EMS717U/EMS717P

Renewable Energy Sources

Hydro power

Hydro energy

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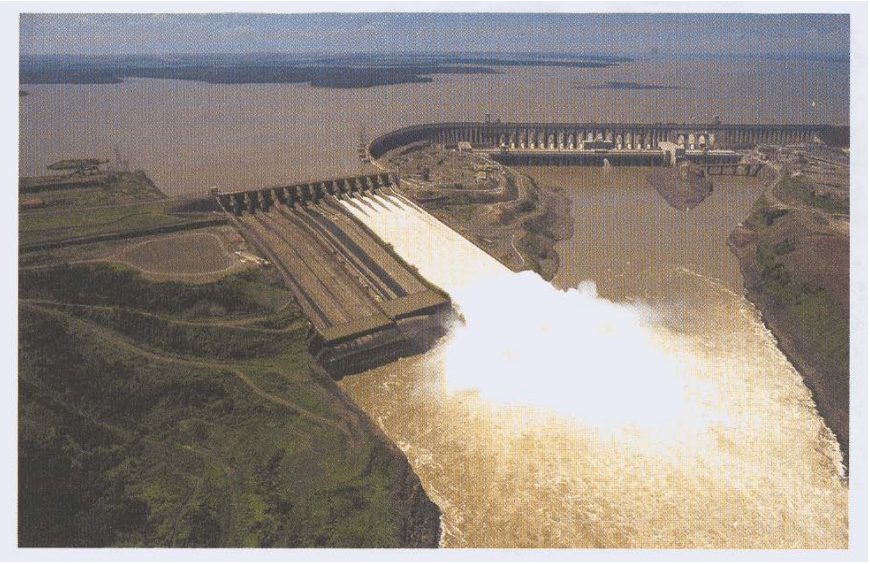
- **Conversion of hydro energy to power**
- **Yearly growth – 1%**
- **Water turbines**
- **Selection of turbines: Head vs Flow rate**
- **Energy storage**

Hydroelectricity



Hydroelectric power plant
Itaipu 14,750 MW
Brazil/Paraguay

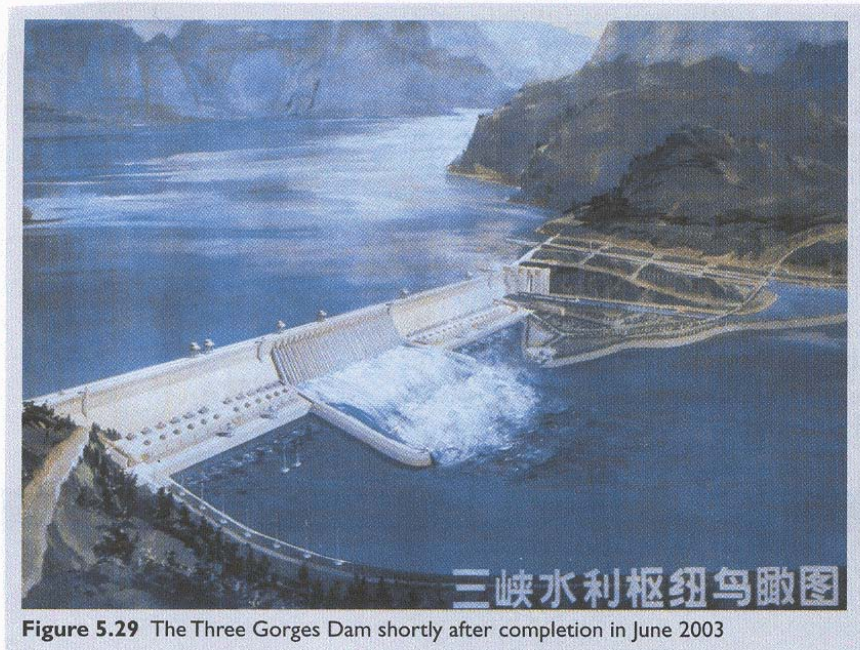


Figure 5.29 The Three Gorges Dam shortly after completion in June 2003

Hydroelectric power plant
Three Gorges 11,360 MW
China

Hydroelectric

Origin of hydro power?

Power [W], Head [m] and flow rate [kg/s, m^3/s]

Potential energy = MgH

$$P = \rho Q g H$$

$$P = \eta \rho Q g H$$

Factors

1. Effective head of water
2. Capacity
3. Type of turbine
4. Location, type of dam, reservoir, etc.

Hydroelectric: Capacity and growth

Table 5.3 Regional hydro potential and output

Region	Technical potential /TWh y^{-1}	Annual output* /TWh y^{-1}	Output as percent of technical. potential
Asia	5093	572	11%
S America	2792	507	18%
Europe	2706	729	27%
Africa	1888	80	4.2%
N America	1668	665	40%
Oceania	232	40	17%
World	14379	2593	18%

* Based on average output for the four years 1999–2002

Source: Adapted from WEC, 2003b and BP, 2003

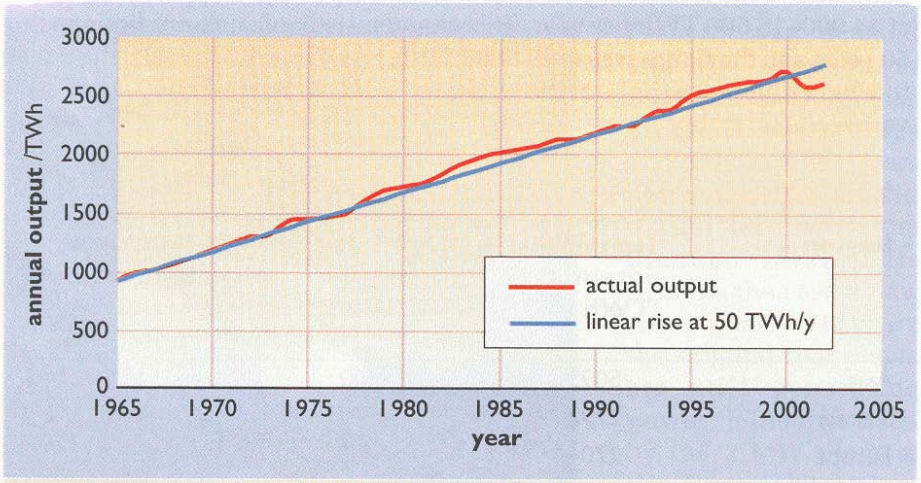


Figure 5.4 World annual hydroelectricity output, 1965–2002 (source: BP, 2003)

