Energy Resources

Dr. Fahad Noor
Assosciate Professor
f.noor@uet.edu.pk

Engr. Adnan Qamar
Lecturer
adnan@uet.edu.pk

Fossil Energy Resources

A fuel (such as coal, oil, or natural gas) that is formed in the earth from dead plants or animals

Any combustible organic material, as oil, coal, or natural gas, derived from the remains of former life

Ancient organic remains (fossils) in sediments which became sedimentary rock, giving rise to solid, liquid, and gaseous fuels such as coal, crude oil, and natural gas.

Coal is derived from vegetable matter altered by pressure, whereas crude oil and natural gas are derived from animal and vegetable matter altered by pressure and heat.

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Coal:

Coal is an organic rock it contains mostly carbon (C), but it also has hydrogen (H), oxygen (O), sulfur (S) and nitrogen (N), as well as some inorganic constituents (minerals) and water (H_2O).

Coal is the altered remains of prehistoric vegetation that originally accumulated in swamps and peat bogs.

Coal formation began during the Carboniferous Period – known as the first coal age – which spanned 360 million to 290 million years ago

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Coal Formation:

Coal was formed from prehistoric plants, in marshy environments, some tens or hundreds of millions of years ago. The presence of water restricted the supply of oxygen and allowed thermal and bacterial decomposition of plant material to take place, instead of the completion of the carbon cycle. Under these conditions of anaerobic decay, in the so-called biochemical stage of coal formation, a carbon-rich material called *peat was formed.*

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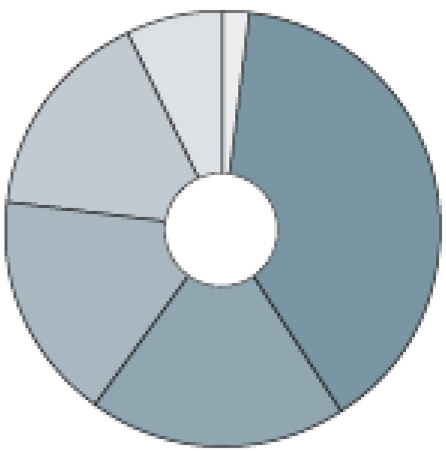
Coal Formation:

Total World Electricity Generation (% by Fuel, 2002)



Coal	39%
Gas	19%
Nuclear	17%
Hydro	16%
Oil	7%
Other*	2%

**Other includes solar, wind, combustible renewables, geothermal and waste*

Source: IEA 2004

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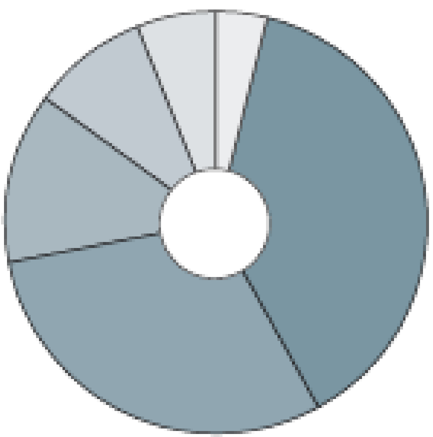
Coal Formation:

Total World Electricity Generation (% by Fuel, projected for 2030)



Coal	38%
Gas	30%
Hydro	13%
Nuclear	9%
Other*	6%
Oil	4%

** Other includes solar, wind, combustible renewables, geothermal and waste*

Source: IEA 2004

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Coal Formation:

Swamps with giant plants hundreds of millions of years ago covered the earth.

Water and dirt covered the plant remains 100 million years ago.

Rocks, dirt and sediment created pressure and heat to form coal deep in the ground.

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Coal Characterization:

TABLE 7-1
Carbon content and age of different coals

Coal type	Approximate age (years)	Approximate carbon content, %
Lignites	60,000,000	65-72
Subbituminous coals	100,000,000	72-76
Bituminous coals	300,000,000	76-90
Anthracites	350,000,000	90-95

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Coal Characterization:

	<---------- Low Rank ------->		<---- High Rank ------------->	
Rank:	Lignite	Subbituminous	Bituminous	Anthracite
Age:	--------------------------------- increases --------------------------------->			
% Carbon:	65-72	72-76	76-90	90-95
% Hydrogen:	~5 ---------------------- decreases ---------------------- ~2			
% Nitrogen:	<----------------------------------- ~1-2 ----------------------------------->			
% Oxygen:	~30 --------------------- decreases ---------------------- ~1			
% Sulfur:	~0 ----------- increases ----------- ~4 --- decreases --- ~0			
%Water:	70-30	30-10	10-5	~5
Heating value (BTU/lb):	~7000	~10,000	12,000–15,000	~15,000

FIGURE 7-3. Variation of selected coal properties with coal rank.

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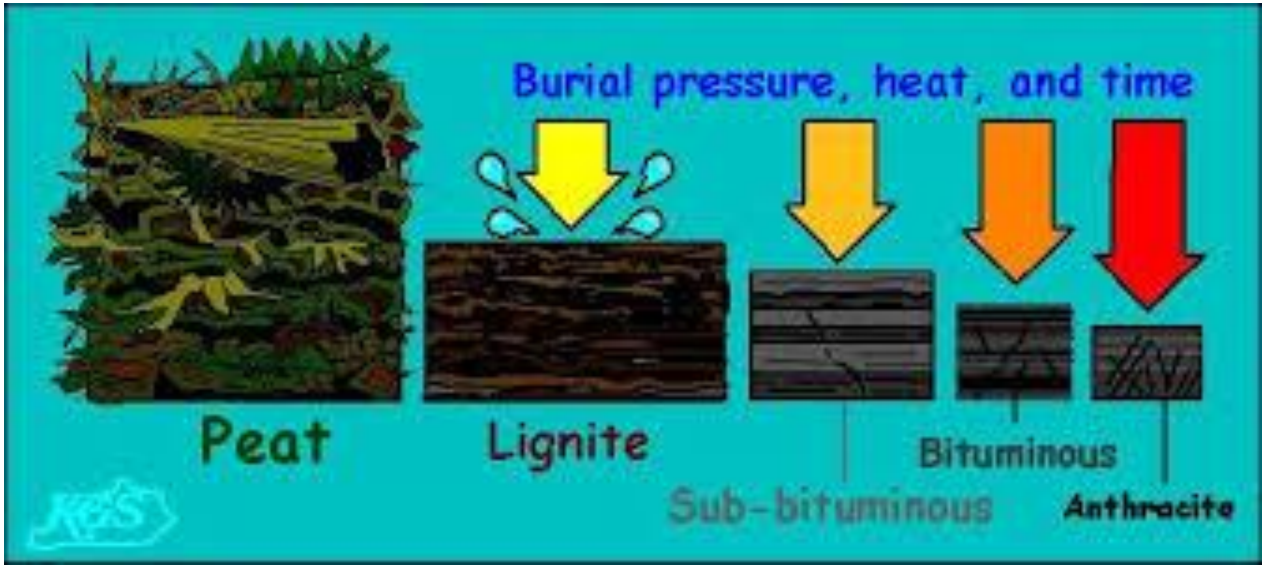
Coal Characterization:



The degree of change undergone by a coal as it matures from peat to anthracite known as coalification.

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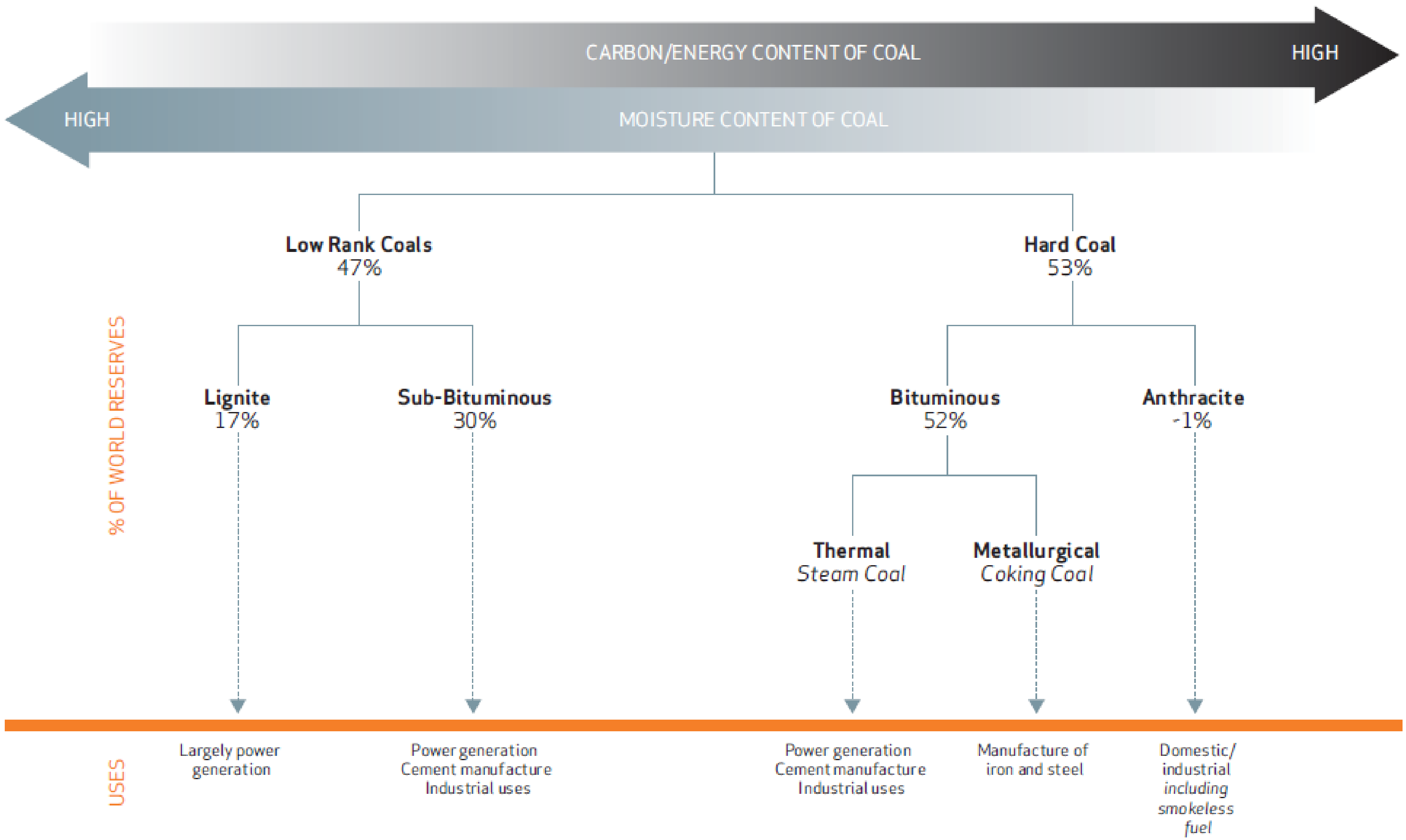
Coal Characterization:



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Coal Characterization:

Low rank coals, such as lignite and subbituminous coals are typically softer, friable materials with a dull, earthy appearance. They are characterized by high moisture levels and low carbon content, and therefore a low energy content.

Higher rank coals are generally harder and stronger and often have a black, vitreous luster. They contain more carbon, have lower moisture content, and produce more energy.

Anthracite is at the top of the rank scale and has a correspondingly higher carbon and energy content and a lower level of moisture

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Coal Analysis:

Ultimate (elemental) Analysis: Elemental or ultimate analysis encompasses the quantitative determination of Carbon, hydrogen, nitrogen, sulfur and oxygen within the coal.

