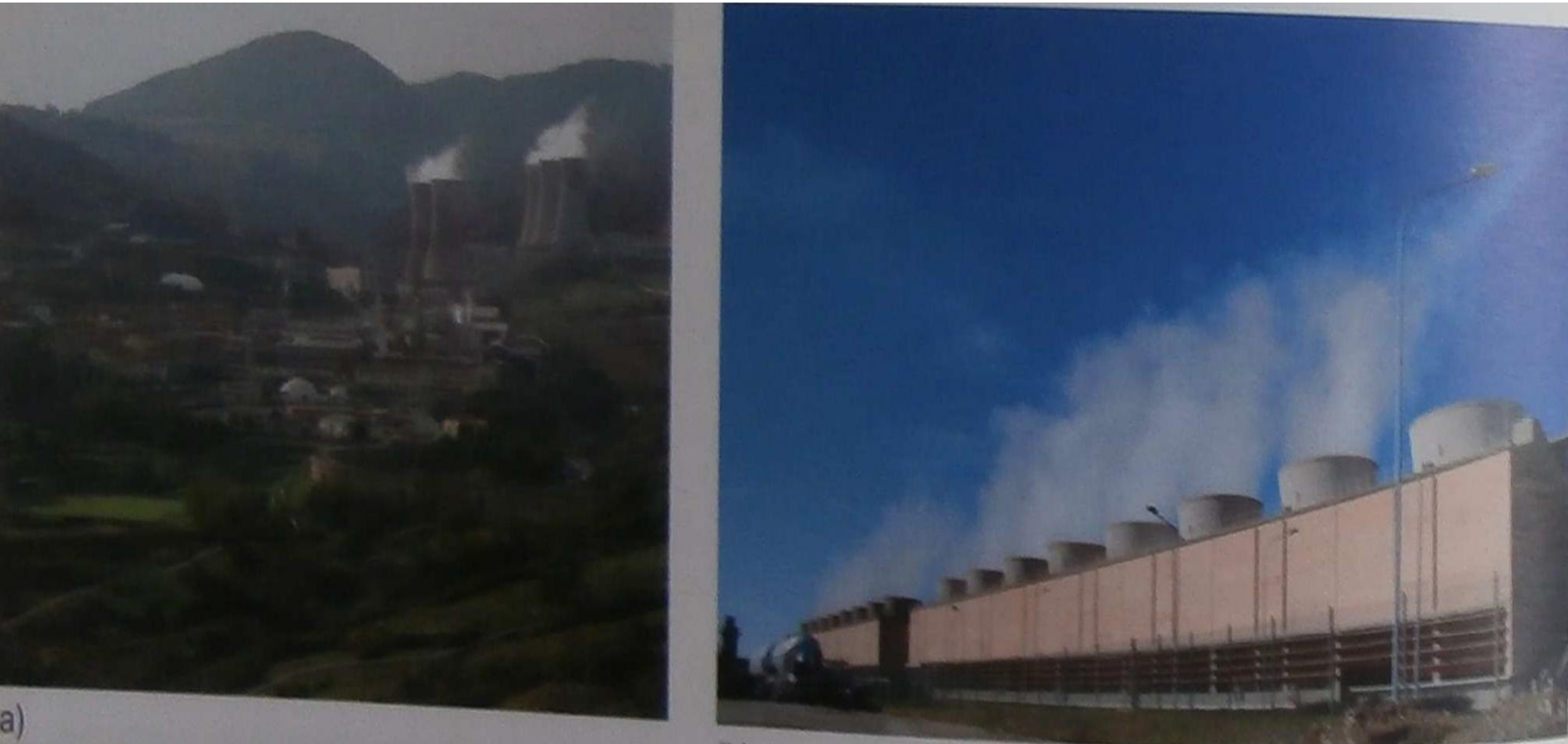
Geothermal energy – The mining of geothermal heat

In the continuing search to find cost-effective forms of energy that neither contribute to global warming nor threaten national security, geothermal energy has become a significant player. This is the only form of 'renewable' energy that is independent of the Sun, having its ultimate source within the Earth. It is a comparatively diffuse resource; the amount of heat flowing through the Earth's surface, 10^{21} J y^{-1}, is tiny in comparison with the massive 5.4×10^{24} J y^{-1} solar heating of the Earth which also drives the atmospheric and hydrological cycles. Fortunately, there are many places where the Earth's heat flow is sufficiently concentrated to have generated natural resources in the form of steam and hot water (180–250 °C), available in rocks within feasible drilling distance of the ground surface and suitable for electricity generation. These are the so-called 'high-enthalpy' resources (see Box 9.1).

The techniques for exploiting the resources are very simple in principle, and are analogous to the well-established techniques for extracting oil and gas. One or more boreholes are drilled into the reservoir, the hot fluid flows or is pumped to the surface and it is then used in conventional steam turbines or heating equipment. Typically, geothermal wells are drilled to depths from 700 to 3000 m.

Obviously, electricity is a more valuable and versatile end-product than hot water, so most attention tends to be focused on those resources capable of supporting power generation, i.e. hot enough to make electricity generation economic. By 2010 world electrical power-generating capacity from geothermal resources had reached 10.7 gigawatts electrical (10.7 GW_e), a small but significant contribution to energy needs in some areas (Table 9.1). It will be seen also that a further 11 countries intend to have geothermal generation plant in service by 2015, with total world capacity forecast to increase to 18.5 GW_e.


North American Plate
China Plate
Caribbean Plate
Philippine Plate
Pacific Plate
Cocos Plate
Nazca Plate
South American Plate
African Plate
Indian Plate
Scotia Sea
Antarctic Plate



a)

(b)

Figure 9.2 (a) The old geothermal power station at Larderello (b) the new power station