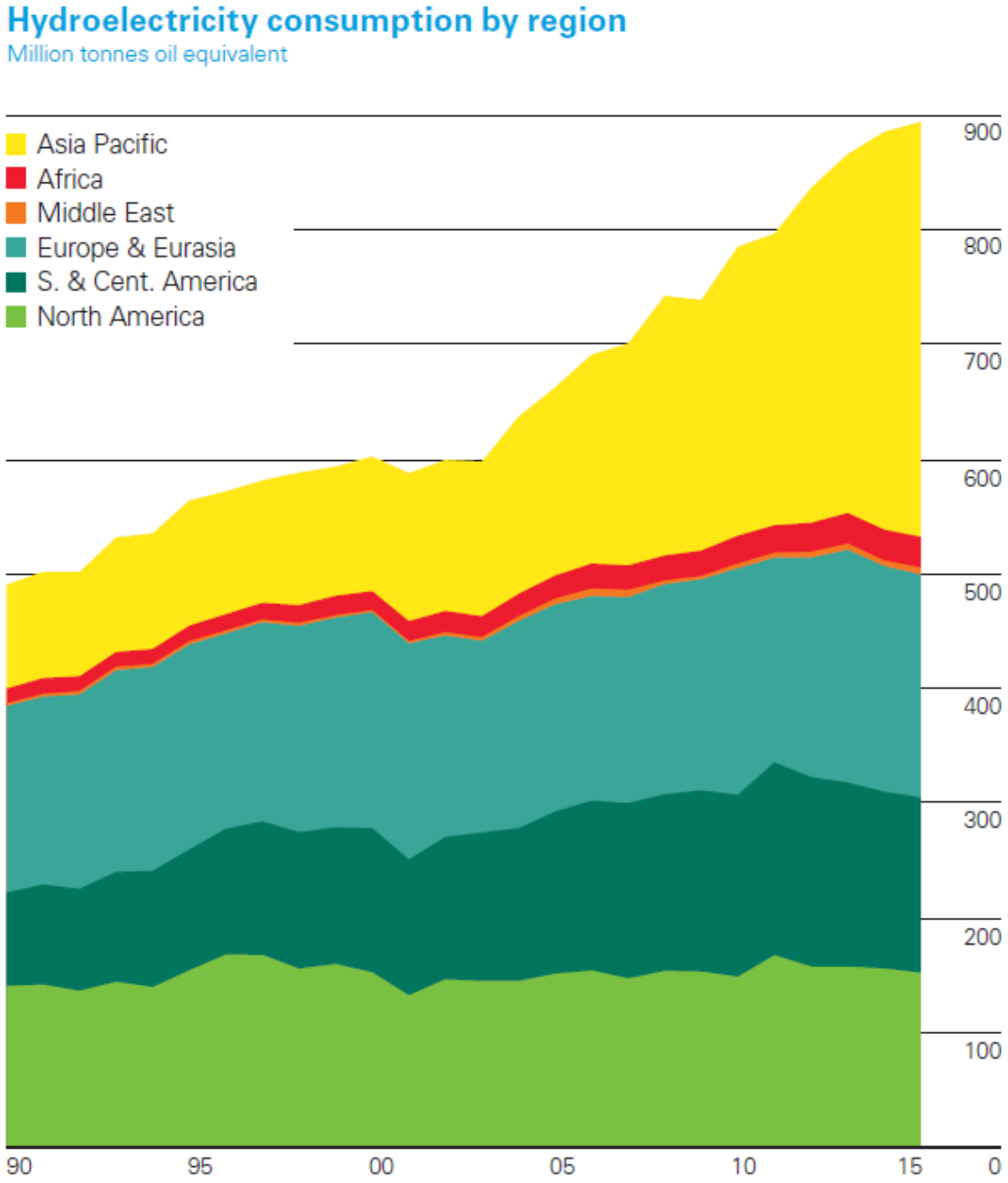
Table 5.4 National hydro contributions

country	output* (TWh y^{-1})
Canada	345
Brazil	288
USA	264
China	231
Russia	167
Norway	129
Japan	91
India	76
Sweden	74
France	74
Venezuela	61
Italy	51
Austria	42
Switzerland	40
Spain	35
Rest of the World	626
World	2593

* Average over four years, 1999–2002

Source: BP, 2003

- John Andrews and Nick Jelley, Energy science – principles, technologies, and impacts, Oxford University Press, 2007.
- Godfrey Boyle (ed.), Renewable Energy – power for a sustainable future, 2nd ed., Oxford University Press, 2004.

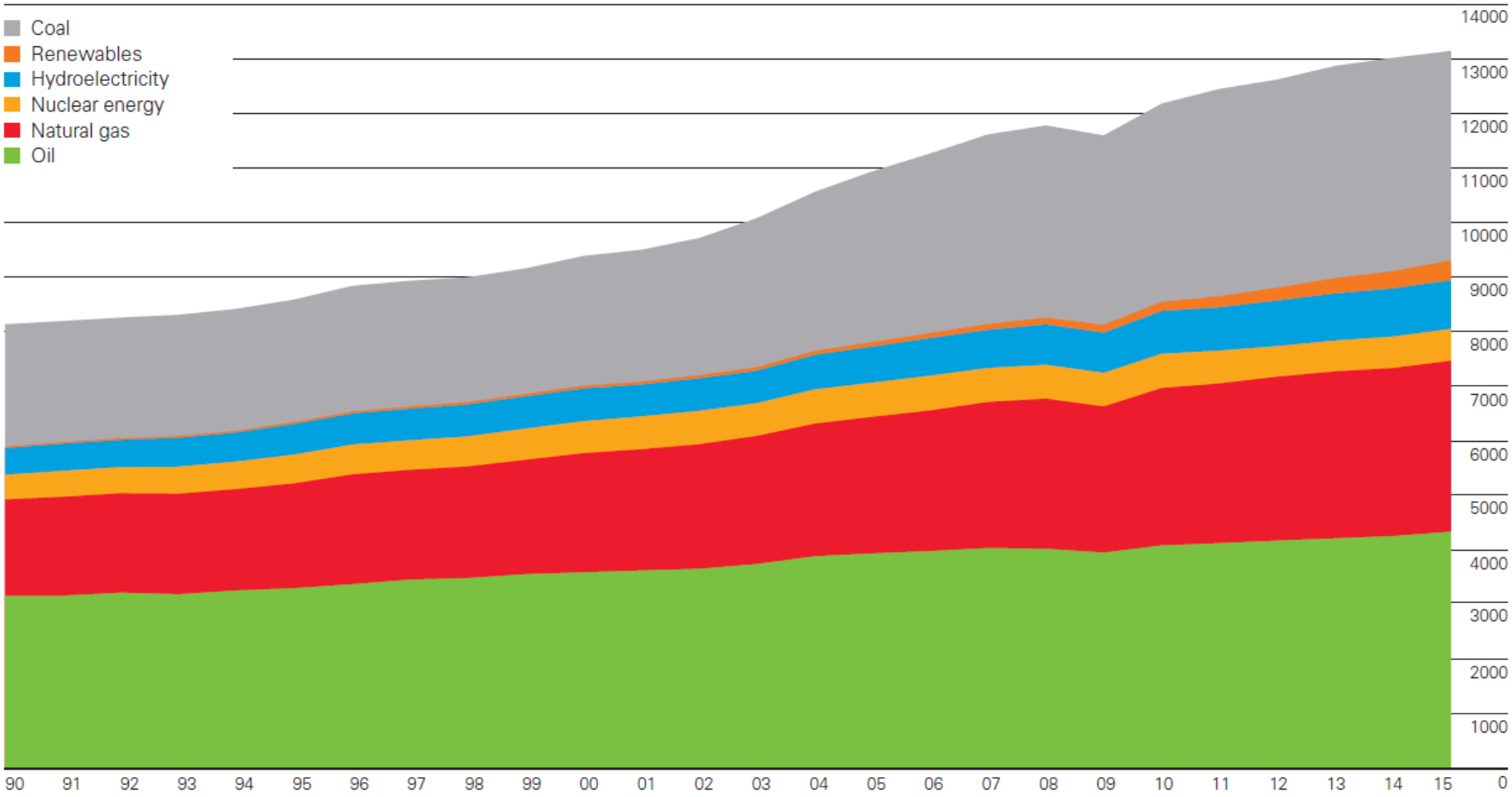


World hydroelectric output grew by a below-average 1%. With the Asia Pacific region accounting for all of the growth, even though the region's growth was just over half the 10-year average

BP Statistical Review of World Energy June 2016/bp.com/statisticalreview

World consumption

Million tonnes oil equivalent



World primary energy consumption grew by a below-average 1.0% in 2015, the slowest rate of growth since 1998 (other than the decline in the aftermath of the financial crisis). Growth was below average in all regions except Europe & Eurasia. All fuels except oil and nuclear power grew at below-average rates. Oil remains the world's dominant fuel and gained global market share for the first time since 1999, while coal's market share fell to the lowest level since 2005. Renewables in power generation accounted for a record 2.8% of global primary energy consumption.