Proximate Analysis: moisture, volatile matter, ash, and fixed carbon.

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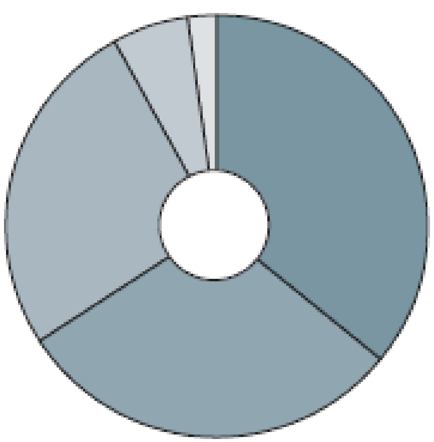
Coal Reserves:

It has been estimated that there are over 984 billion tonnes of proven coal reserves worldwide. This means that there is enough coal to last us over 190 years.

Coal Reserves Showing Regional Shares (at end of 2003)



Europe and Eurasia	36%
Asia Pacific	30%
North America	26%
Africa	6%
South and Central America	2%

Middle East coal reserves less than 1% of total reserves

Source: BP 2004

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Coal Reserves:

The United States, former Soviet Union and China together possess more than 80% of the ultimately recoverable resources.

Amount of heat required to raise the temperature of one pound of water (at or near 39.2 degrees Fahrenheit) by one degree Fahrenheit.

1 BTU=252 Calories= 1055.06 Joules

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Coal Reserves:

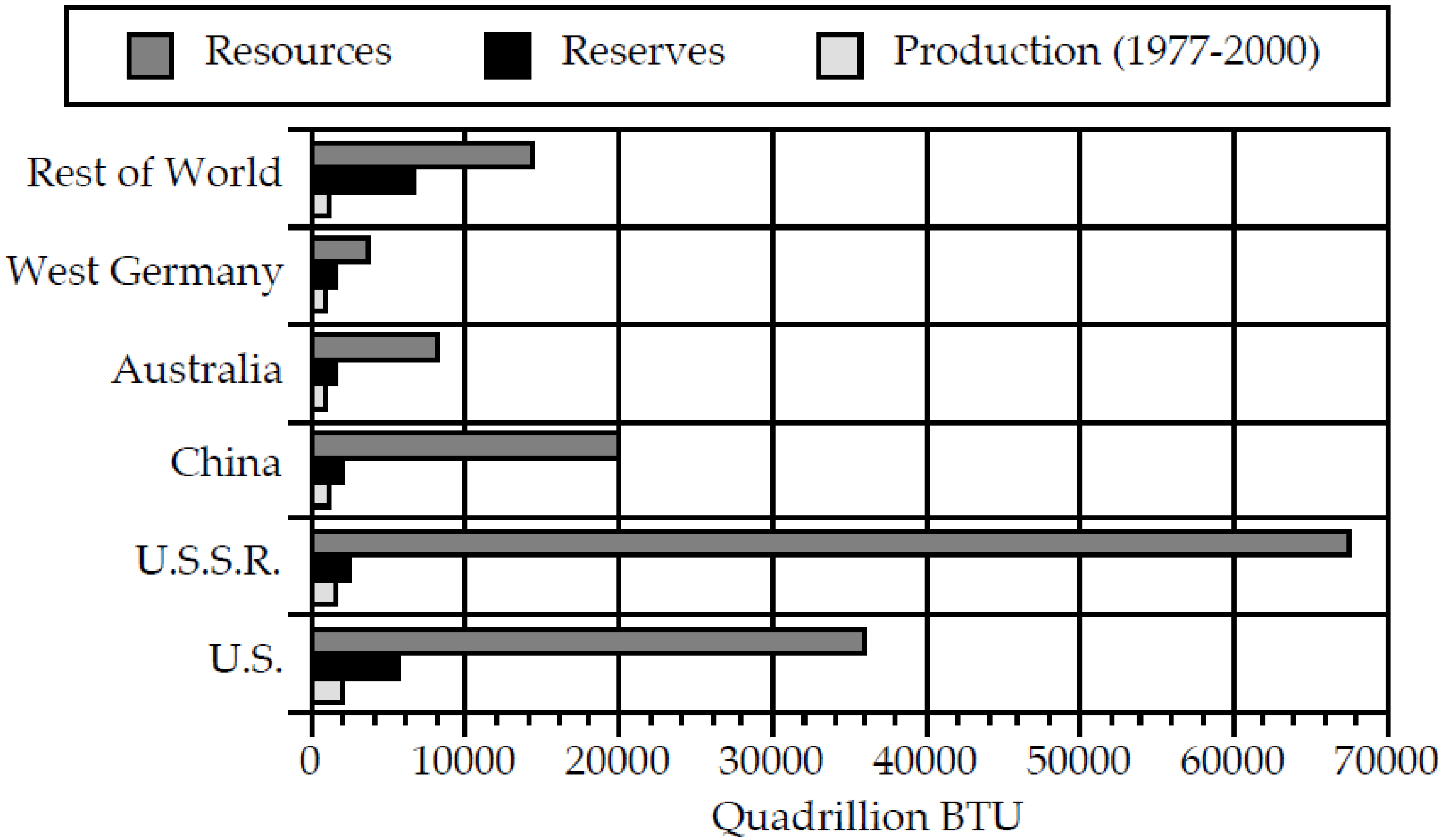

FIGURE 7-1. World distribution of coal resources and reserves.
[Source: W. Fulkerson et al., *Scientific American*, September 1990, p. 129.]

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Coal Reserves:

Resource

The amount of coal that may be present in a deposit or coalfield. This does not take into account the feasibility of mining the coal economically. Not all resources are recoverable using current technology.

Reserves

Reserves can be defined in terms of proved (or measured) reserves and probable (or indicated) reserves. Probable reserves have been estimated with a lower degree of confidence than proved reserves.

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How long will it last: Answer is not that straight forward

- Exact quantity is not known
- Advancement in mining technology may enhance productivity
- Not easy to predict rate of utilization

Assumptions:

No new coal reserves will be found

No new mining technologies will be developed

All available coal will be burned regardless of Quality

The annual coal consumption will increase at 5% per year (that is, it will double every 14 years)

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Coal Utilization:

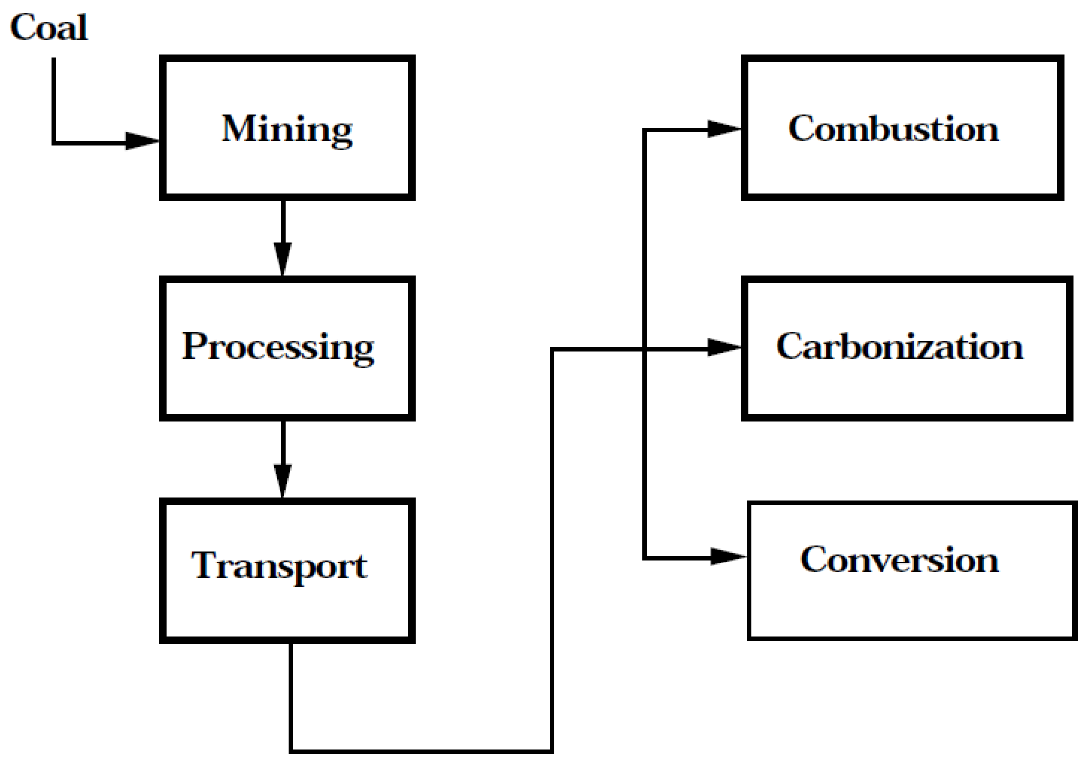

FIGURE 7-4
Pathways to coal utilization.

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Coal Mining:

Surface/Strip/Opencast Mining

Highly efficient and highly productive method

Controversial from environmental point of view

Underground/deep Mining

Less productive

Highly mechanized

Air must be kept safe

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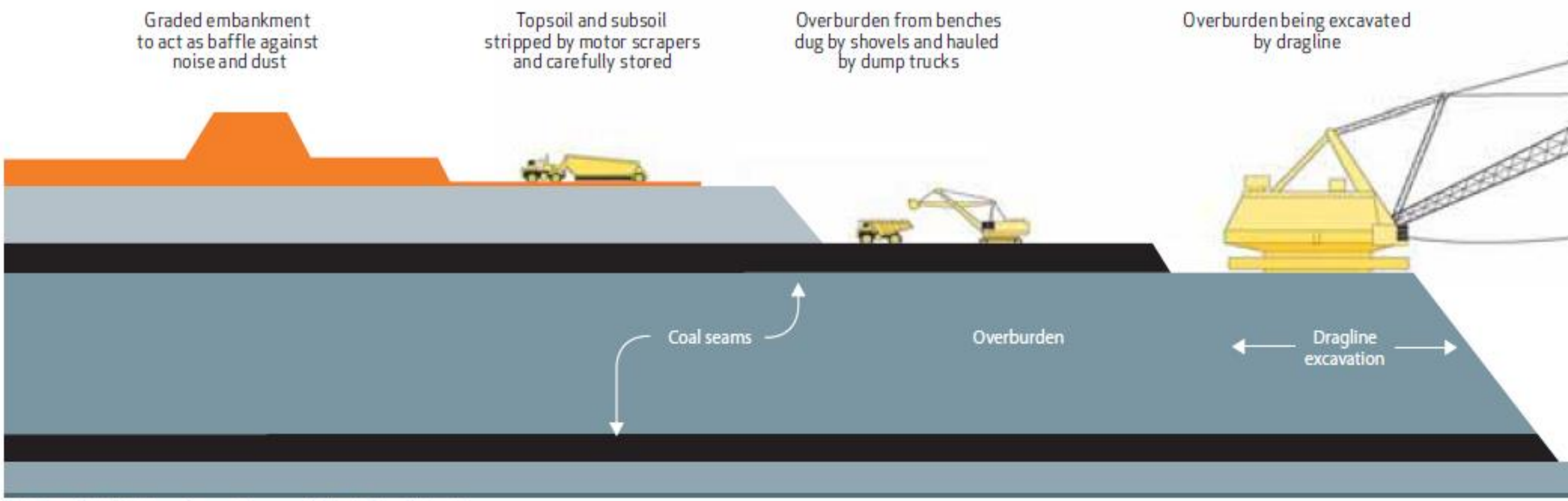
Coal Mining:



Surface Coal Mining Operations and Mine Rehabilitation

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Coal Mining:

The choice of mining method is largely determined by the geology of the coal deposit.