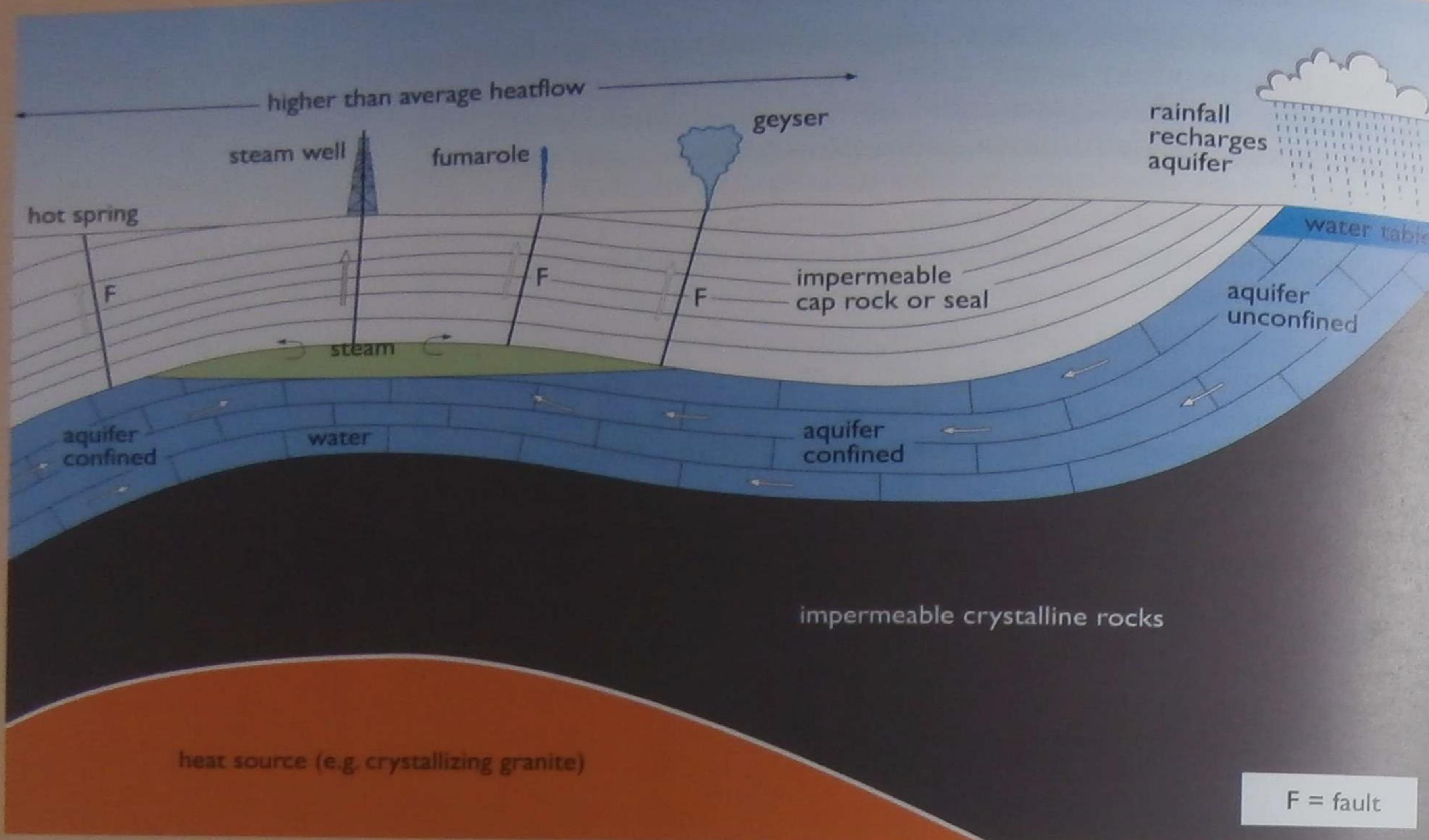


Figure 9.3 Simplified schematic cross-section to show the three essential characteristics of a geothermal site: an aquifer (e.g. fractured limestone with solution cavities); an impermeable cap rock to seal the aquifer (e.g. clays or shales); and a heat source (e.g. crystallizing granite). Steam and hot water escape naturally through faults (F) in the cap rock, forming fumaroles (steam only), geysers (hot water and steam), or hot springs (hot water only). The aquifer is unconfined where it is open to the surface in the recharge area, where rainfall infiltrates to keep the aquifer full, as indicated by the water table just below the surface. The aquifer is confined where it is beneath the cap rock. Impermeable crystalline rocks prevent downward loss of water from the aquifer

Figure 9.4 The relationship between grain size, shape and porosity in sedimentary rocks, especially sandstones (a–d); vesicular porosity in crystallized lava flows due to gas bubbles (e); and solution porosity resulting from rock dissolution, especially where acid groundwaters attack limestone (f). Porosity also develops in rocks along original planes of weakness, especially bedding planes and fractures (joints and faults) (g)

Here, H is the effective head of water driving the flow, and is measured in metres of water. The pressure gradient, or hydraulic gradient (H/L) is the change in this head per metre of distance L along the flow direction.

The volume of water (Q) flowing in unit time through a cross-sectional area A m^2 is v times A. So Darcy's Law may also be written:

$$Q = AK_w \frac{H}{L} \qquad (2)$$

and K_w (the hydraulic conductivity) may be interpreted as the volume flowing through one square metre in unit time under unit hydraulic gradient. Some values of hydraulic conductivity for different rocks are given in Table 9.3.