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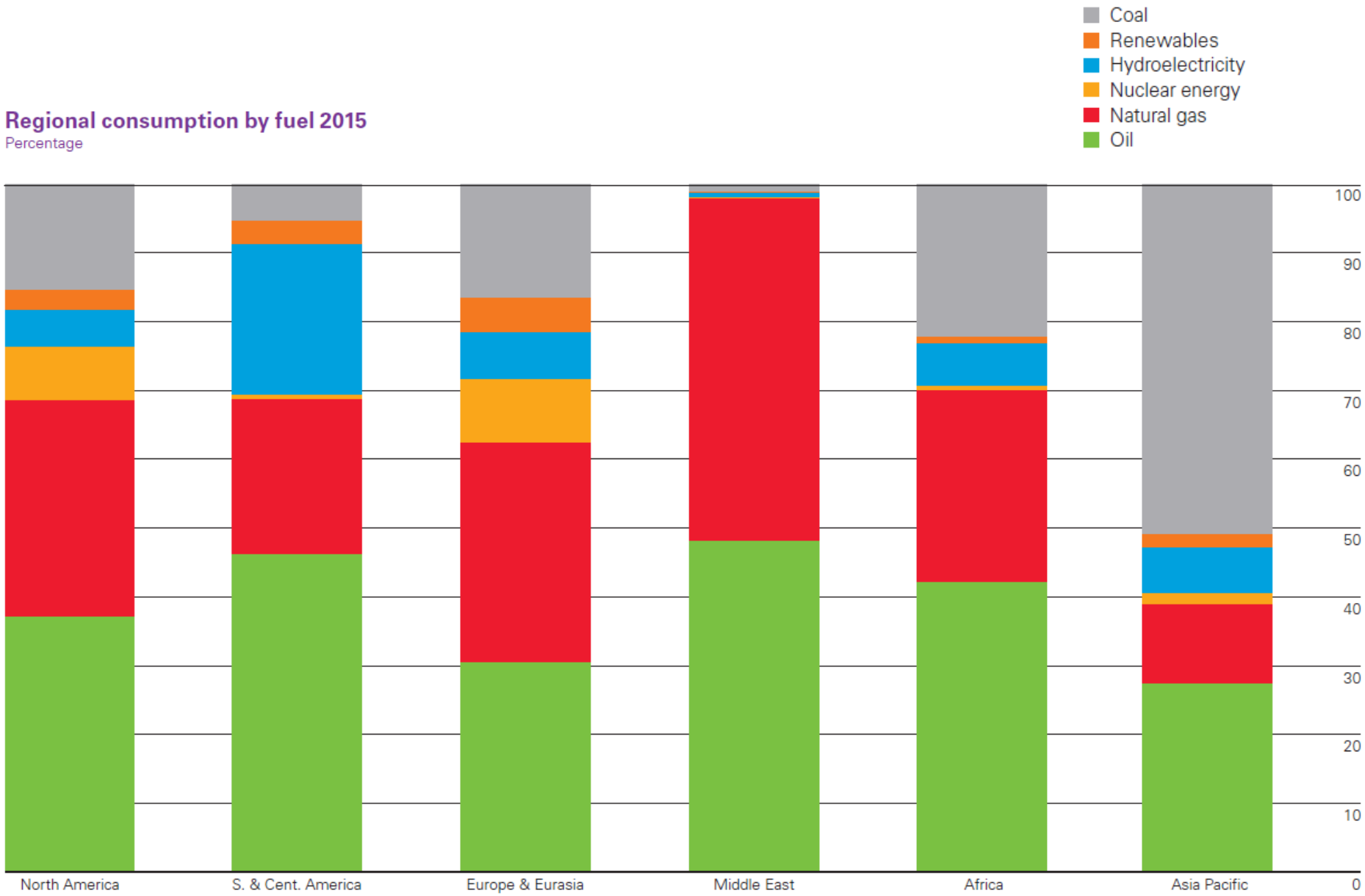
Regional consumption by fuel 2015

Percentage



Oil remains the dominant fuel in Africa and the Americas, while natural gas dominates in Europe & Eurasia and the Middle East. Coal is the dominant fuel in the Asia Pacific region, accounting for 51% of regional energy consumption – the highest share of any fuel for any region. Europe & Eurasia is the only region with no fuel reaching one-third of the total energy mix. The Middle East has the least diverse fuel mix, with oil and gas combined accounting for 98% of energy consumption.