Underground mining currently accounts for about 60% of world coal production, although in several important coal producing countries surface mining is more common.

The choice of mining technique is site specific but always based on economic considerations; differences even within a single mine can lead to both methods being used.

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Coal processing:

Coal straight from the ground, known as run-of-mine (ROM) coal, often contains unwanted impurities such as rock and dirt and comes in a mixture of different-sized fragments. However, coal users need coal of a consistent quality.

Once the coal has been mined, it is usually processed to separate the inorganic, ash-forming components and to produce appropriately sized particles. The various operations involved in this processing are collectively known as **coal preparation** or **coal beneficiation.**

The treatment depends on the properties of the coal and its intended use.

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Coal Transportation:

After the coal has been prepared, it will be transported to the point of use. It may then be stored at the plant site for some time before being consumed. Transportation of coal is efficient but very expensive process.

Coal is generally transported by conveyor or truck over short distances. Trains and barges are used for longer distances

within domestic markets, or alternatively coal can be mixed with water to form a coal slurry and transported through a pipeline.

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Coal Transportation:

Ships are commonly used for international transportation, in sizes ranging from Handymax (40-60,000 DWT), Panamax (about 60-80,000 DWT) to large Capesize vessels (about 80,000+ DWT). Around 700 million tonnes (Mt) of coal was traded internationally in 2003 and around 90% of this was seaborne trade. Coal transportation can be very expensive – in some instances it accounts for up to 70% of the delivered cost of coal.

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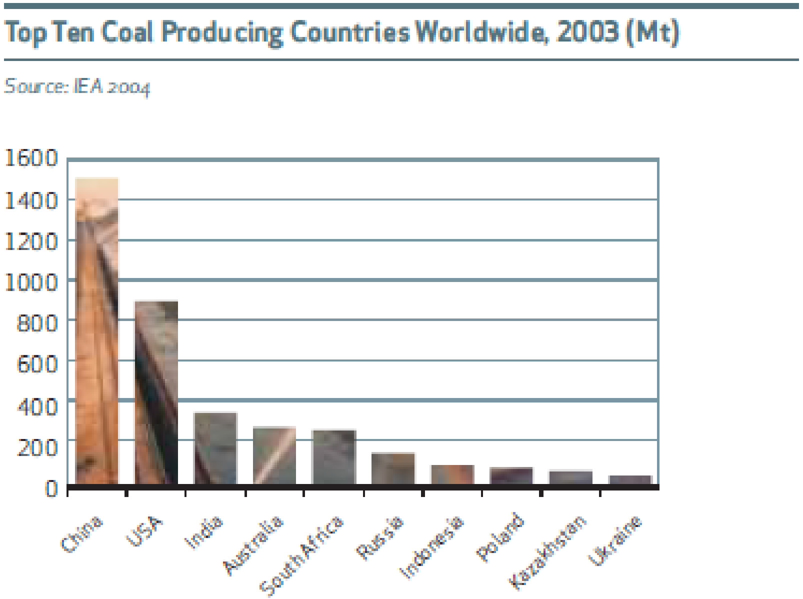
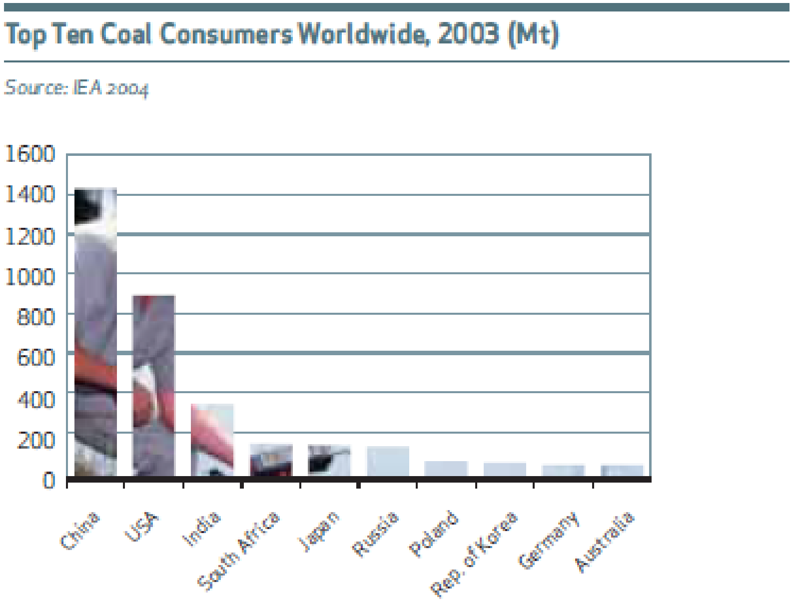
Global coal production and consumption:





Global coal production is expected to reach 7 billion tonnes in 2030-with China accounting for around half the increase over this period.

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Energy security issue:

Coal reserves are very large and will be available for the foreseeable future without raising geopolitical or safety issues.

Coal is readily available from a wide variety of sources in a well-supplied worldwide market.

Coal can be easily stored at power stations and stocks can be drawn on in emergencies

Coal-based power is not dependent on the weather and can be used as a backup for wind and hydropower.

Coal does not need high pressure pipelines or dedicated supply routes.

Coal supply routes do not need to be protected at enormous expense.

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Coal Utilization:

Coal has a very long and varied history. Some historians believe that coal was first used commercially in China. There are reports that a mine in northeastern China provided coal for smelting copper and for casting coins around 1000 BC.

The first practical coal-fired electric generating station, developed by Thomas Edison, went into operation in New York City in 1882

Coal has many important uses worldwide. The most significant uses are in electricity generation, steel production, cement manufacturing and other industrial processes, and as a liquid fuel.

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Coal Utilization:

Coal still plays a vital role in the world's primary energy mix, providing 23.5% of global primary energy needs in 2002, 39% of the world's electricity, more than double the next largest source, and an essential input into 64% of the world's steel production.

Primary Energy is all energy consumed by end-users. This includes the energy used to generate electricity, but does not include the electricity itself

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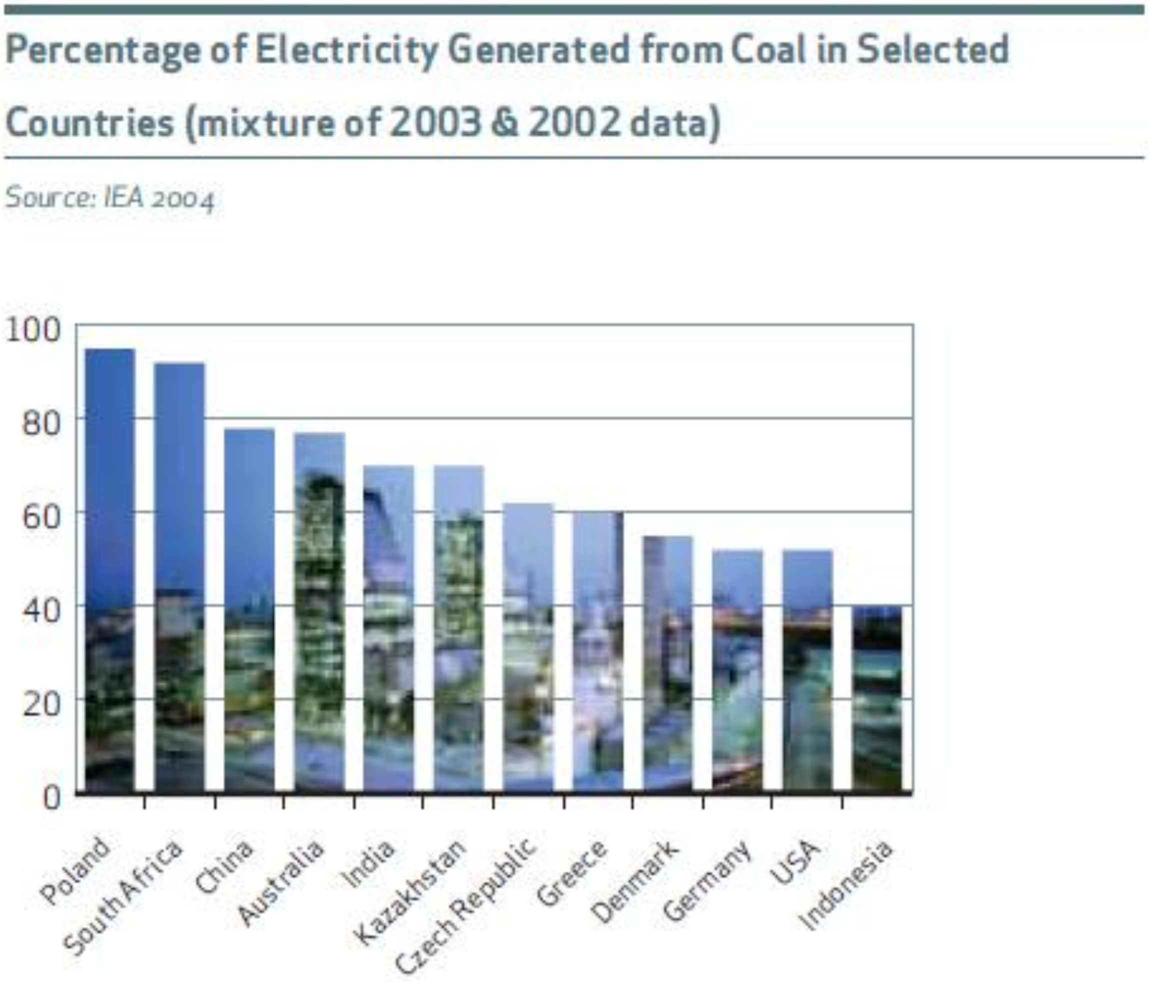
Coal Utilization:



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Coal Utilization-Power Production:

Steam coal, also known as thermal coal, is used in power stations to generate electricity. The earliest conventional coal-fired power stations used lump coal which was burnt on a grate in boilers to raise steam. Nowadays, the coal is first milled to a fine powder, which increases the surface area and allows it to burn more quickly. In these pulverized coal combustion (PCC) systems, the powdered coal is blown into the combustion chamber of a boiler where it is burnt at high temperature. The hot gases and heat energy produced converts water-in tubes lining the boiler -into steam.