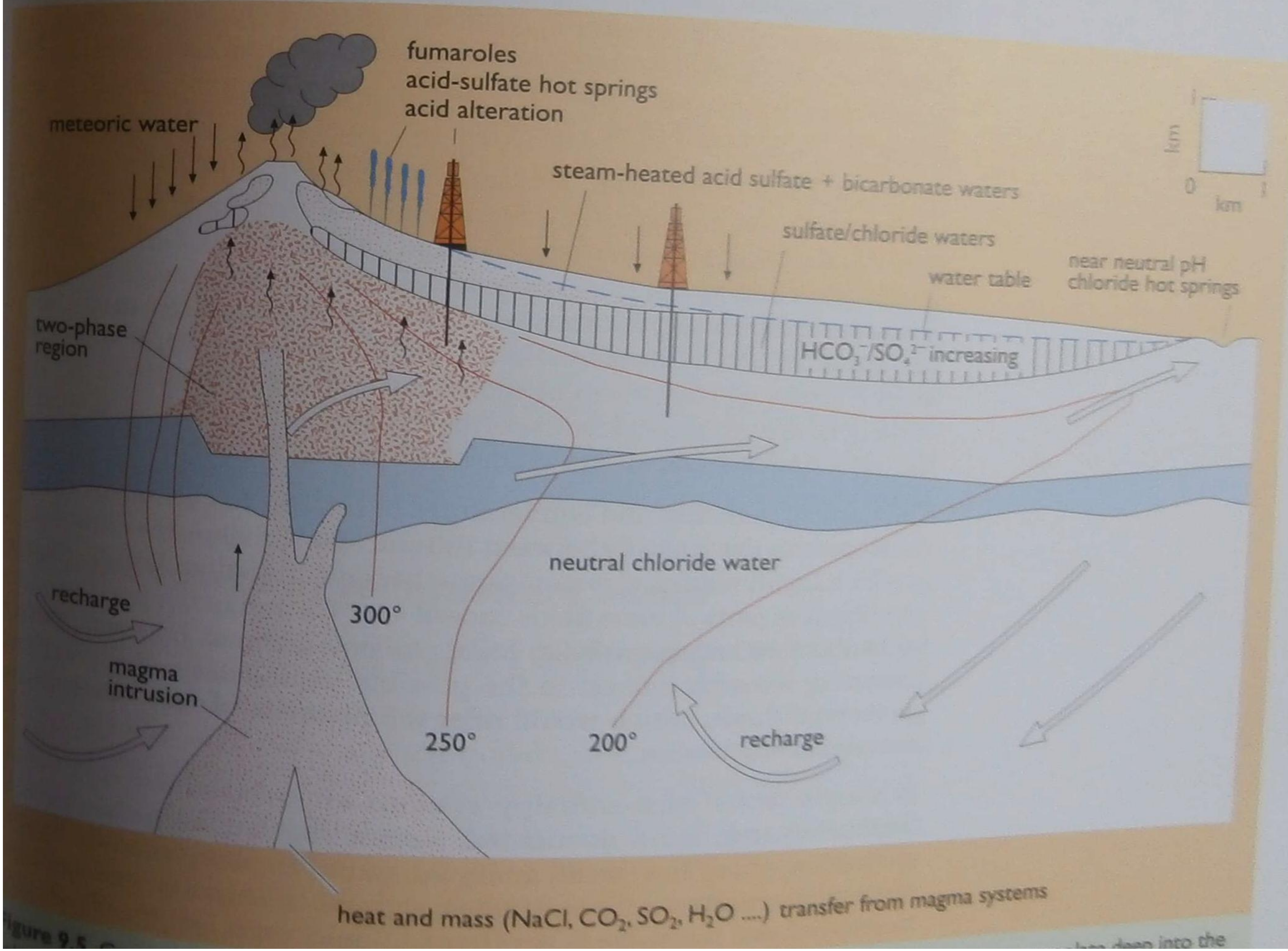
Notice that

Table 9.3 Typical porosities and hydraulic conductivities

Material	Porosity/%	Hydraulic conductivity/m day^{-1}
Unconsolidated sediments		
Clay	45–60	$<10^{-2}$
Silt	40–50	10^{-2}–1
Sand, volcanic ash	30–40	1–500
Gravel	25–35	500–10 000
Consolidated sedimentary rocks		
Mudrock	5–15	10^{-8}–10^{-6}
Sandstone[1]	5–30	10^{-4}–10
Limestone[1]	0.1–30	10^{-5}–10
Crystalline rocks		
Solidified lava[1]	0.001–1	0.0003–3
Granite[2]	0.0001–1	0.003–0.03
Slate	0.001–1	10^{-8}–10^{-5}

[1] The larger values of porosity and hydraulic conductivity apply to heavily fractured rocks and, for limestones, may also reflect the presence of solution cavities (see Figure 9.4(f)).

[2] Granite is a coarsely crystalline rock that has cooled down slowly from a melt at depth in the Earth. Such rocks are generally non-porous and impermeable, but contain many natural fractures and acquire limited permeability.



igure 9.5

deep into the

The range of pressures and temperatures of interest to current geothermal developments lies typically between 100 and 300 °C, below the critical point at which liquid water and water vapour become indistinguishable (though conditions in parts of some fields exceed 400 °C), and in the pressure range up to about 20 megapascals (20 MPa). As noted above, however, there is increasing research interest in the possible exploitation of supercritical geothermal fluids, which would offer the prospect of very much greater conversion efficiencies.

The heat source in sedimentary basins

An important key to understanding many geothermal resources is the heat conduction equation:

$$q = K_T \frac{\Delta T}{z} \qquad (3)$$

This is analogous to Darcy's Law, but here q is the one-dimensional vertical **heat flow** in watts per square metre ($W\ m^{-2}$). ΔT is the temperature difference across a vertical height z, and $\Delta T/z$ is thus the **thermal gradient**. The constant K_T relating these quantities is the **thermal conductivity** of the rock (in $W\ m^{-1}\ K^{-1}$) and is equal to the heat flow per second through an area of 1 m^2 when the thermal gradient is 1 °C per metre along the flow direction.

Values of

BOX 9.4 Thermal gradient and heat flow

Consider the situation where there is a steady upward flow of heat through the top few kilometres of the Earth's crust. We can use Equation 3 to relate this flow to the temperature at any depth if we know the thermal conductivity of the rock.

If, for instance, the temperature is found to be 58 °C at a depth of 2 km (2000 metres) and the surface temperature is 10 °C, the temperature gradient is:

$$(58 - 10)/2000 = 0.024\ ^{\circ}\mathrm{C\ m^{-1}}$$

and if the thermal conductivity of the rock is 2.5 W m^{-1} °C^{-1}, the heat flow rate is:

$$2.5 \times 0.024 = 0.060\ \mathrm{W\ m^{-2}}$$

or 60 mW m^{-2}.

Suppose, however, that this same 60 mW flows up through several layers with different thermal conductivities. Equation 3 tells us that the thermal gradient must be different in each layer, with the temperature changing most rapidly through the layer with the lowest conductivity, as in Figure 9.6 below.

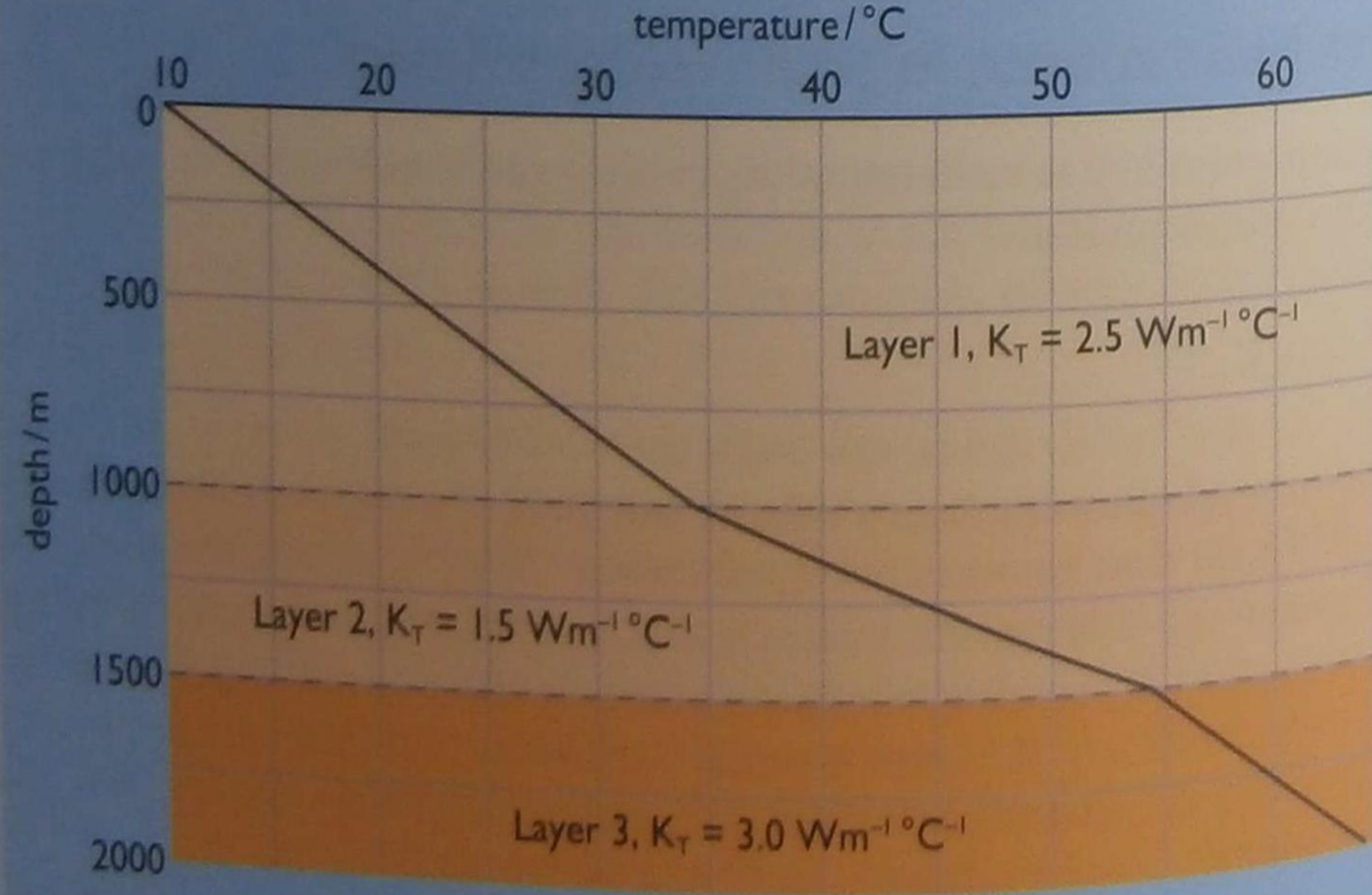


Figure 9.6 Variation of temperature with depth across three zones of differing thermal conductivity, K_T