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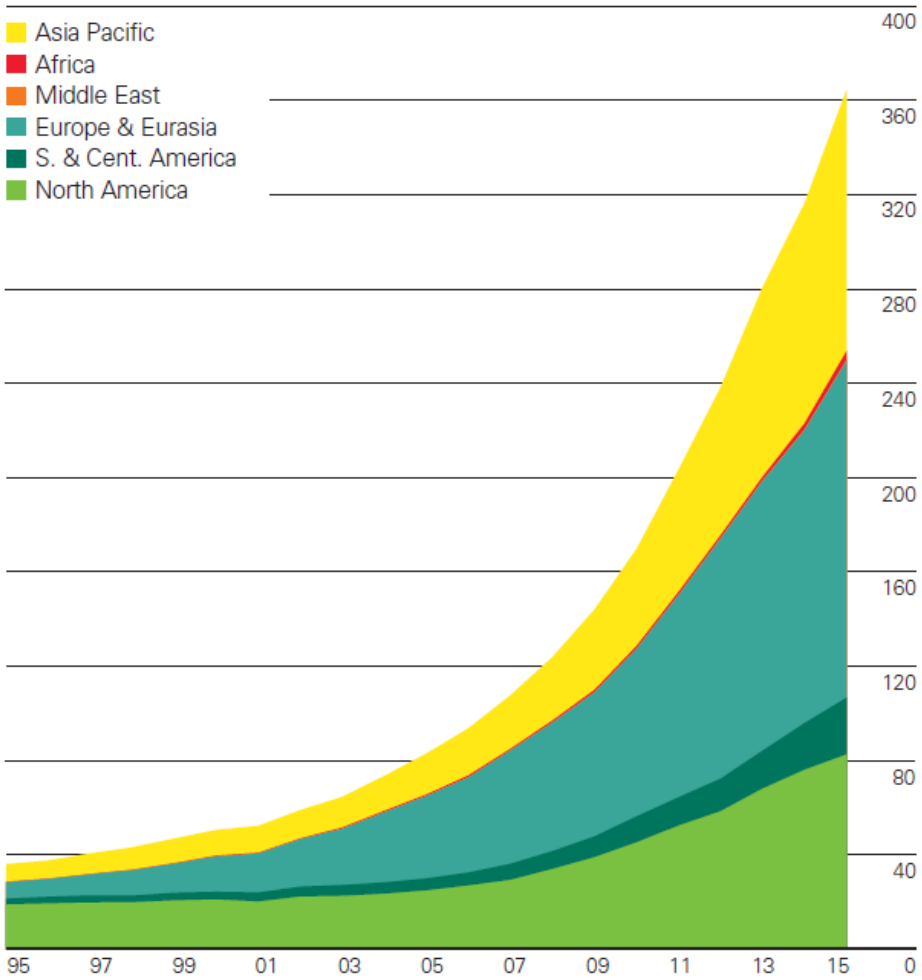
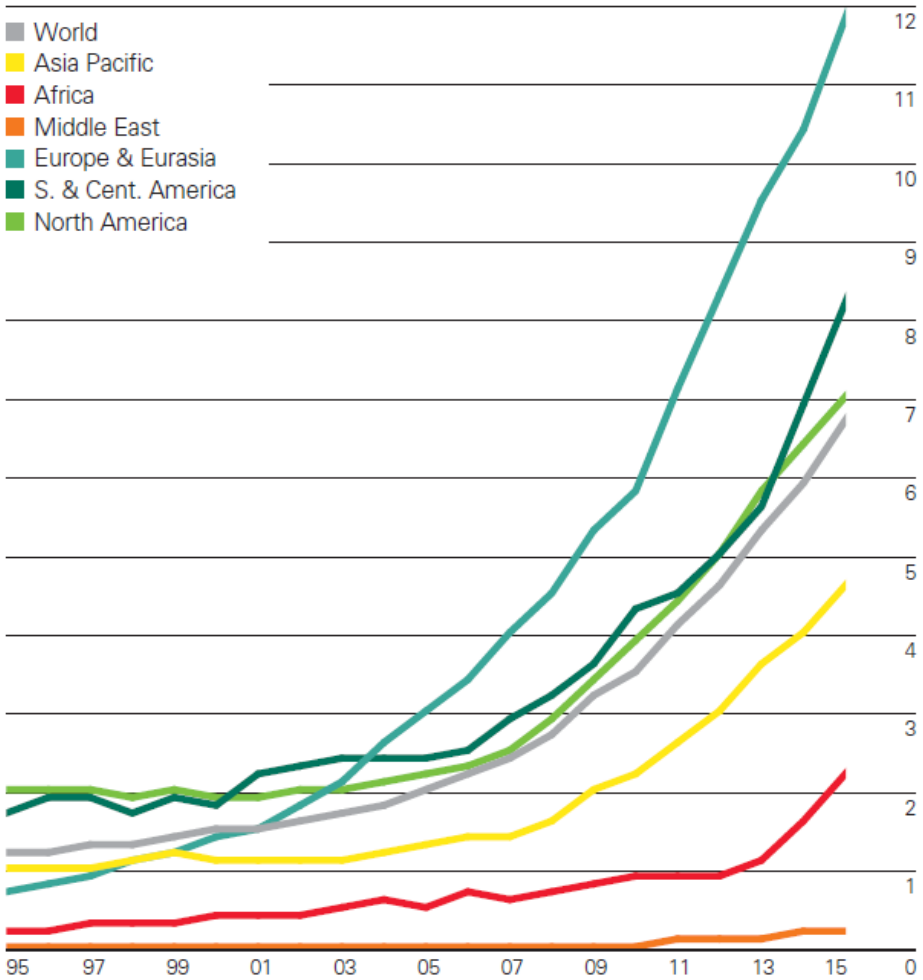
Other renewables consumption by region

Million tonnes oil equivalent



Other renewables share of power generation by region

Percentage



Renewable energy in power generation grew by 15.2%, slightly below the 10-year average growth rate, but the largest increment on record (+48 mtoe). Globally, wind provided the largest growth increment (+28 mtoe), but solar had the highest growth rate (+32.6%). Regionally, Europe & Eurasia and Asia Pacific provided the largest growth increments (+18.8 mtoe and 17.5 mtoe, respectively). Non-hydro renewable energy accounted for 6.7% of global power generation in 2015, up from 2% a decade ago. The Europe & Eurasia region has the highest share of power from renewables, at 11.9% (reaching 18.6% in the EU).

Hydroelectric: Industrial revolution

Radial outflow turbines (axial inflow) **80% efficiency**

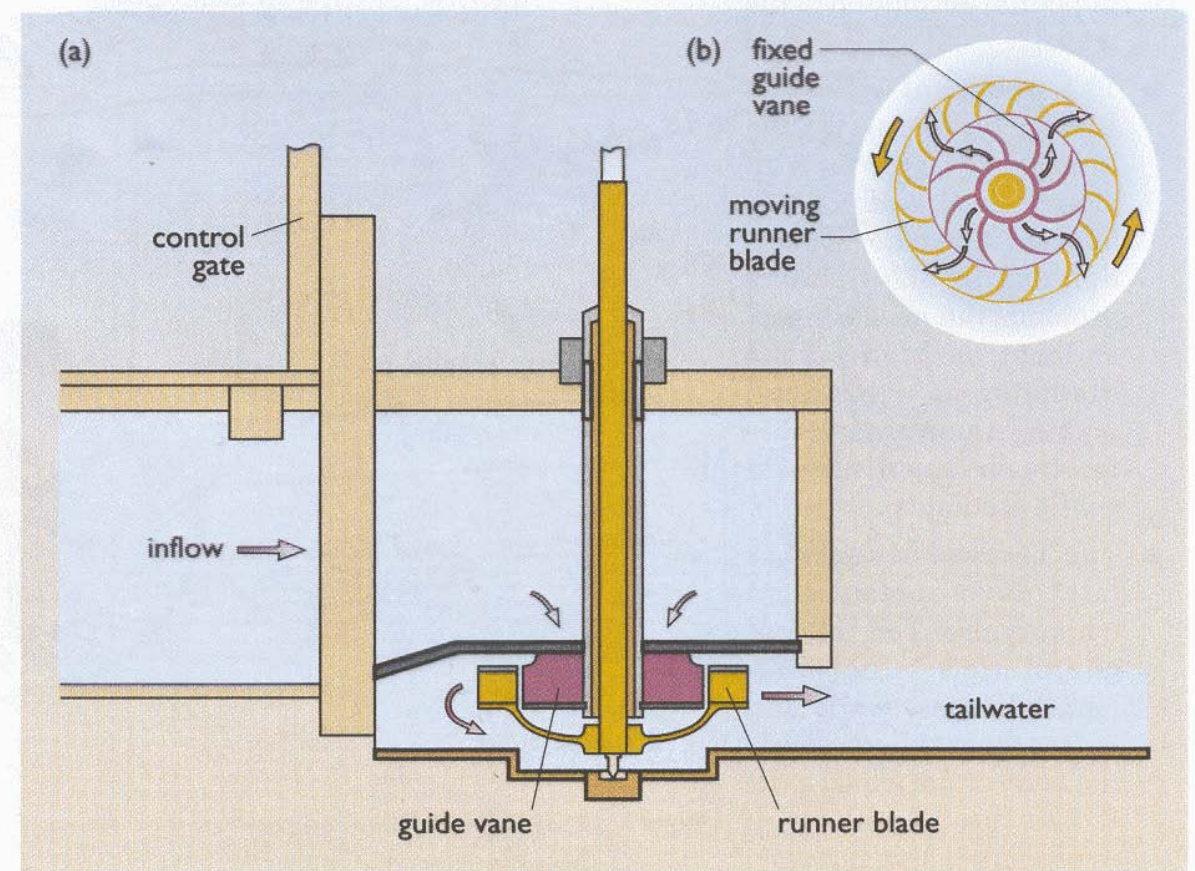


Figure 5.10 Fourneyron's turbine. The runner consists of a circular plate with curved blades around its rim and a central shaft. It spins under the force exerted by water flowing outwards between the fixed guide vanes and across its blades: (a) vertical section; (b) flow across guide vanes and runner