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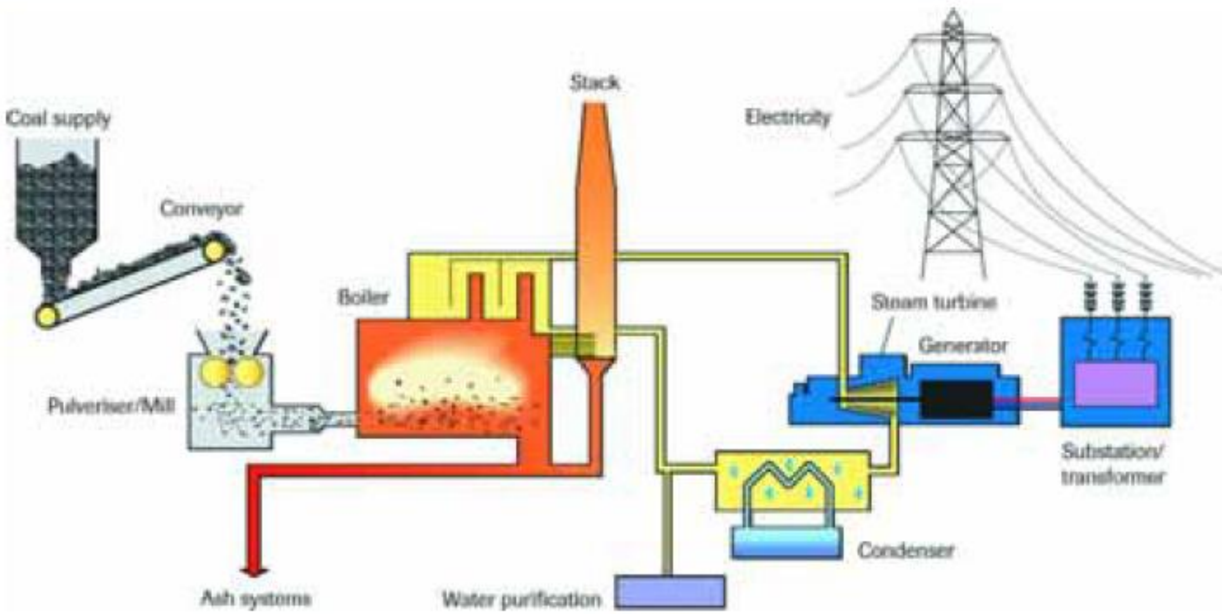
Coal Utilization-Power Production:

Top Five Coking Coal Producers (Mt)

China	159
Australia	112
Russia	55
USA	40
Canada	23

Source: IEA 2004

Converting Coal to Electricity



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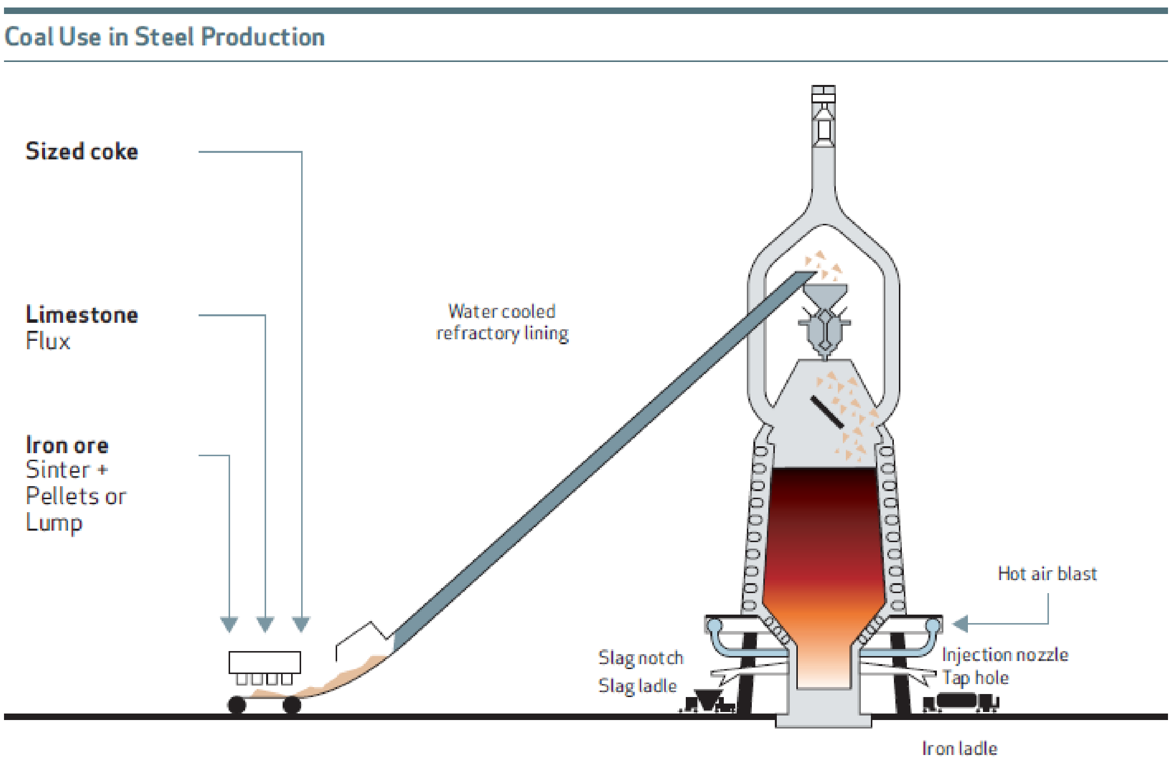
Coal Utilization-Steel Mills:

Some 64% of steel production worldwide comes from iron made in blast furnaces A blast furnace uses iron ore, coke (made from specialist coking coals) and small quantities of limestone.



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Coal Utilization-Steel Mills:

Coke has certain physical properties that cause them to soften, liquefy and then re-solidify into hard but porous lumps when heated in the absence of air. Coking coals must also have low Sulphur and phosphorous contents and, being relatively scarce, are more expensive than the steam coals used in electricity generation.

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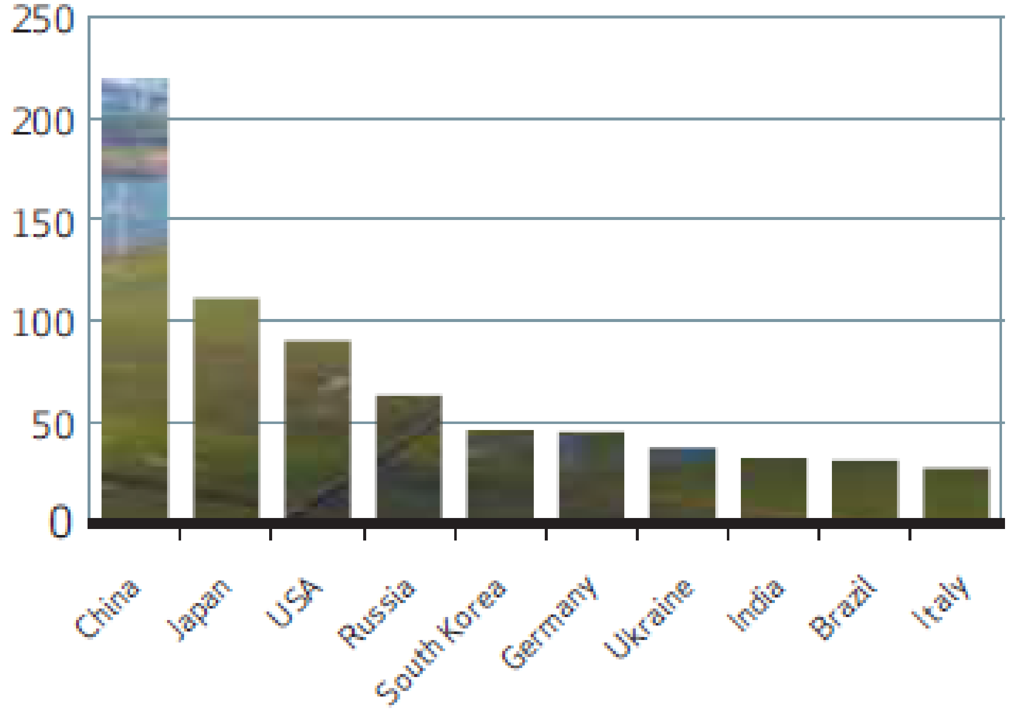
Coal Utilization-Steel Mills:

Top Ten Steel Producing Countries, 2003 (Mt)

Source: IISI



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Coal Utilization-Coal Liquefication:

In a number of countries coal is converted into a liquid fuel – a process known as liquefaction. The liquid fuel can be refined to produce transport fuels and other oil products, such as plastics and solvents. There are two key methods of liquefaction:

>> direct coal liquefaction – where coal is converted to liquid fuel in a single process;

>> indirect coal liquefaction – where coal is first gasified and then converted to liquid.

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Coal Utilization-Cement Industry:

Cement is made from a mixture of calcium carbonate (generally in the form of limestone), silica, iron oxide and alumina. A high temperature kiln, **often fueled by coal**, heats the raw materials to a partial melt at 1450°C, transforming them chemically and physically into a substance known as clinker. This grey pebble-like material is comprised of special compounds that give cement its binding properties. Clinker is mixed with gypsum and ground to a fine powder to make cement.

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Coal Utilization-Other:

Other important users of coal include alumina refineries, paper manufacturers, and the chemical and pharmaceutical industries.

Several chemical products can be produced from the by-products of coal. Refined coal tar is used in the manufacture of chemicals, such as creosote oil, naphthalene, phenol, and

benzene. Ammonia gas recovered from coke ovens is used to manufacture ammonia salts, nitric acid and agricultural fertilisers.

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Coal and the environment:

Our consumption of energy can have a significant impact on the environment. Minimizing the negative impacts of human activities on the natural environment– including energy use – is a key global priority.

“Sustainable development---development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

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Coal and the environment:

Coal mining raises a number of environmental challenges, including soil erosion, dust, noise and water pollution, and

impacts on local biodiversity.

For coal, the release of pollutants, such as oxides of sulphur

and nitrogen (SOx and NOx), and particulate and trace elements, such as mercury, have been a challenge.

Clean coal technologies (CCTs) are a range of technological options which improve the environmental performance of coal. These technologies reduce emissions, reduce waste, and increase the amount of energy gained from each tonne of coal

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Coal and the environment:

Emissions of particulates, such as ash, have been one of the more visible side-effects of coal combustion in the past. They can impact local visibility, cause dust problems and affect people's respiratory systems.

Coal cleaning-Lowering level of Sulphur and minerals

Electrostatic precipitator and Fabric Filters---about 99.5% ash can be removed

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Coal and the environment:

In electrostatic precipitators, particulate-laden flue gases pass between collecting plates, where an electrical field creates a charge on the particles. This attracts the particles towards the collecting plates, where they accumulate and can be disposed of.

Fabric filters, also known as ‘baghouses’, are an alternative approach and collect particles from the flue gas on a tightly woven fabric primarily by sieving.