We can check that the diagram shows the correct temperatures by using Equation 3 to calculate the temperature gradient for each layer and comparing this with the gradient read from the graph:

Layer 1

The calculated gradient is $0.060/2.5 = 0.024\ °C\ m^{-1}$

The measured gradient is $(34.5 - 10.0)/1000 = 0.0245\ °C\ m^{-1}$

Layer 2

The calculated gradient is $0.060/1.5 = 0.040\ °C\ m^{-1}$

The measured gradient is $(54.5 - 34.5)/500 = 0.040\ °C\ m^{-1}$

Layer 3

The calculated gradient is $0.060/3.0 = 0.020\ °C\ m^{-1}$

The measured gradient is $(64.5 - 54.5)/500 = 0.020\ °C\ m^{-1}$

Within the precision of the data therefore, the temperatures shown are consistent with a heat flow rate of 60 mW m^{-2} through each layer. Comparing this case (Figure 9.6) with the uniform rock considered above, it is obvious that the presence of the thin layer with low thermal conductivity has appreciably enhanced the temperature at a depth of 2 km.

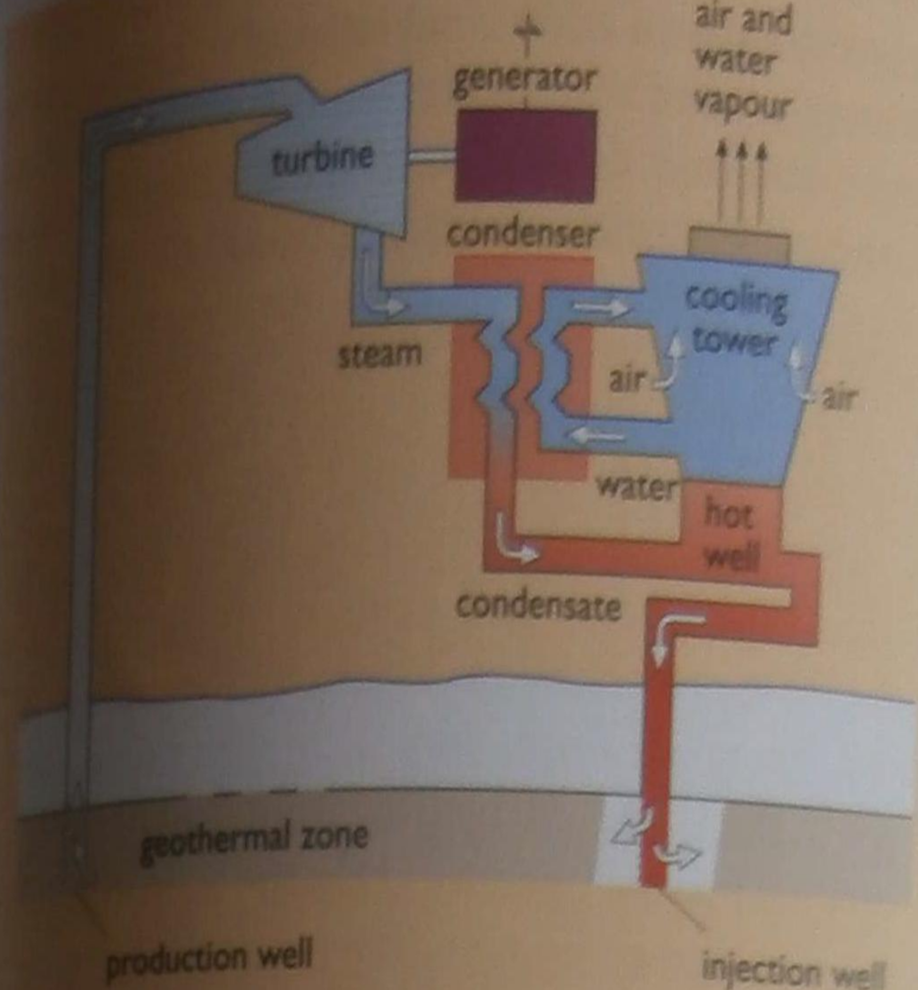
'Hot dry rocks' or engineered geothermal systems (EGS)

Our attention now turns from sedimentary strata to the underlying crystalline 'basement'. Most rocks, especially crystalline and basement rocks, do not contain sufficient water to provide a viable geothermal resource, although far greater amounts of heat are stored in such rocks than are available in aquifers. It was thought initially that deep basement rocks would indeed be dry, and so the term **hot dry rock** (HDR) was coined around 1970 to describe the heat stored in impermeable (or poorly permeable) rock strata and the process of trying to extract that heat. More recently, it has been recognized that few if any rocks are actually dry, and there is now a general acceptance of the term 'enhanced' – or 'engineered' – 'geothermal systems' (EGS) to categorize the various projects aimed at extracting this heat.