Hydroelectric: Industrial times

Radial inflow turbines (axial outflow)

Figure 5.17 The 450 kW horizontal-axis Francis turbine of a small-scale plant in Scotland, commissioned in 1993. The inflow (at lower right) is 2.1 $m^3 s^{-1}$ at a head of 25 m. The turbine, rotating at 750 rpm, drives the generator whose casing can be seen on the left

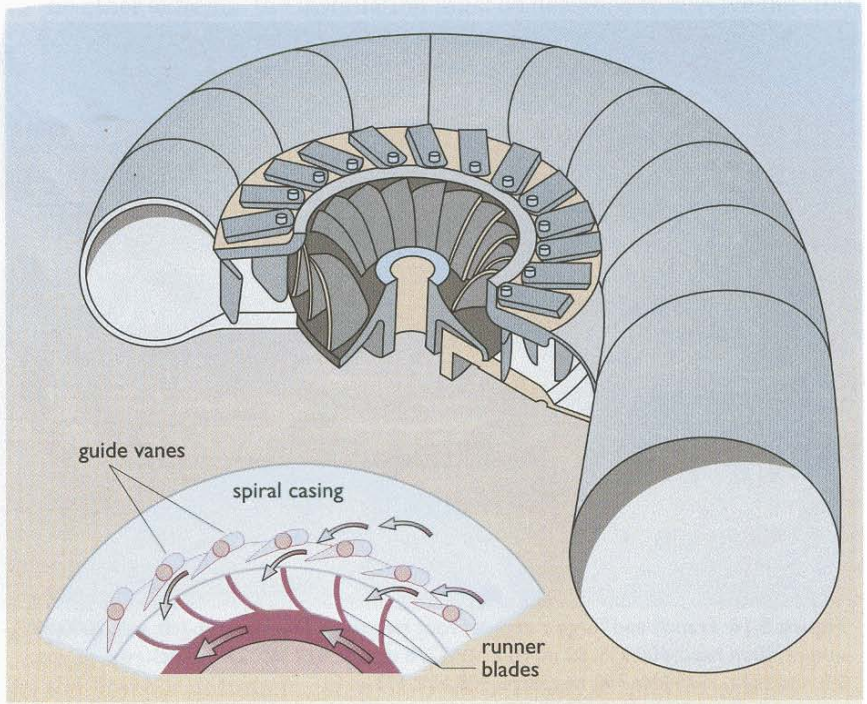


Figure 5.18 Francis turbine: (a) cut-away diagram; (b) flow across guide vanes and runner

Hydroelectric: Industrial times

Axial flow, ducted propeller type

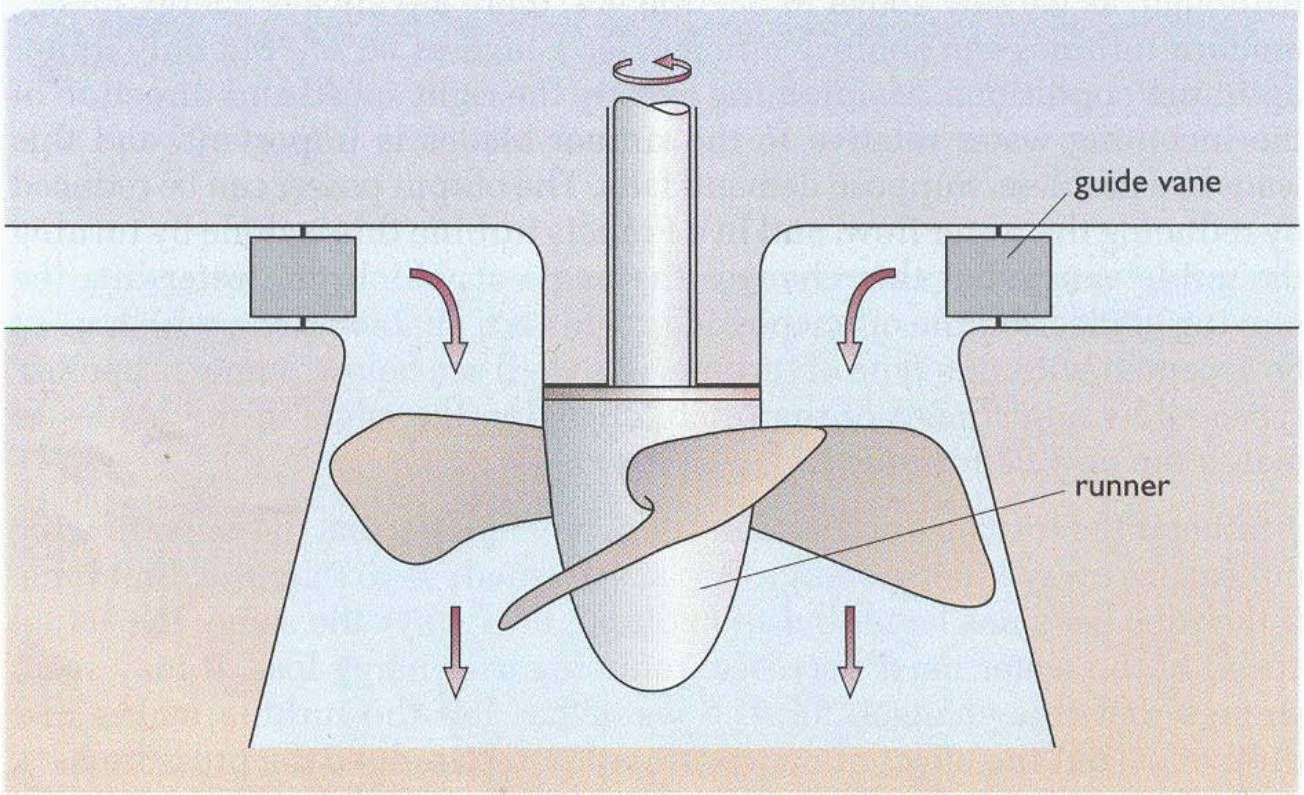


Figure 5.19 A 'propeller' or axial-flow turbine

Suitable for low head, large volume flow; Simpler to vary efficiency

Hydroelectric: Industrial times

Pelton wheels

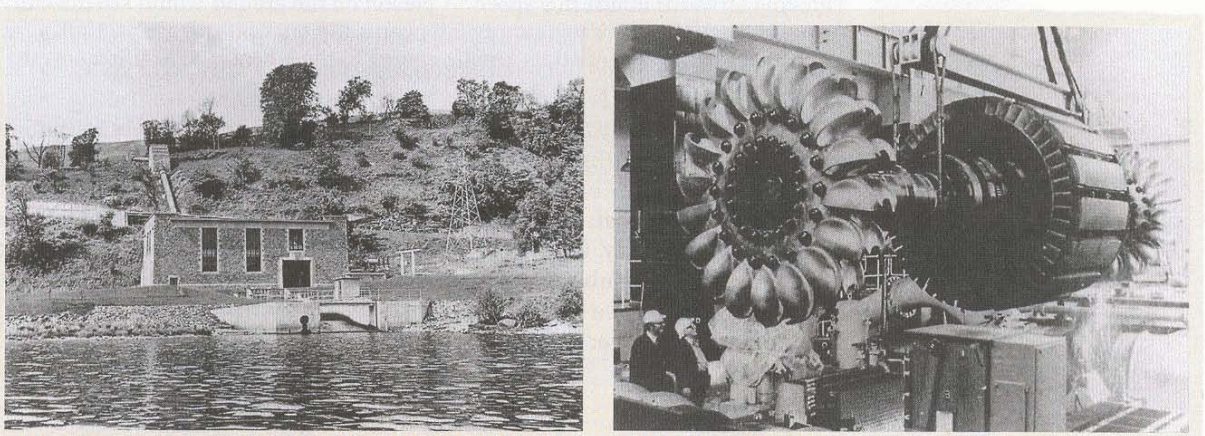


Figure 5.20 Finlarig power station, on the shores of Loch Tay, Scotland draws its water from Loch na Lairige at a gross head of 415 metres. Its average annual output is 64 million kWh. Left: the power station; Right: the original double twin-jet Pelton wheel and horizontal-axis 30 MW generator