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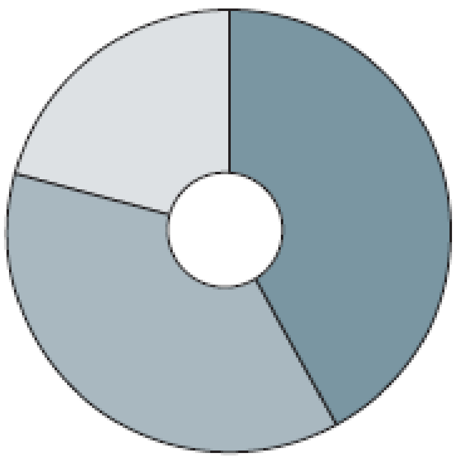
Coal and the environment:

CO_2 Emissions from Fossil Fuels



Oil	41%
Coal	38%
Gas	21%

Source: IEA 2004

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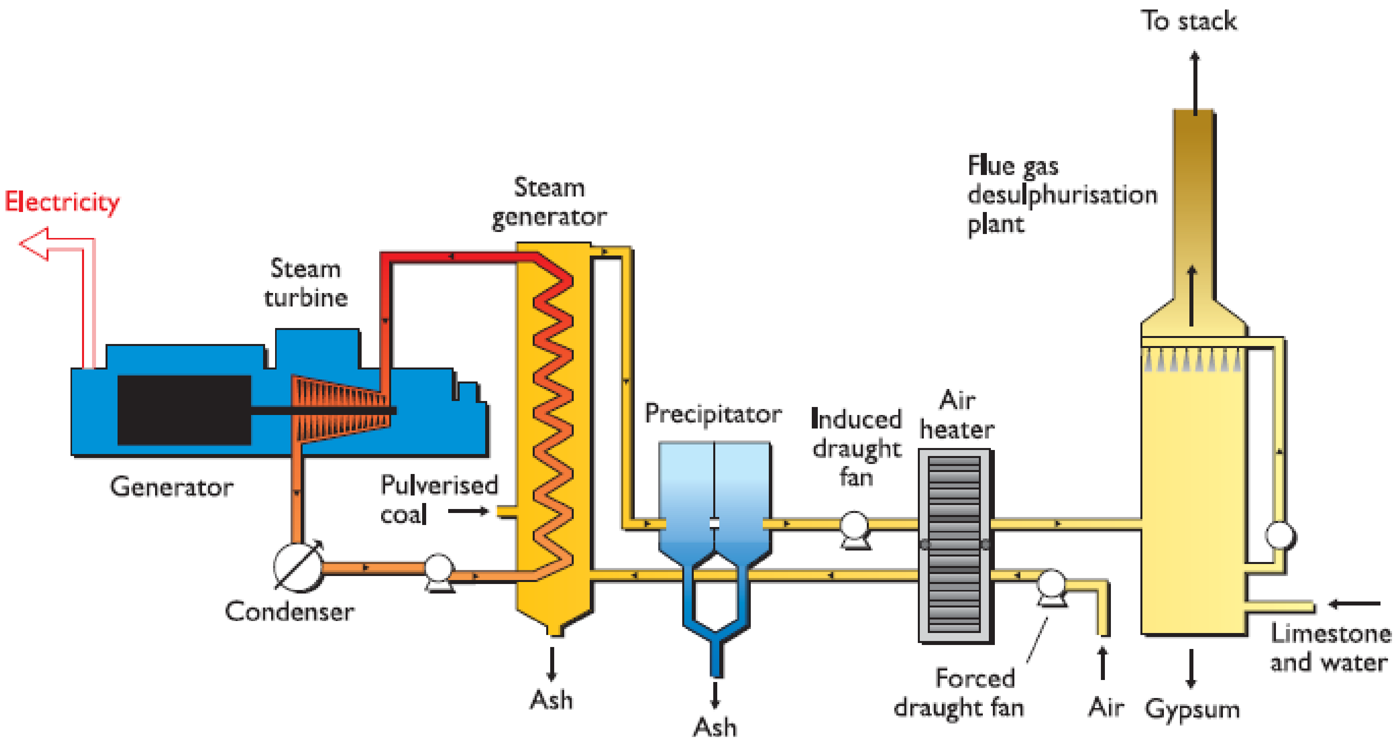
Coal and the environment:

A Flue Gas Desulphurisation System



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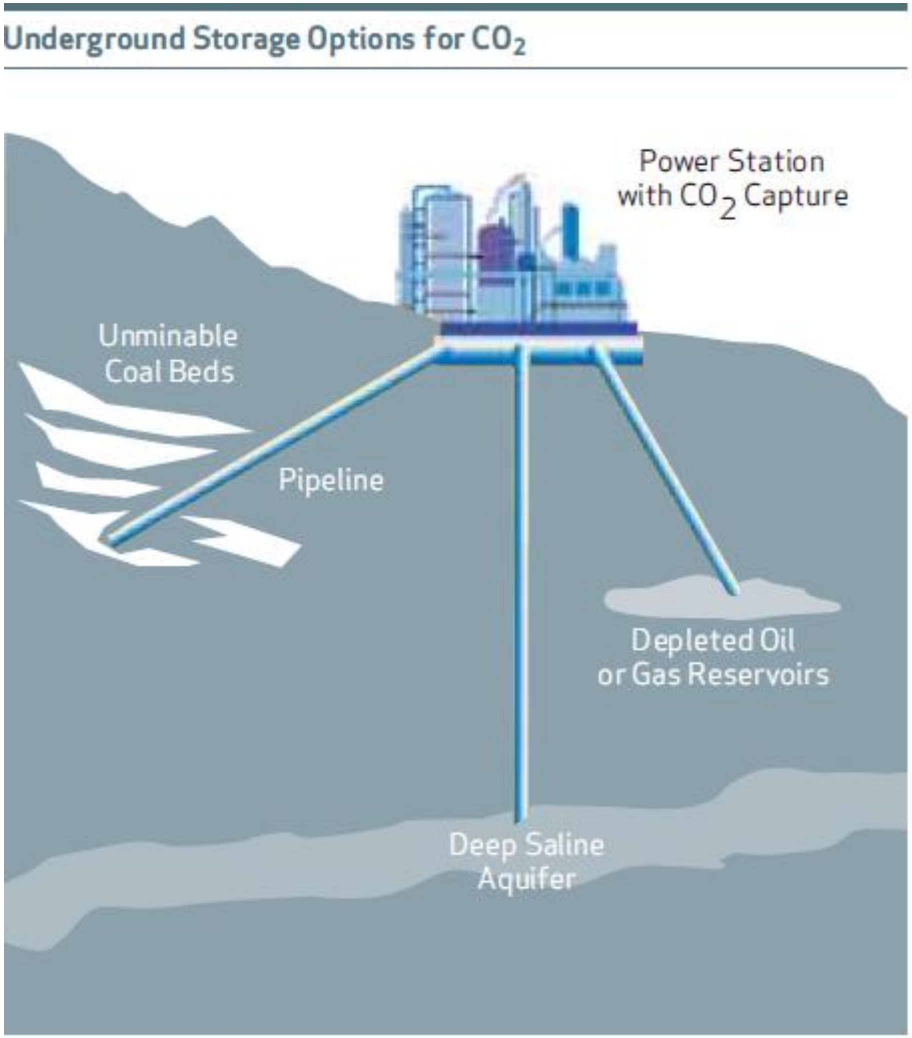
Coal and the environment:



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Coal-Local context:

Province	Resources in Million Tonnes	Heating Value (Btu/lb)
Sindh	184,623	5,219 -13,555
Balochistan	217	9,637 -15,499
Punjab	235	9,472 -15,801
NWFP	91	9,386 -14,217
AJK	9	7,336 -12,338
Total	**185,175**	

Source: Geological Survey of Pakistan / Pakistan Energy Year Book 2003

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Coal-Local context:

SINDH

Thar	175,506	6,244 – 11,045
Lakhra	1,328	5,503 – 9,158
Sonda-Jherruck	5,523	5,219 – 13,555
Meting- Jhimpir	473	5,219 – 8,612
Indus East	1,777	7,782 – 8,660
Badin	16	11,415 – 11,521
Sub-Total:-	**184,623**	

BALOCHISTAN

Sor-Range/Degari	50	11,245 – 13,900
Khost-Sharigh-Harnai-Ziarat	88	9,637 – 15,499
Mach	23	11,110 – 12,937
Duki	56	10,131 – 14,357
Sub-Total:-	**217**	

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Coal-Local context:

PUNJAB

Salt-Range	213	9,472 – 15,801
Makarwal	22	10,688 – 14,029
Sub-Total:-	**235**	

NWFP

Hangu	82	10,500 – 14,149
Cherat	9	9,386 – 14,217
Sub-Total:	**91**	

AZAD KASHMIR

Kotli	9	7,336 – 12,338
Grand Total:-	**185,175**	

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Coal-Local context:

Table 2: THAR COAL QUALITY & RESERVES

Moisture (%)	29.60 – 55.50
Ash content (%)	02.90 – 11.50
Volatile Matter (%)	23.10 – 36.60
Fixed Carbon (%)	14.20 – 34.00
Sulfur (%)	00.40 – 02.90
Heating Value (Btu/lb)	
As received	6,244 – 11,045
Dry Basis	10,723 - 11,353

The quality of coal is Lignite-B to Lignite-A

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Coal-Local context:

Table 3: LAKHRA COAL QUALITY & RESERVES

Moisture (%)	09.70 – 38.10
Ash (%)	04.30 – 49.00
Volatile Matter (%)	18.30 – 38.60
Fixed Carbon (%)	09.80 – 38.20
Sulfur (%)	01.20 – 14.80
Calorific Value (Btu/lb)	5,503 – 9,158

The quality of the coal is Lignite-A

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Coal-Local context:

a) The power station must be located at the mine site, because the low energy and high moisture content of lignite coal do not justify the transportation cost.

b) Transmission and power line losses require the load centre to be in reasonable proximity to the power station (200 km) and, consequently, relatively close to the mine.

c) Lignite coal has certain characteristics which require special consideration when selecting the type of equipment for mining and power generation, e.g. high moisture content will reduce the efficiency of power generation and add to the cost of capital for the equipment required to burn the coal. On the other hand, boiler efficiency and the coal feed rate increases as the moisture content of the coal increases. Similarly, the ash content of lignite may contain mineral matter bound with the organic material, and these elements, especially sodium, can cause severe slugging and fouling problems in conventional boiler.

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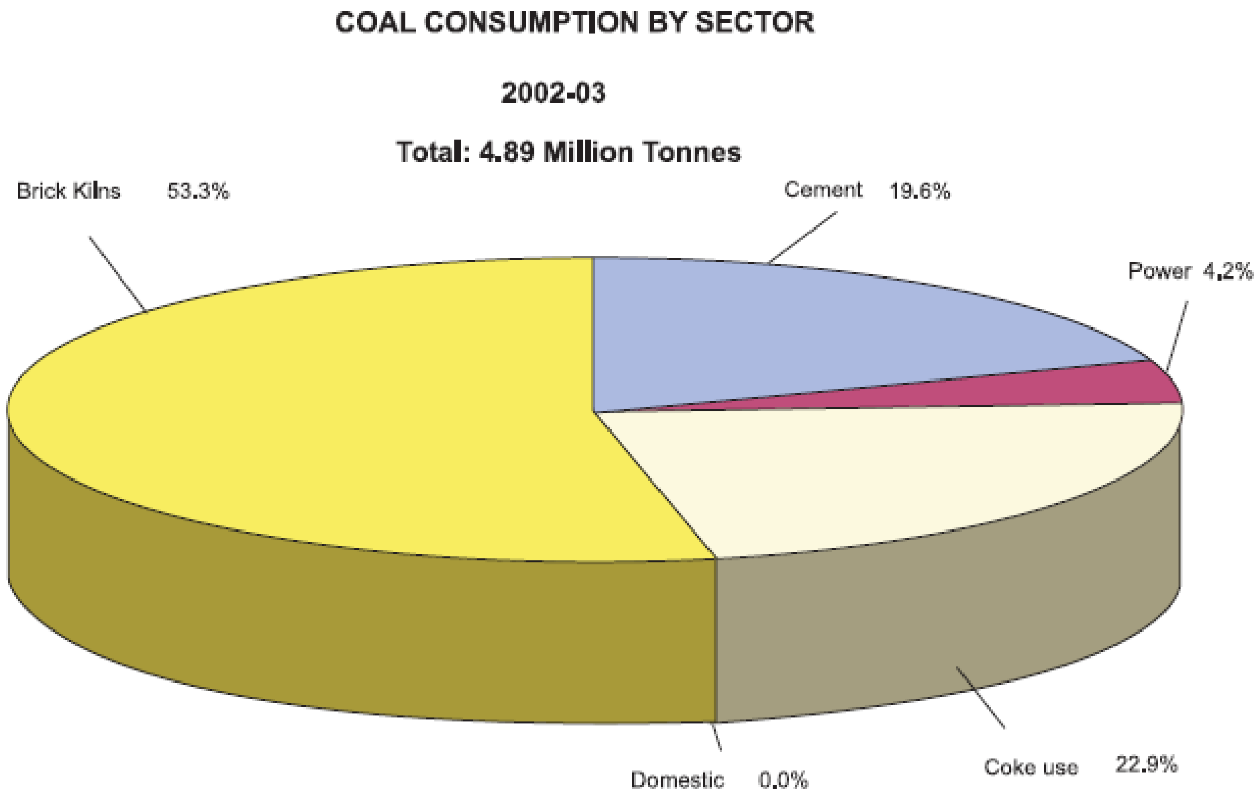
Coal-Local context:



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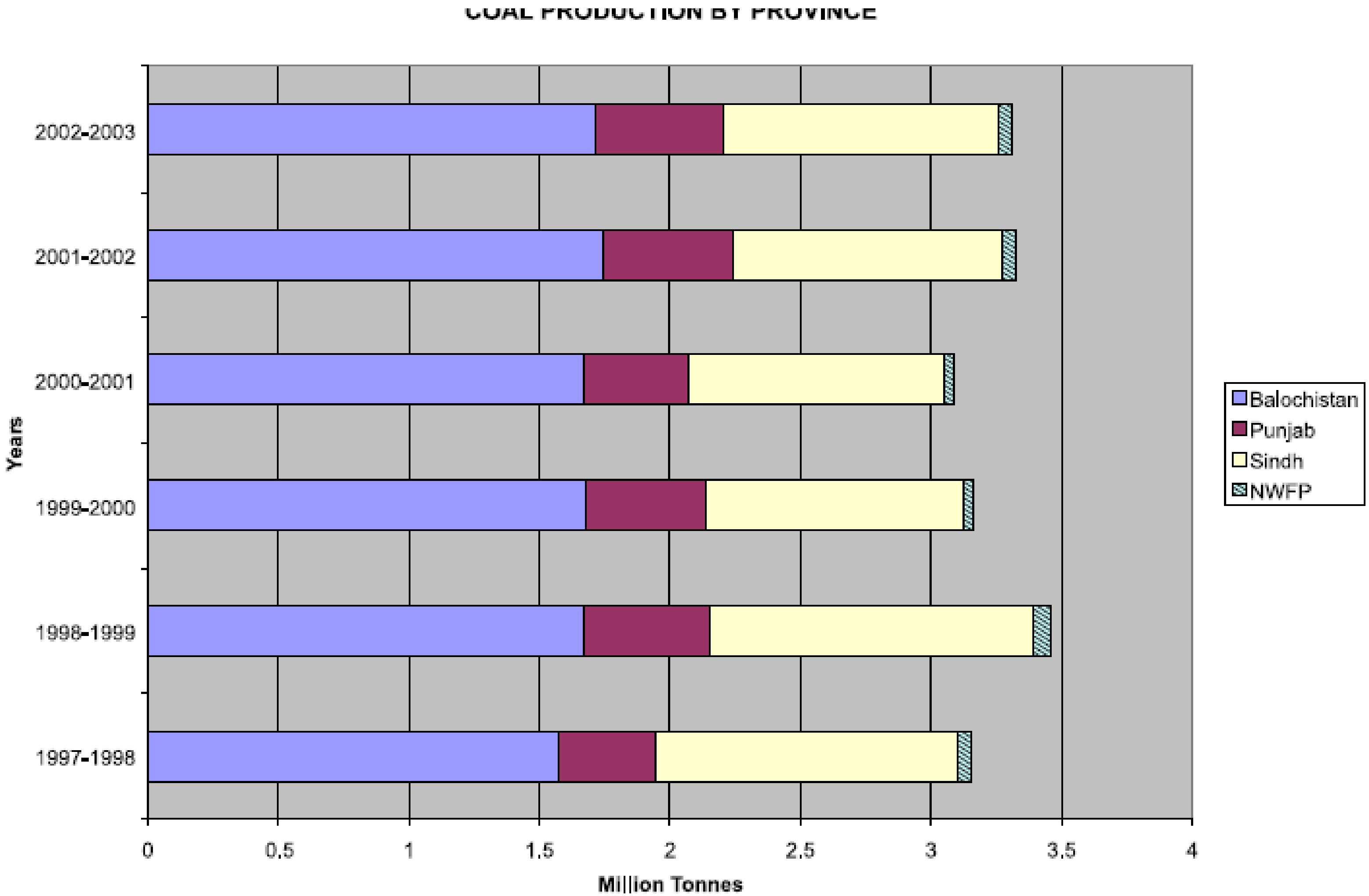
Coal-Local context:



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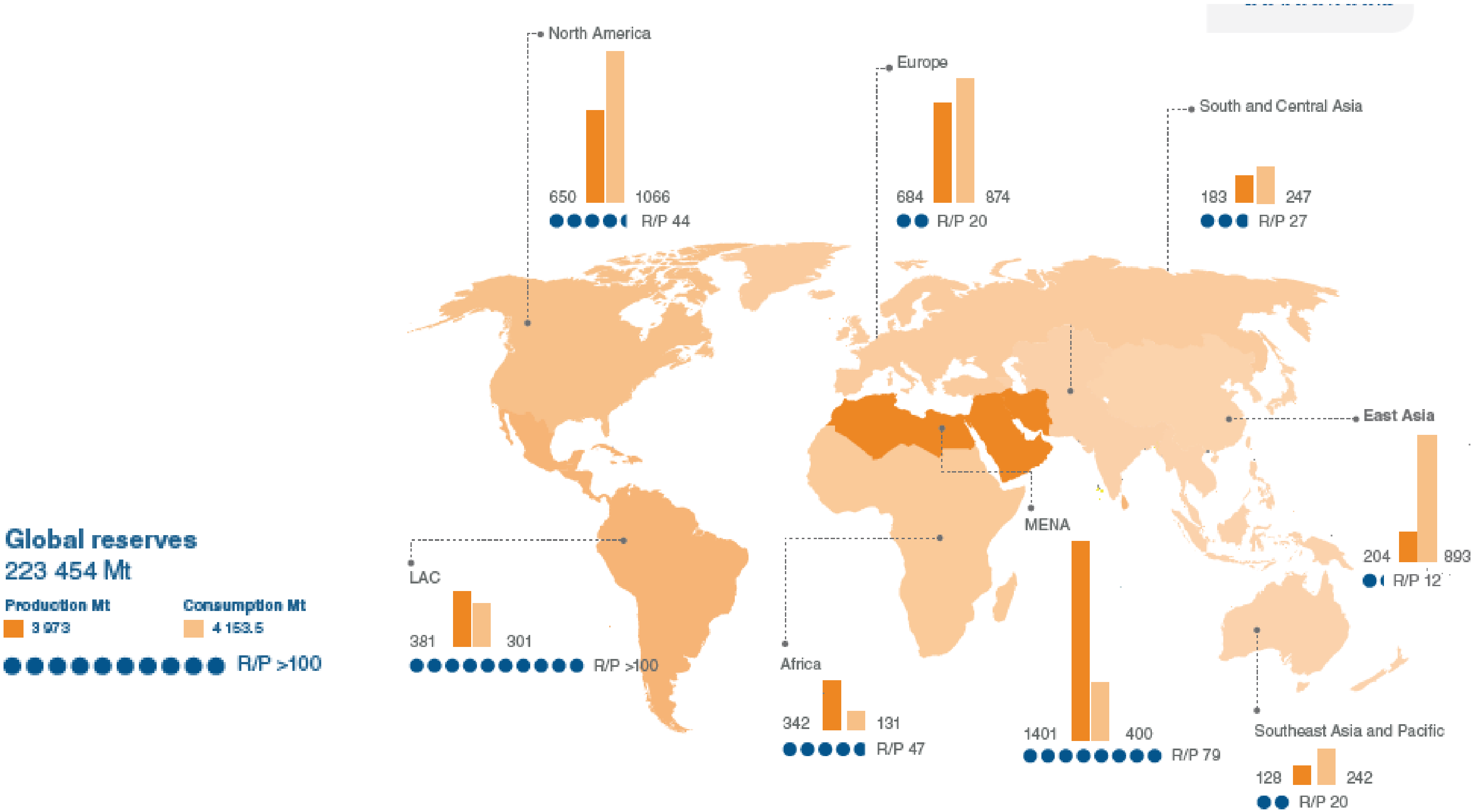
Coal-Local context:

7.11 Coal Pricing (2002 – 03)

Fuel	Selling Price (At Pit Head)	Price/Million Btu
Sindh Coal	Rs 600 / Tonne	Rs 32.02
Balochistan Coal	Rs 1800 / Tonne	Rs 96.05
Punjab Coal	Rs 1500 / Tonne	Rs 80.04
NWFP Coal	Rs 1400 / Tonne	Rs 74.7i
AJK Coal	Rs 1200 / Tonne	Rs 64.03
Furnace Oil (At Refinery)	Rs 11,835 / Tonne	Rs 290.13
Natural Gas (At Well Head)	Rs 185 / Million cu. fit.	Rs 188.78

Fossil Energy Resources-Oil

Estimated oil reserves:



Fossil Energy Resources-Oil

Estimated oil reserves:

Crude oil reserves: top 5 countries

	Reserves (Mt)		Production (Mt)		R/P
Country	**2011**	**1993**	**2011**	**1993**	**years**
Venezuela	40 450	9 842	155	129	> 100
Saudi Arabia	36 500	35 620	526	422	69
Canada	23 598	758	170	91	> 100
Iran	21 359	12 700	222	171	96
Iraq	19 300	13 417	134	29	> 100
Rest of World	82 247	68 339	2 766	2 338	30
Global total	**223 454**	**140 676**	**3 973**	**3 179**	**56**

Fossil Energy Resources-Oil

Estimated oil reserves:

TABLE 5.1. ESTIMATED OIL RESERVES

Region	Identified reserves (Masters and others, 1994)		Identified reserves plus 95%[a] (Masters and others, 1994)		Identified reserves plus mode[b] (Masters and others, 1994)		Identified reserves plus 5%[c] (Masters and others, 1994)		Proven recoverable reserves (WEC, 1998)		Proven reserves (BP, 1999)		Total resources from enhanced oil recovery[d]	
	Gigatonnes	Exajoules	Gigatonnes	Exajoules	Gigatonnes	Exajoules	Gigatonnes	Exajoules	Gigatonnes	Exajoules	Gigatonnes	Exajoules	Gigatonnes	Exajoules
North America	8.5	356	14.3	599	17.0	712	23.7	992	4.6	193	4.6	193	13.6	569
Latin America and Caribbean	17.3	724	22.6	946	26.2	1,097	41.6	1,742	19.2	804	19.9	833	23.8	996
Western Europe	5.6	234	6.8	285	7.7	322	11.2	469	2.5	105	2.5	105	3.9	163
Central and Eastern Europe	0.3	13	0.4	17	0.5	21	1.1	46	0.3	13	0.2	8	0.5	21
Former Soviet Union	17.0	712	25.1	1,051	30.6	1,281	49.9	2,089	8.0	335	9.1	381	11.2	469
Middle East and North Africa	87.6	3,668	97.0	4,061	104.6	4,379	126.4	5,292	99.6	4,170	96.8	4,053	59.2	2,479
Sub-Saharan Africa	4.0	167	5.9	247	7.3	306	12.3	515	4.0	167	4.5	188	3.3	138
Pacific Asia	3.1	130	4.1	172	4.8	201	7.3	306	1.5	63	1.5	63	2.1	88
South Asia	1.0	42	1.1	46	1.3	54	1.8	75	0.8	33	0.5	21	0.6	25
Centrally planned Asia	5.1	214	7.8	327	9.8	410	17.9	749	5.4	226	3.4	142	3.7	155
Pacific OECD	0.4	17	0.6	25	0.7	29	1.3	54	0.4	17	0.4	17	0.5	21
Total[e]	**150**	**6,277**	**186**	**7,776**	**210**	**8,812**	**295**	**12,329**	**146**	**6,126**	**143**	**6,004**	**123**	**5,124**