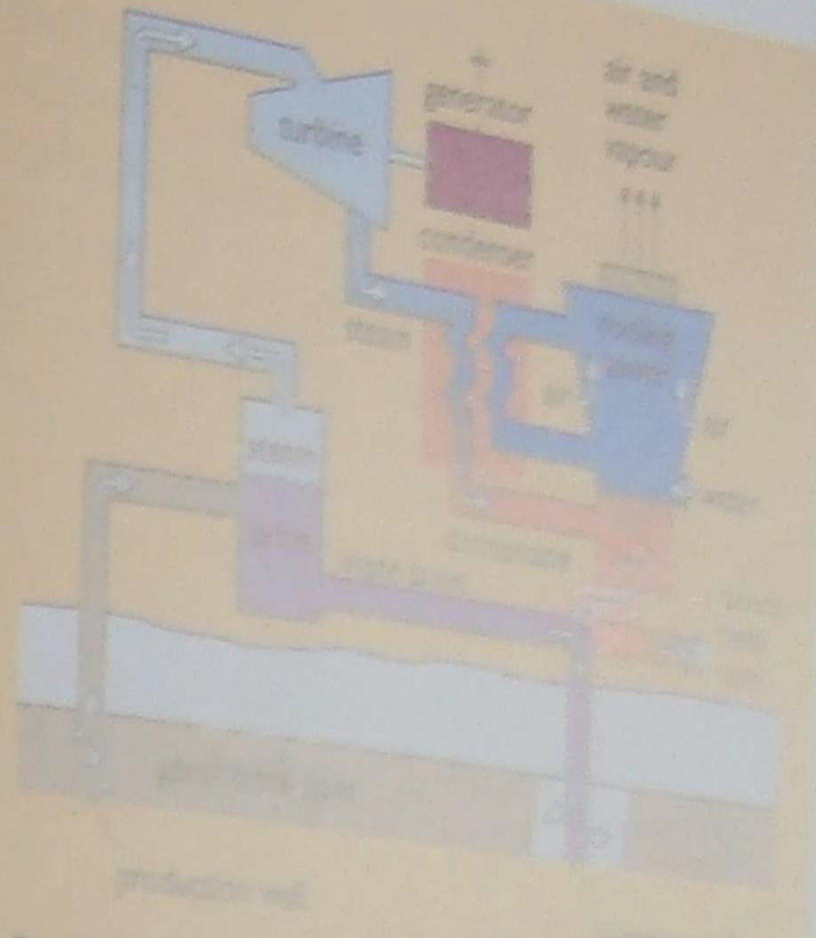
Dry steam power plant

As the name implies, this type of system (Figure 9.7(a)) is ideal for vapour-dominated resources where steam production is not contaminated with liquid. The reservoir produces superheated steam, typically at 180–225 °C and 4–8 MPa, reaching the surface at several hundred kilometres per hour and, if vented to the atmosphere, sounding like a jet engine at close proximity. Passing through the turbine, the steam expands, causing the blades and shaft to rotate and hence generating power. Temperatures up to 300–350 °C and correspondingly greater pressures are increasingly being exploited, leading to greater efficiency in electricity production.

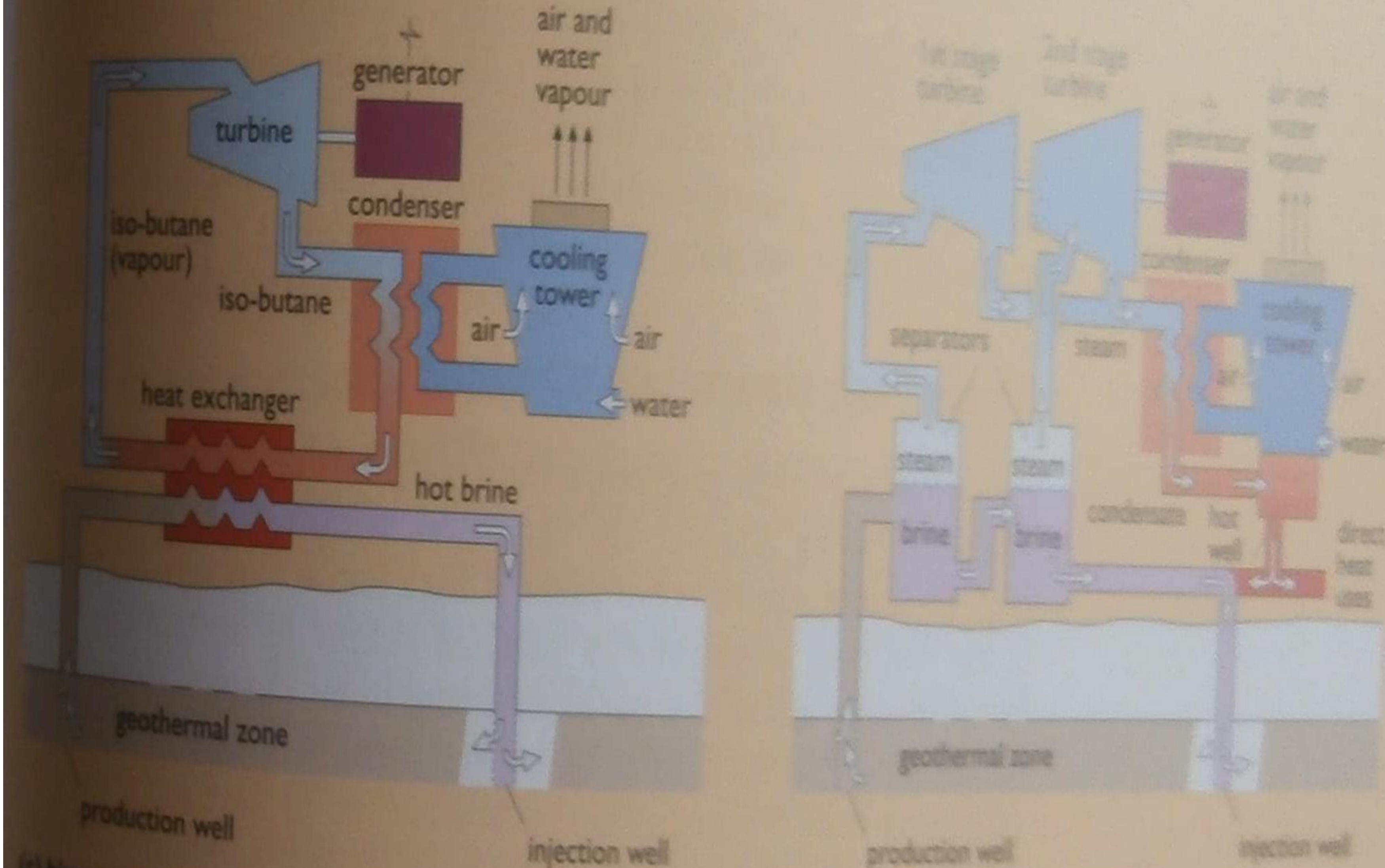
In the simplest form of



(a) dry steam power plant



(b) single flash steam power plant



(c) binary cycle power plant

(d) double flash power plant

Figure 9.7 Simplified flow diagrams (a–d) showing the four main types of geothermal electrical energy production