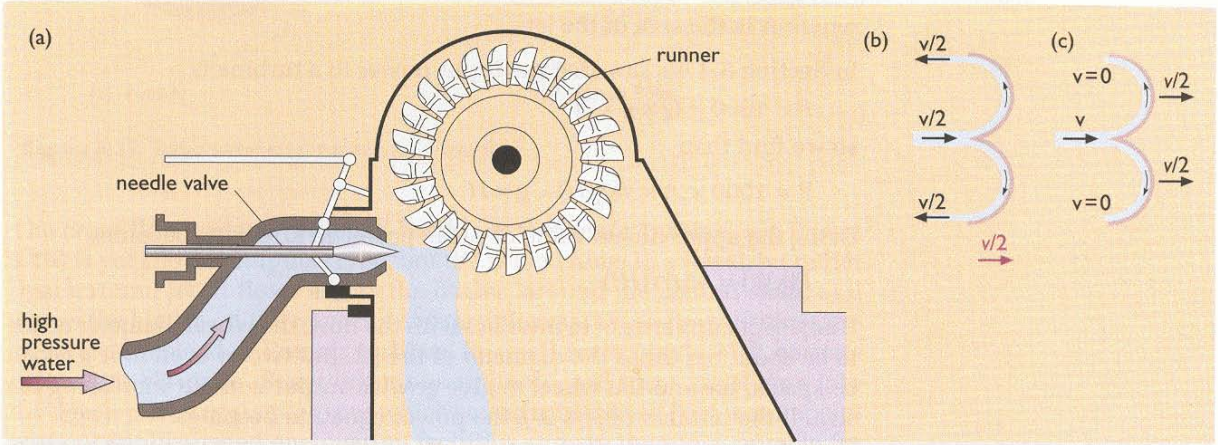


Figure 5.21 Pelton wheel turbine: (a) vertical section; (b) water flow as seen from moving cup; (c) actual motion of water and cup

Suitable for high head; Control?

Hydroelectric: Industrial times

Mixed flow

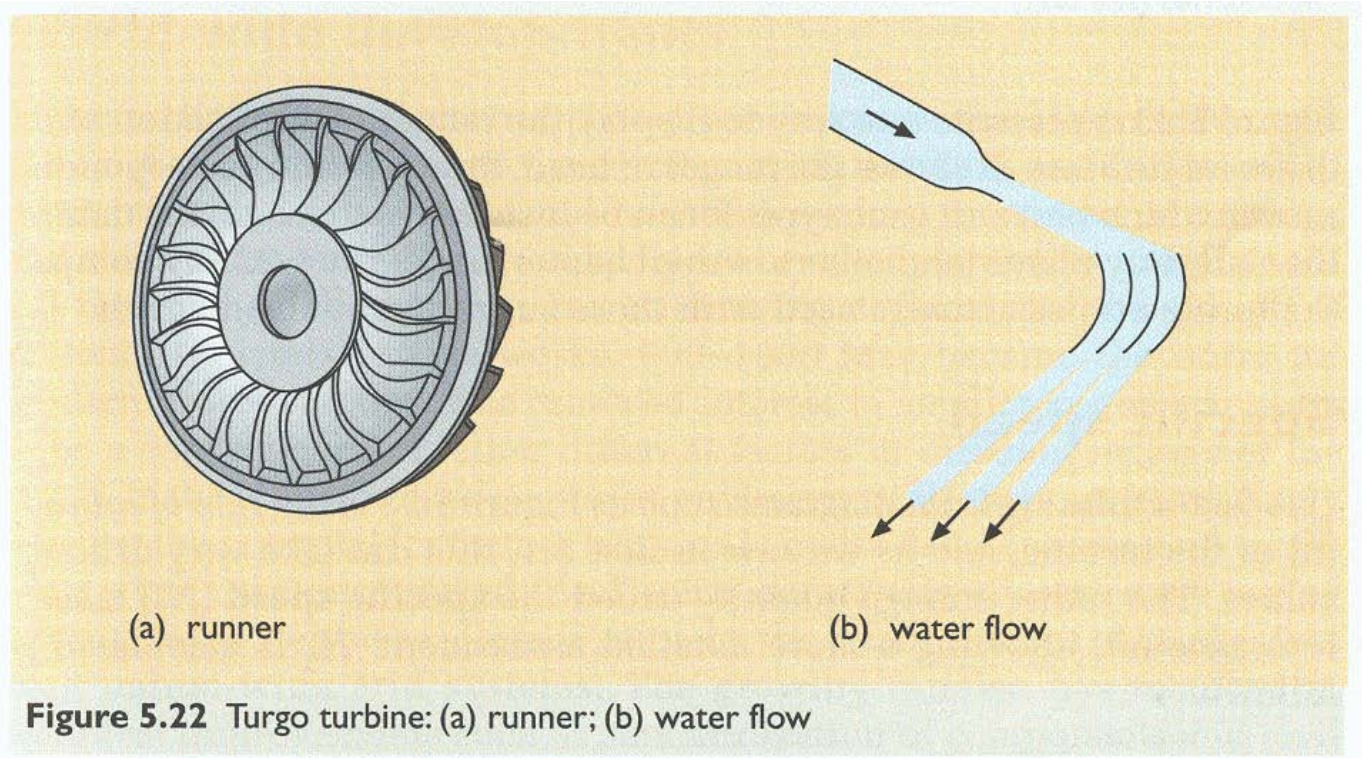


Figure 5.22 Turgo turbine: (a) runner; (b) water flow

Hydroelectric

Head [m], versus flow [kg/s, m^3/s]