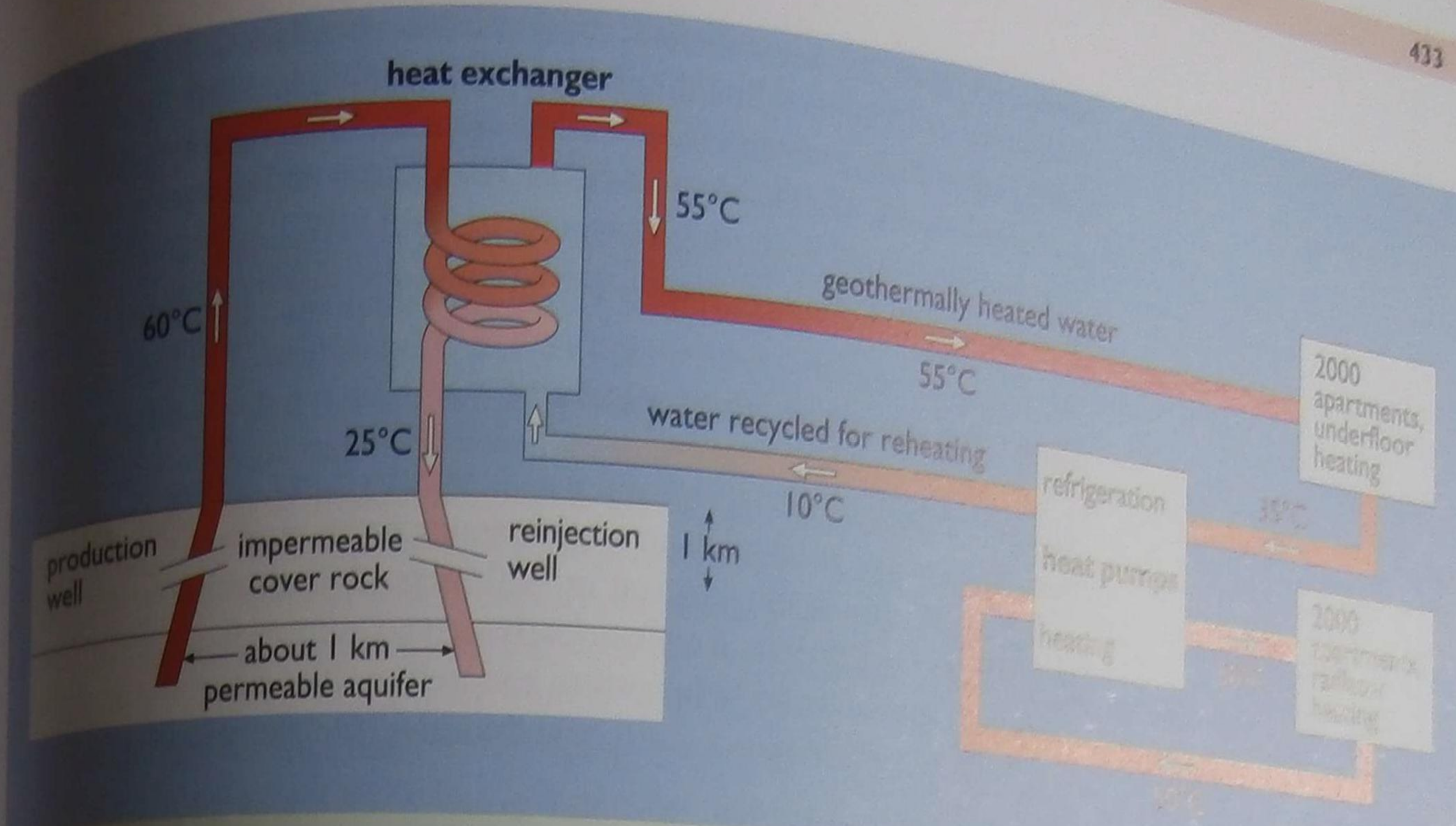


Figure 9.8 An example of a district heating scheme installed in the Paris region. This shows how the geothermal heat is exchanged to a secondary freshwater circuit. The circuit is used first to heat 2000 apartments by underfloor heating; the residual energy is then boosted using heat pumps to provide radiator heating in a further 2000 apartments. Note that the main function of the heat pumps is to lower the reinjection temperature and so extract more heat from the geothermal fluid rather than to raise the production temperature

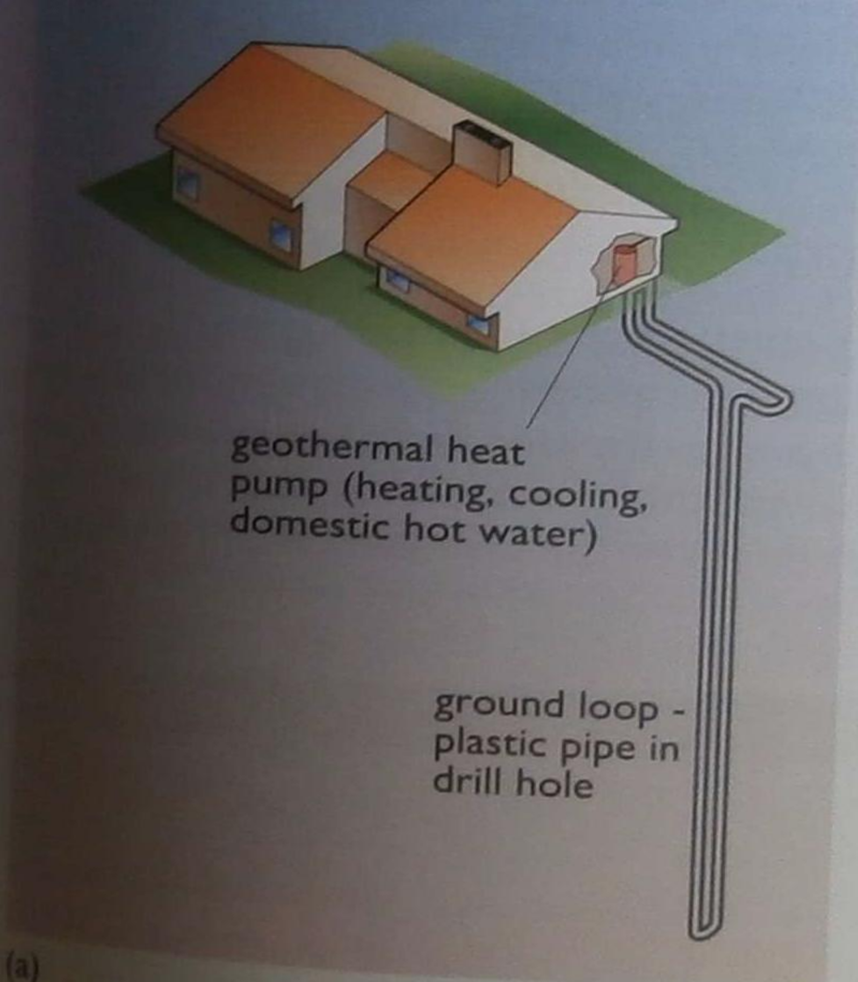
Some of the countries that are exploiting geothermal resources for non-electrical purposes have chosen to develop these direct use applications in areas flanking the main steam fields. Japan, New Zealand, Iceland and Italy are obvious examples, where wet steam or warm water at a range of temperatures is readily available for industrial, domestic and leisure applications. In this section, however, we leave these aside and concentrate principally on the low-temperature resources found in regions remote from plate boundaries, typically in sedimentary basins, several of which have been developed across central Europe. Drilling techniques resemble those discussed earlier, but the process is generally less hazardous since the geothermal fluid is found under much lower pressure and temperature conditions than in hot steam fields, and pumps are often required to bring the fluid to the surface at adequate flow rates. However, the hot water is

Ground source heat pumps

The technology of the heat pump was introduced in Chapter 2, Box 2.3. It may be used for cooling, as in a refrigerator or an air conditioning plant, or for space and water heating in buildings. It is this latter use that is increasingly of interest. An electrically driven compressor can be used to raise heat from a lower temperature and deliver it at a higher temperature to a building. More heat is delivered than the electricity consumed.

heating, ... at only 40 °C. ... underfloor

The general arrangement of a GSHP is illustrated in Figure 9.10(a). Unlike other geothermal techniques, this one relies on heat transfer by conduction from the walls of the borehole, not on the extraction of groundwater. The heat available from a well 100–150 m deep is only a few kW_t, but that is sufficient for a single domestic installation, and boreholes of this depth are often cheap enough to make the installation competitive with conventional heating systems. A simple loop of pipe is inserted in the well and grouted in place. A heat transfer fluid (usually water) circulates in the loop and transfers heat from the surrounding subsoil to a heat pump. More than 20 years' experience has shown that a few kilowatts can be extracted throughout the heating season; the subsoil temperature drops by a few


geothermal heat pump (heating, cooling, domestic hot water)
ground loop - plastic pipe in drill hole
(a)

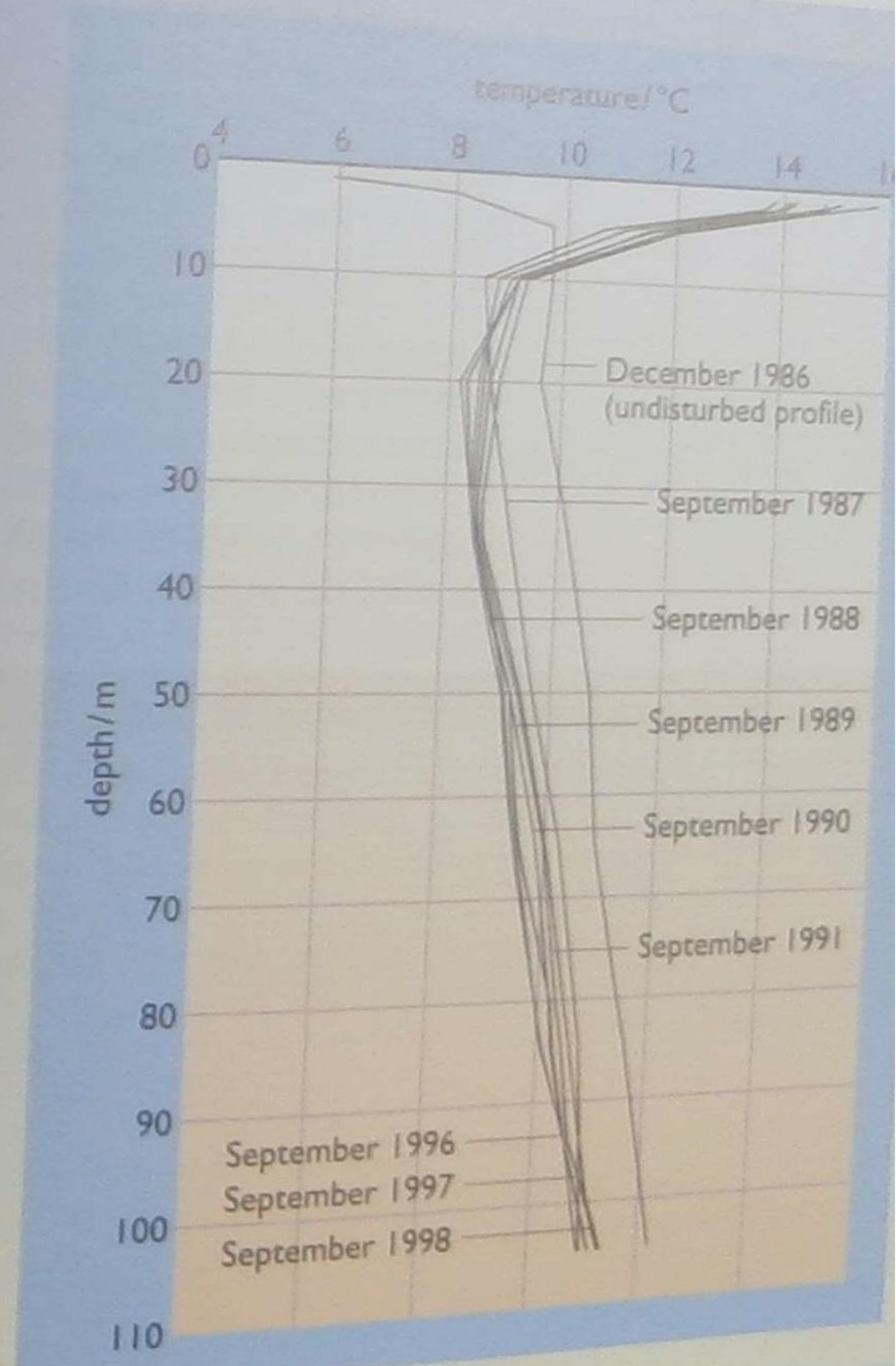

temperature/°C
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80
90
100
110
depth/m
December 1986 (undisturbed profile)
September 1987
September 1988
September 1989
September 1990
September 1991
September 1996
September 1997
September 1998
(b)

Table 9.4 Borehole heat exchanger performance in different rock types

Rock type	Thermal conductivity /W m^{-1} K^{-1}	Specific extraction rate/W m^{-1}	Energy yield per metre of borehole /kWh m^{-1} a^{-1}
Hard rock	3.0	max. 80	135
Unconsolidated rock, saturated	2.0	45–50	100
Unconsolidated rock, dry	1.5	max. 30	65

Source: Rybach and Eugster, 1998

Enhanced (or engineered) geothermal systems

All conventional geothermal systems (except, perhaps, GSHPs) rely on the presence of water circulating through the rock to extract heat and bring it to the surface. However, even in a good aquifer more than 90% of the heat is contained in the rock rather than in the water. Moreover, the vast majority of rocks are poorly permeable at best and the occurrence of an exploitable geothermal reservoir is a rarity. On the other hand, heat exists everywhere, and the amount of energy stored within accessible drilling depths (say, down to 7000 m, where temperatures of >200 °C would be widespread) is colossal. Cooling one cubic kilometre of rock (which is about the scale of a geothermal reservoir) by 1 °C will provide the energy equivalent of 70 000 tonnes of coal.