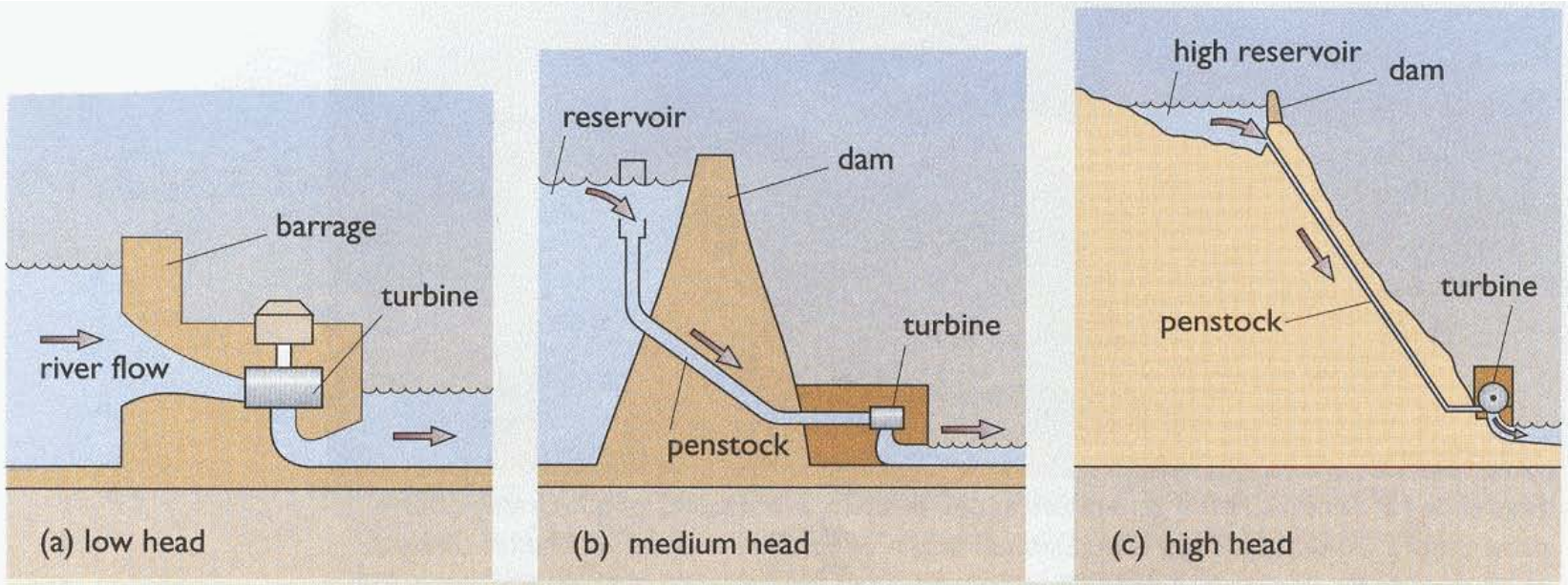


Figure 5.13 Types of hydroelectric installation

Hydroelectric

Types of water turbine impeller

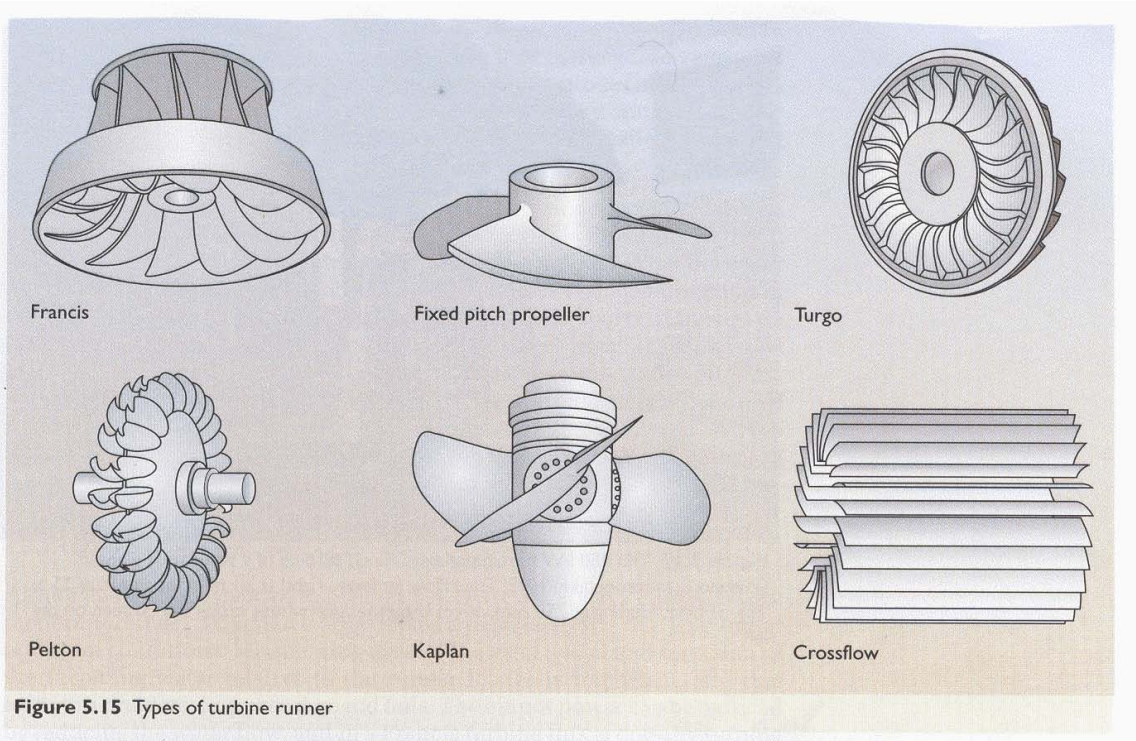


Figure 5.15 Types of turbine runner

Figure 5.16 Francis and Turgo runners. Front two rows, Francis, from left: pair, 2000 kW output, 80 m head; 600 kW, 80 m; 10.2 MW, 278 m; pair, 412 kW, 29 m. Back row, Turgos: left and right, 1575 kW, 190 m; centre, 428 kW, 175 m

Hydroelectric: how to choose impellers

Specific diameter versus specific speed

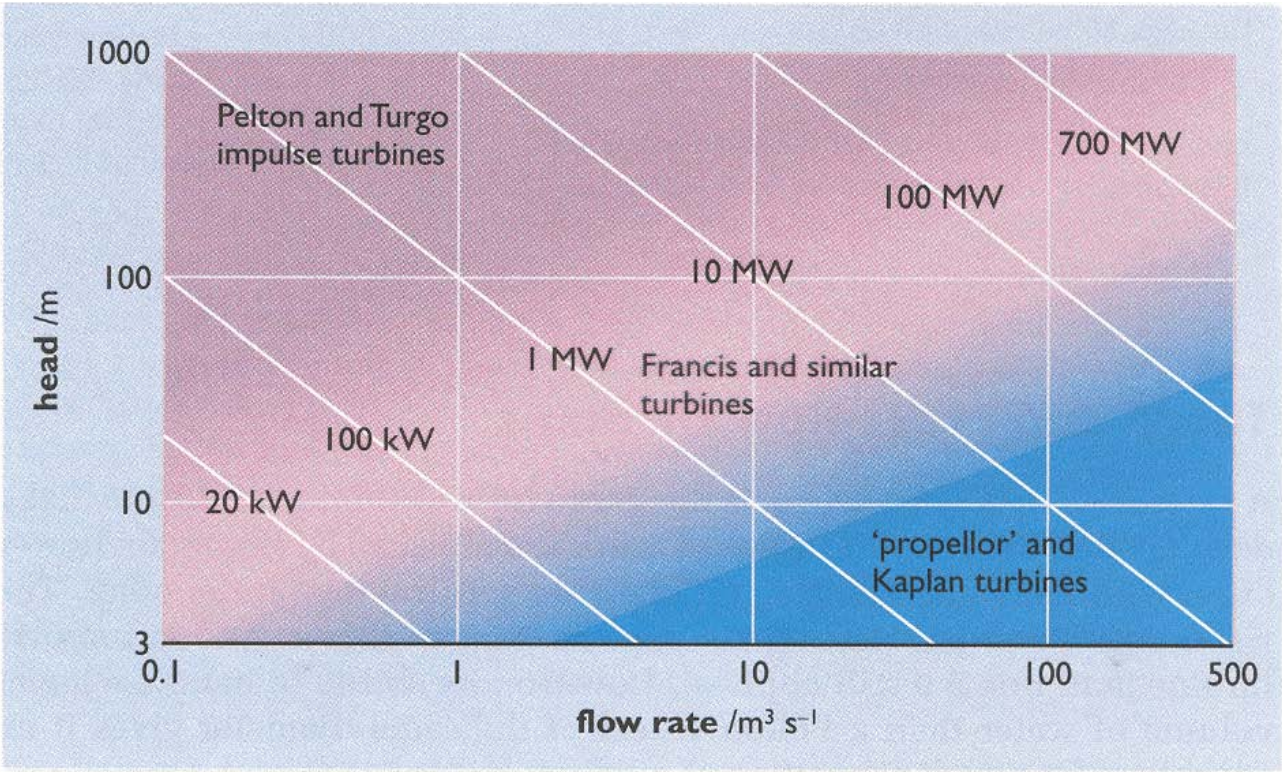


Figure 5.23 Ranges of application of different types of turbine. Note the overlap at the boundaries (see text)

Hydro power: Storage

Characteristic of renewable energy?