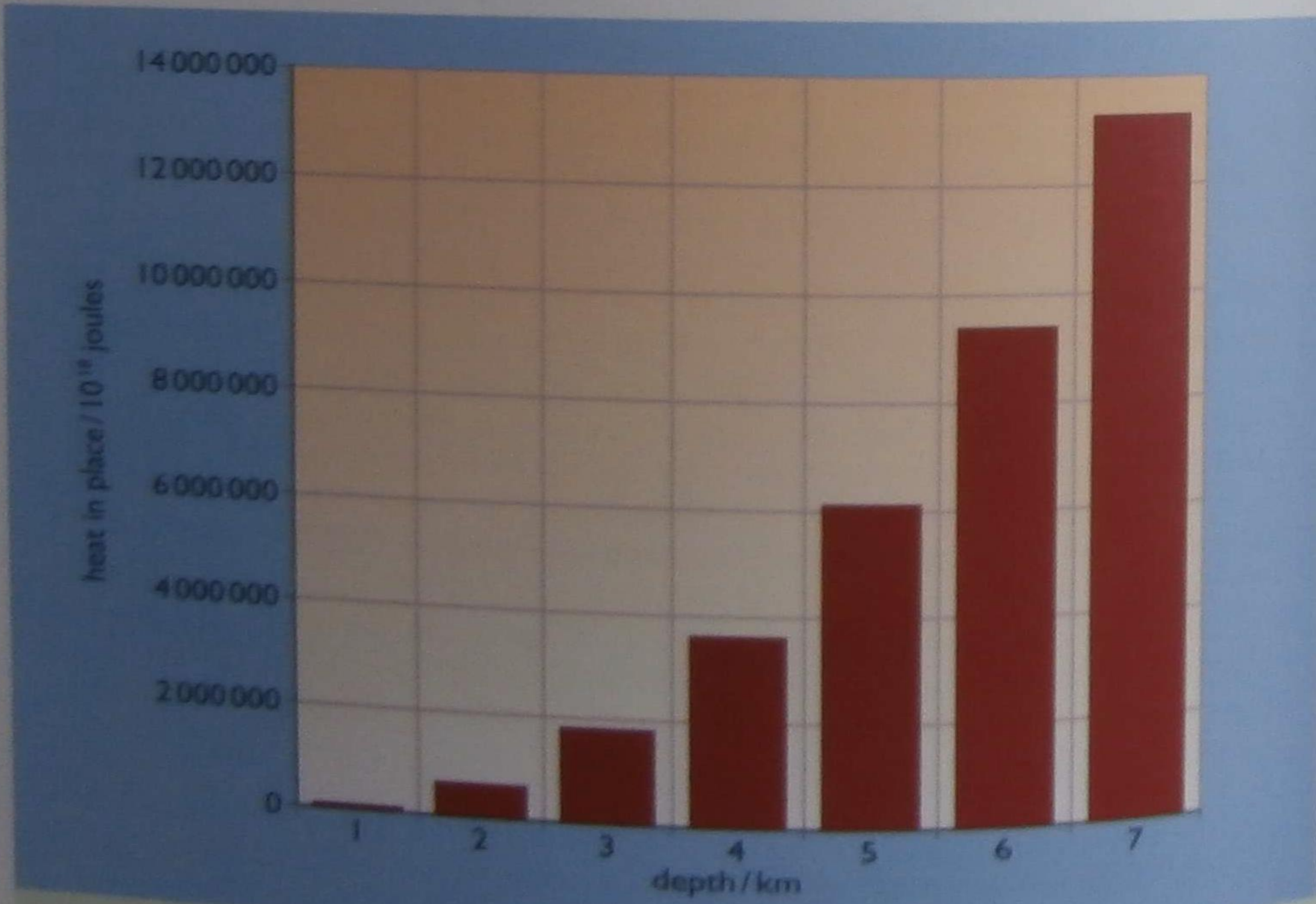


Figure 9.12 The total heat in place at various depths beneath the continental USA, excluding Alaska, Hawaii and Yellowstone (source: adapted from MIT, 2006)

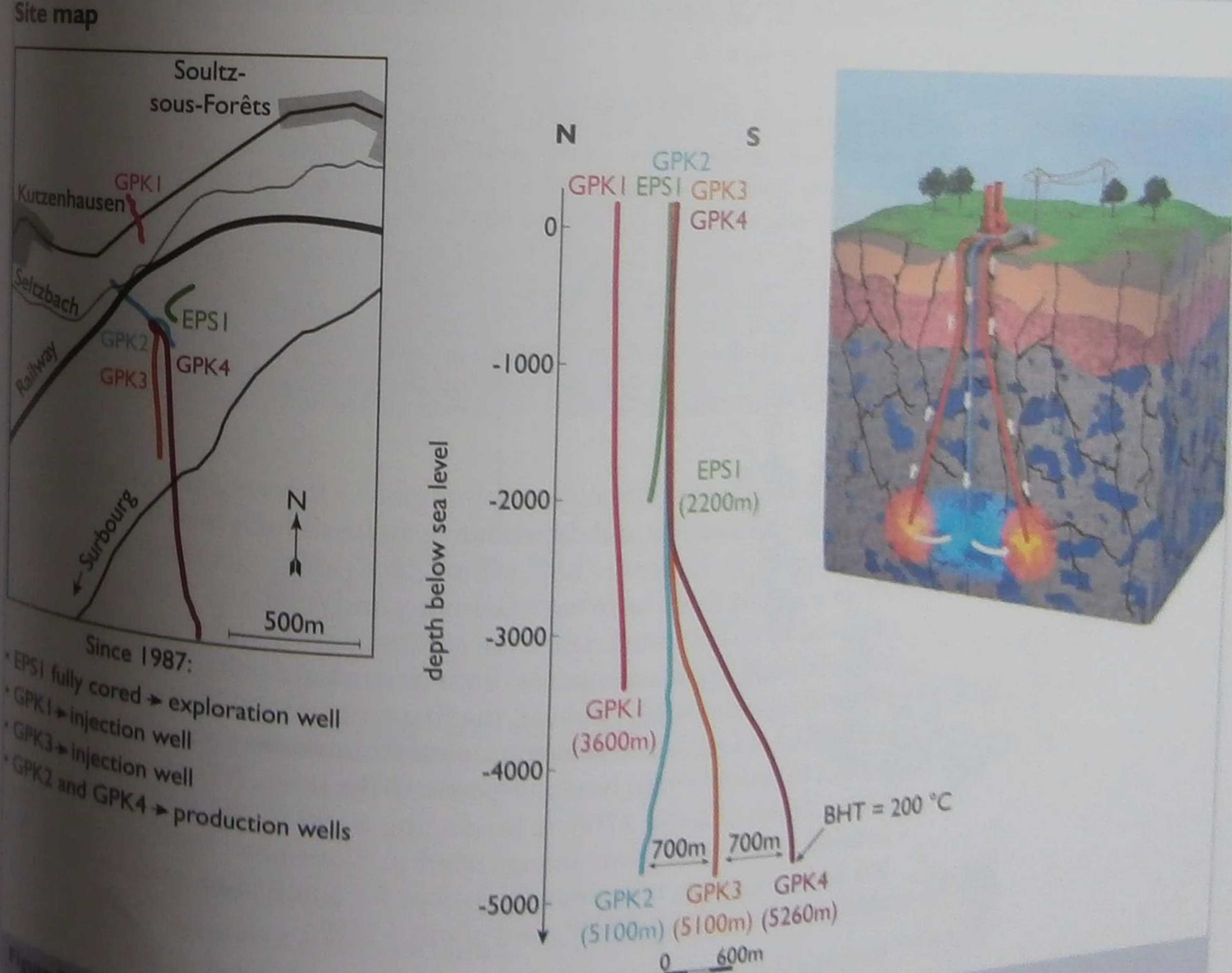

Site map
Soultz-sous-Forêts
Kutzenhausen
GPK1
Seltzbach
EPS1
GPK2
GPK3
GPK4
Railway
Surbourg
N
500m
Since 1987:
• EPS1 fully cored ➤ exploration well
• GPK1 ➤ injection well
• GPK3 ➤ injection well
• GPK2 and GPK4 ➤ production wells
N
S
GPK1
EPS1
GPK2
GPK3
GPK4
0
-1000
-2000
-3000
-4000
-5000
depth below sea level
EPS1 (2200m)
GPK1 (3600m)
700m
700m
BHT = 200 °C
GPK2 (5100m)
GPK3 (5100m)
GPK4 (5260m)
0 600m

Figure 9.14 The EGS site at Soultz-sous-Forêts