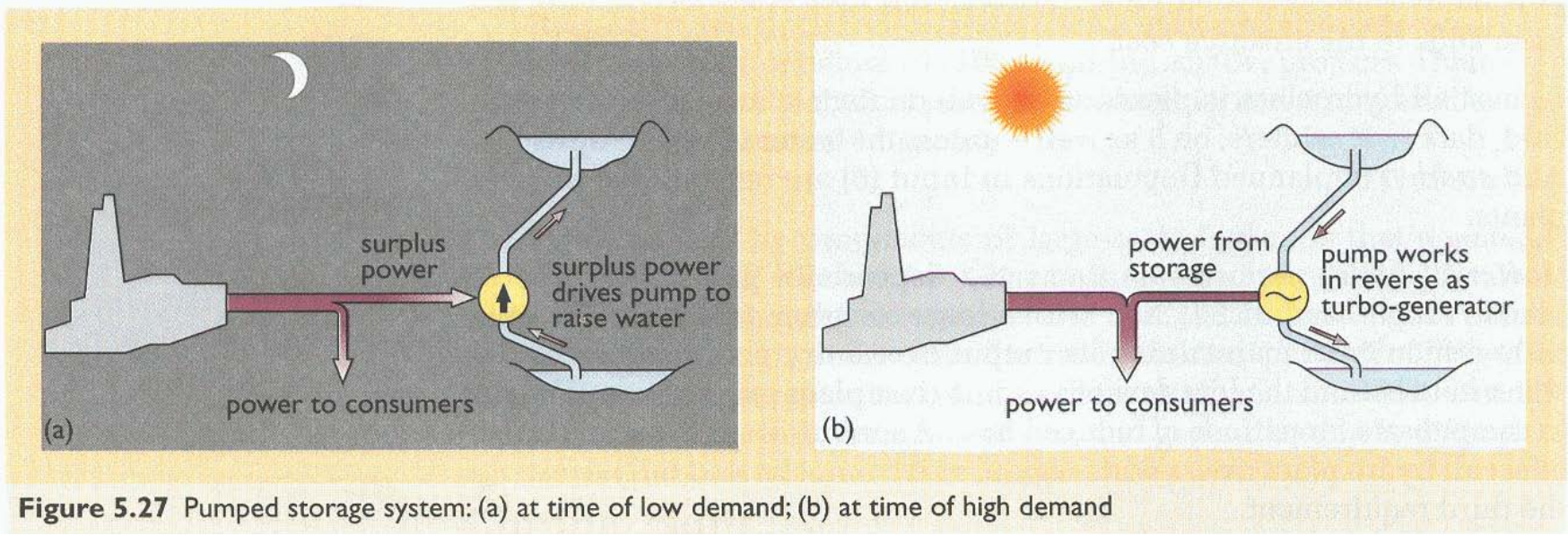
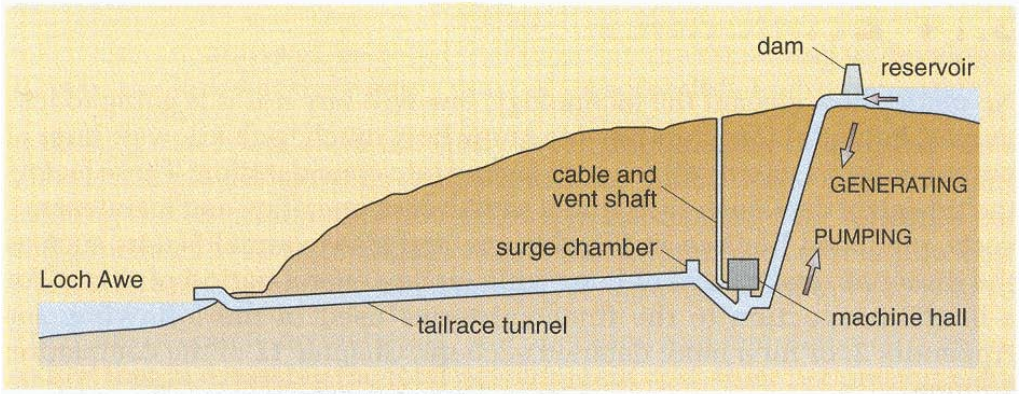


Figure 5.27 Pumped storage system: (a) at time of low demand; (b) at time of high demand

Hydro power: Storage



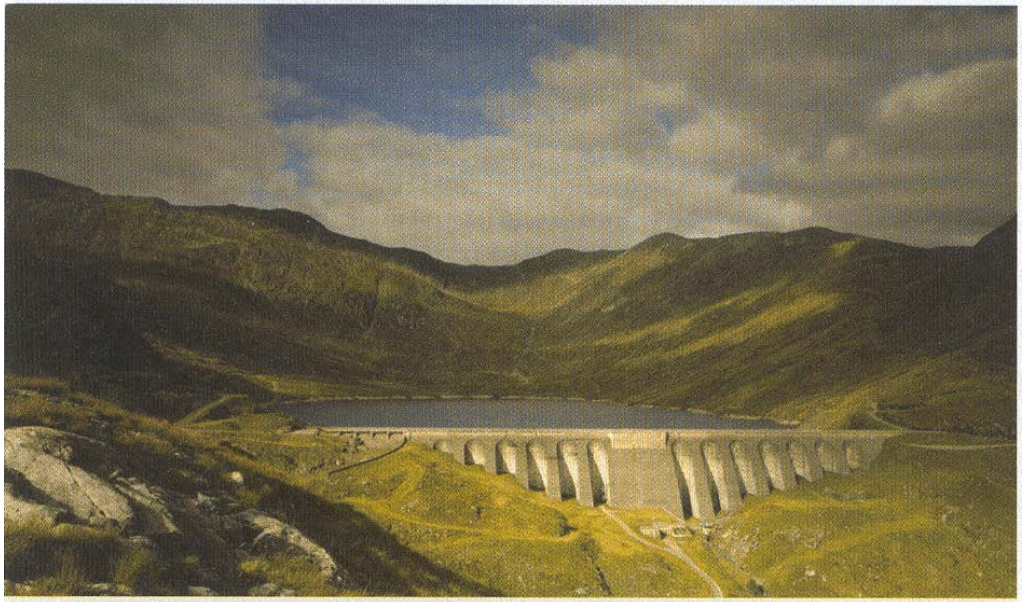


Figure 5.28 Cruachan pumped storage plant. The reservoir of this Scottish plant, commissioned in 1965, can store 10 million cubic metres of water at an operating head of about 370 m. Running the four 100 MW reversible machines for an hour at full capacity, as electric pumps or turbo-generators, raises or lowers reservoir level by about a metre. (top) the installation; (bottom) the dam