Fossil Energy Resources-Oil

Estimated oil reserves:

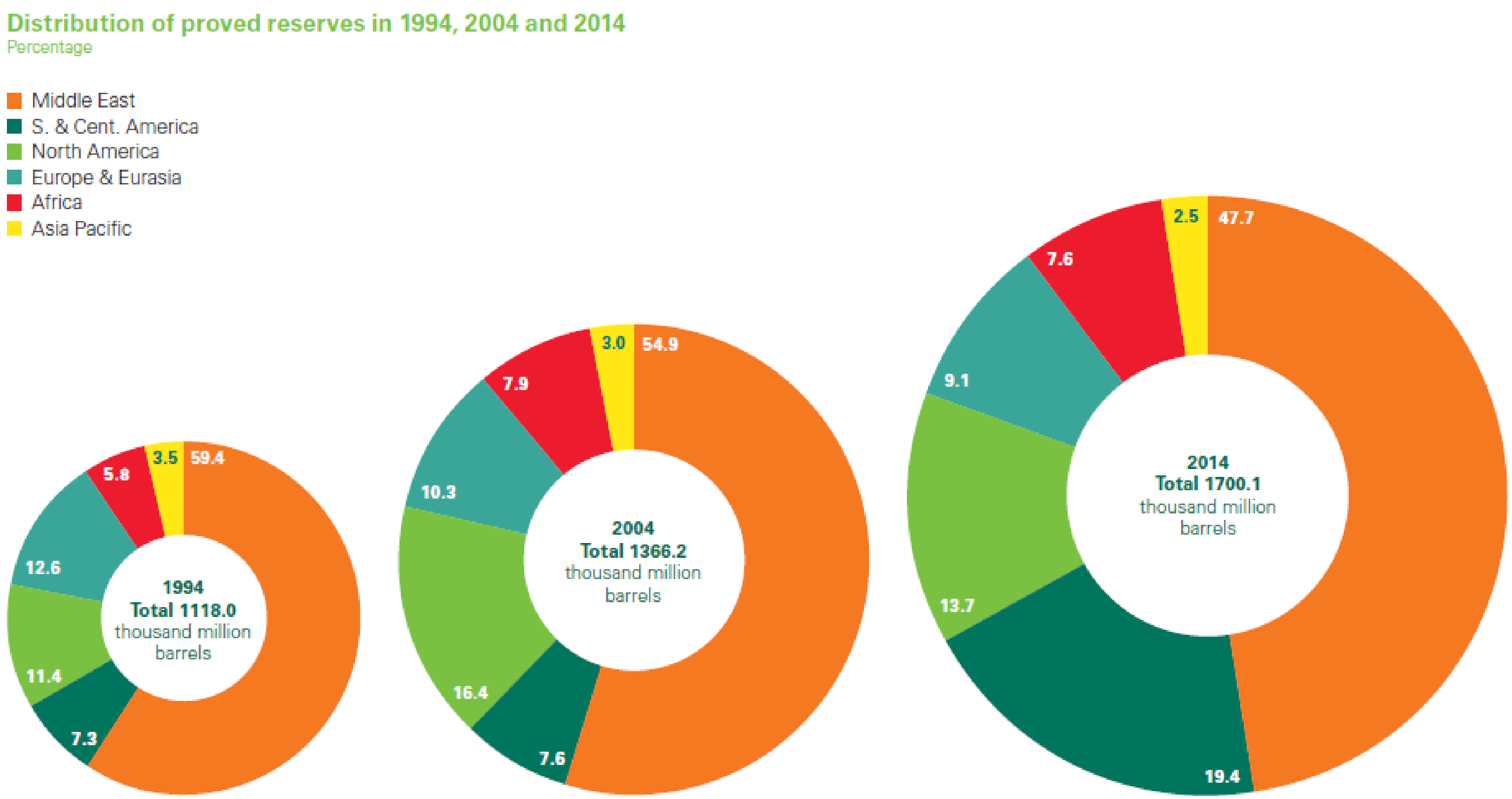
Oil

Total proved reserves

	At end 1994 Thousand million barrels	At end 2004 Thousand million barrels	At end 2013 Thousand million barrels	At end 2014 Thousand million tonnes	At end 2014 Thousand million barrels	At end 2014 Share of total	At end 2014 R/P ratio
US	29.6	29.3	48.5	**5.9**	**48.5**	2.9%	11.4
Canada	48.1	179.6	172.9	**27.9**	**172.9**	10.2%	*
Mexico	49.8	14.8	11.1	**1.5**	**11.1**	0.7%	10.9
Total North America	127.6	223.7	232.5	**35.3**	**232.5**	13.7%	34.0
Argentina	2.3	2.5	2.3	**0.3**	**2.3**	0.1%	10.1
Brazil	5.4	11.2	15.6	**2.3**	**16.2**	1.0%	18.9
Colombia	3.1	1.5	2.4	**0.4**	**2.4**	0.1%	6.8
Ecuador	3.5	5.1	8.2	**1.2**	**8.0**	0.5%	39.4
Peru	0.8	1.1	1.6	**0.2**	**1.6**	0.1%	40.2
Trinidad & Tobago	0.6	0.8	0.8	**0.1**	**0.8**	◆	20.3
Venezuela	64.9	79.7	298.3	**46.6**	**298.3**	17.5%	*
Other S. & Cent. America	1.0	1.5	0.5	**0.1**	**0.5**	◆	9.6
Total S. & Cent. America	81.5	103.4	329.8	**51.2**	**330.2**	19.4%	*
Azerbaijan	1.2	7.0	7.0	**1.0**	**7.0**	0.4%	22.6
Denmark	0.8	1.3	0.7	**0.1**	**0.6**	◆	10.0
Italy	0.8	0.5	0.6	**0.1**	**0.6**	◆	14.5
Kazakhstan	5.3	9.0	30.0	**3.9**	**30.0**	1.8%	48.3
Norway	9.7	9.7	7.0	**0.8**	**6.5**	0.4%	9.5
Romania	1.0	0.5	0.6	**0.1**	**0.6**	◆	19.4
Russian Federation	115.1	105.5	105.0	**14.1**	**103.2**	6.1%	26.1
Turkmenistan	0.5	0.5	0.6	**0.1**	**0.6**	◆	6.9
United Kingdom	4.3	4.0	3.0	**0.4**	**3.0**	0.2%	9.8
Uzbekistan	0.3	0.6	0.6	**0.1**	**0.6**	◆	24.3
Other Europe & Eurasia	2.3	2.2	2.0	**0.3**	**2.0**	0.1%	14.0
Total Europe & Eurasia	141.2	140.8	157.2	**20.9**	**154.8**	9.1%	24.7
Iran	94.3	132.7	157.8	**21.7**	**157.8**	9.3%	*

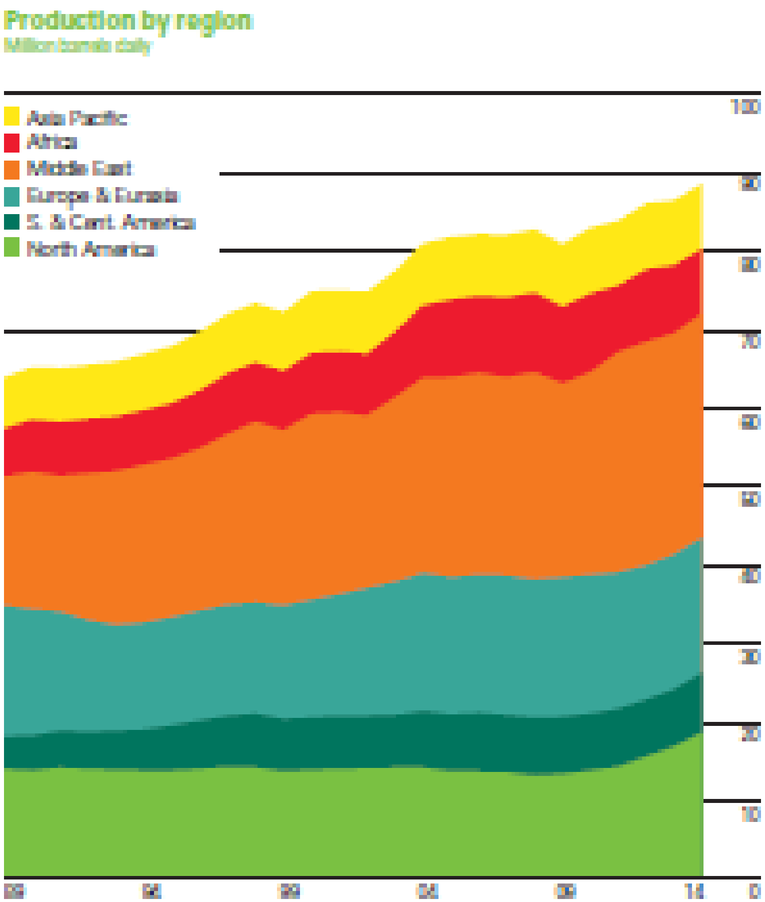
Fossil Energy Resources-Oil

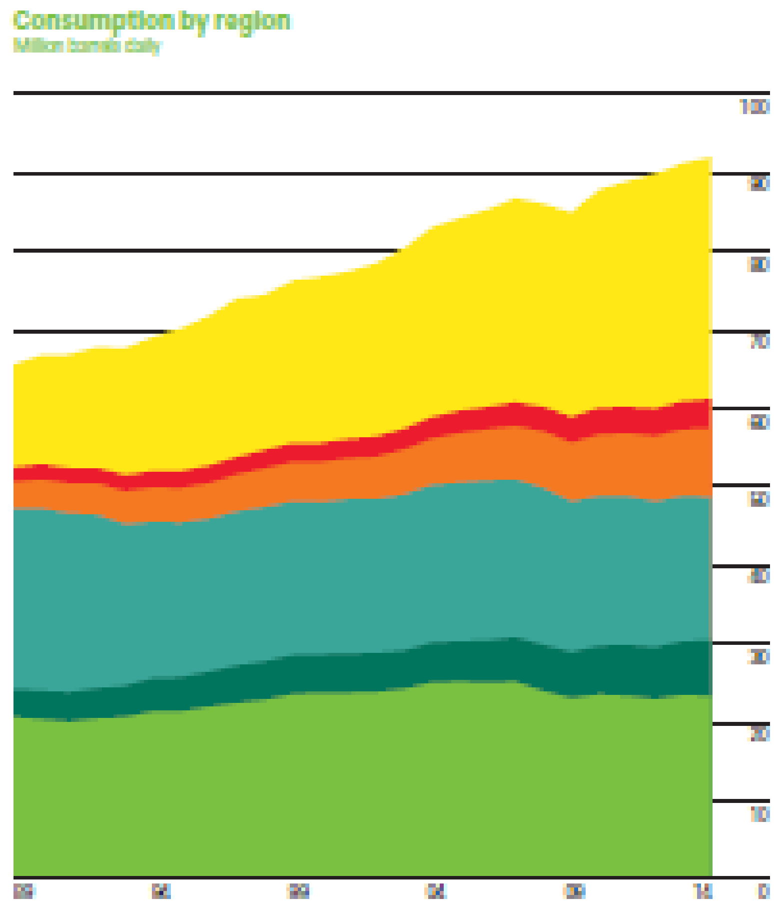
Estimated oil reserves:



Fossil Energy Resources-Oil

Oil production and consumption:





Fossil Energy Resources-Oil

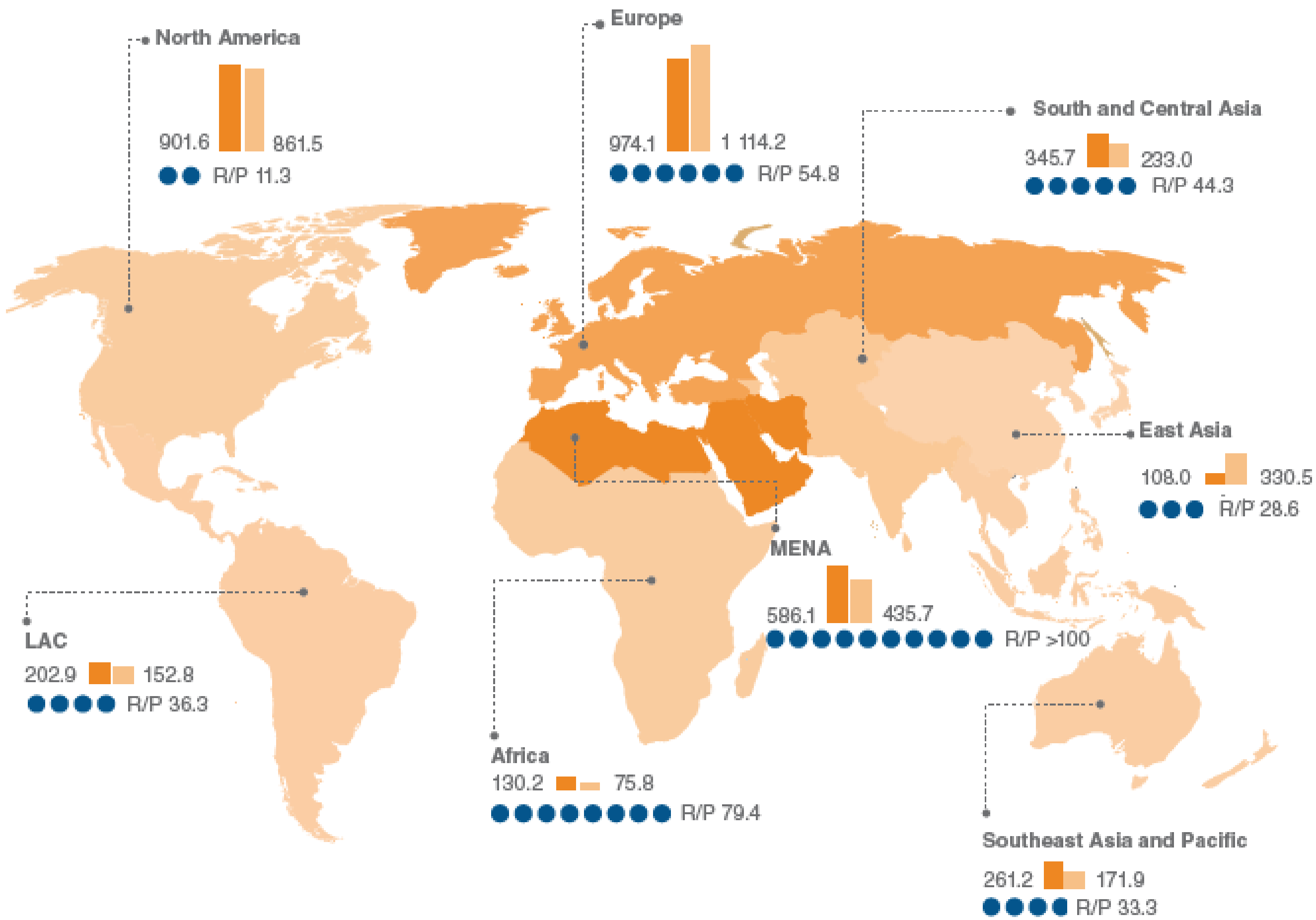
Benefits	Drawbacks
Currently indispensable for road transport and petrochemical industries	High price volatility
Leading tradable commodity	Geopolitical tensions related to areas of greatest reserves
Flexible, easy to transport fuel	Market dominated by leading oil producers (OPEC and large NOCs)

Fossil Energy Resources-Natural Gas

- The cleanest of all fossil-based fuels, natural gas is plentiful and flexible. It is increasingly used in the most efficient power generation technologies, such
- as, Combined Cycle Gas Turbine (CCGT) with conversion efficiencies of about 60%.
- The reserves of conventional natural gas have grown by 36% over the past two decades and its production by 61%. Compared to the 2010 survey, the proved natural gas reserves have grown by 3% and production by 15%.
- The exploration, development and transport of gas usually requires significant upfront investment. Close coordination between investment in the gas and power infrastructure is necessary.

Fossil Energy Resources-Natural Gas

Estimated Natural Gas reserves:



Fossil Energy Resources-Natural Gas

Estimated Natural Gas reserves:

Natural gas reserves: top 5 countries

	Reserves (bcm)		Production (bcm)		R/P
Country	2011	1993	2011	1993	years
Russian Federation	47 750	48 160	670	604	71
Iran	33 790	20 659	150	27	> 100
Qatar	25 200	7 079	117	14	> 100
Turkmenistan	25 213	2 860	75	57	> 100
Saudi Arabia	8 028	5 260	99	36	81
Rest of World	69 761	57 317	2 407	1 438	22
Global Totals	**209 742**	**141 335**	**3 518**	**2 176**	**55**

Fossil Energy Resources-Natural Gas

Estimated Natural Gas reserves:

TABLE 5.3. ESTIMATED NATURAL GAS RESERVES

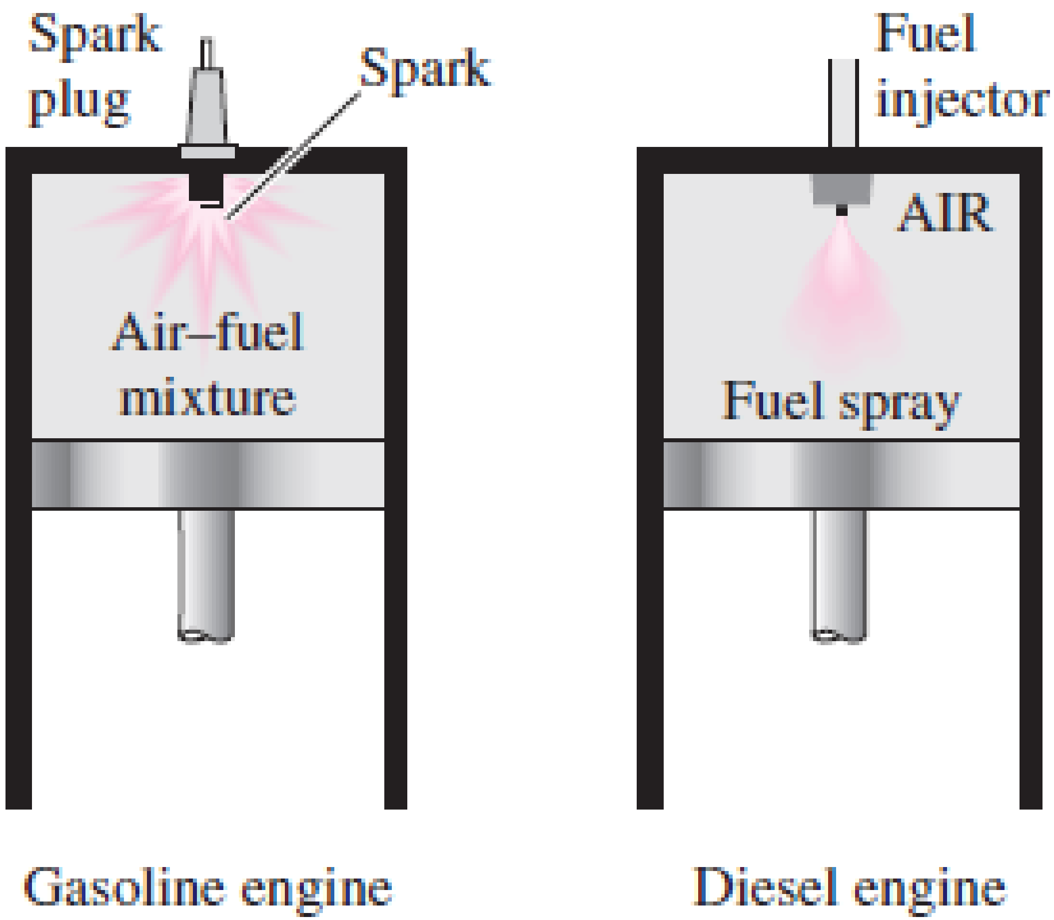
Region	Proven recoverable reserves (WEC, 1998)		Total recoverable reserves (WEC, 1998)		Proven and additional reserves (IGU, 2000)		Proven reserves (BP, 1999)		Enhanced gas recovery	
	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3
North America	252	6.8	389	10.5	2,307	63.0	244	6.6	884	23.9
Latin America and Caribbean	303	8.2	426	11.5	1,556	42.5	298	8.0	306	8.3
Western Europe	181	4.9	300	8.1	436	11.9	177	4.8	306	8.3
Central and Eastern Europe	26	0.7	26	0.7	77	2.1	17	0.5	45	1.2
Former Soviet Union	2,087	56.4	2,583	69.8	5,767	157.5	2,112	56.7	1,923	52.0
Middle East and North Africa	2,076	56.1	2,250	60.8	5,343	149.5	2,065	55.4	1,421	38.4
Sub-Saharan Africa	155	4.2	155	4.2	238	6.5	161	4.3	93	2.5
Pacific Asia	207	5.6	207	5.6	798	21.8	196	5.3	158	4.3
South Asia	63	1.7	63	1.7	377	10.3	54	1.5	50	1.4
Centrally planned Asia	48	1.3	48	1.3	641	17.5	82	2.2	41	1.1
Pacific OECD	56	1.5	89	2.4	850	23.2	47	1.3	62	1.7
Total	**5,450**	**147.3**	**6,534**	**176.6**	**18,390**	**502.2**	**5,454**	**146.4**	**5,290**	**143.0**

Fossil Energy Resources-Natural Gas

Benefits	Drawbacks
Cleanest of fossil fuels	Fields increasingly off-shore and in remote areas
Flexible and efficient fuel for power generation	High upfront investment requirement for transport and distribution system
Increasing proved reserves (reassessments and shale gas)	Increasingly long supply routes and high cost of infrastructure

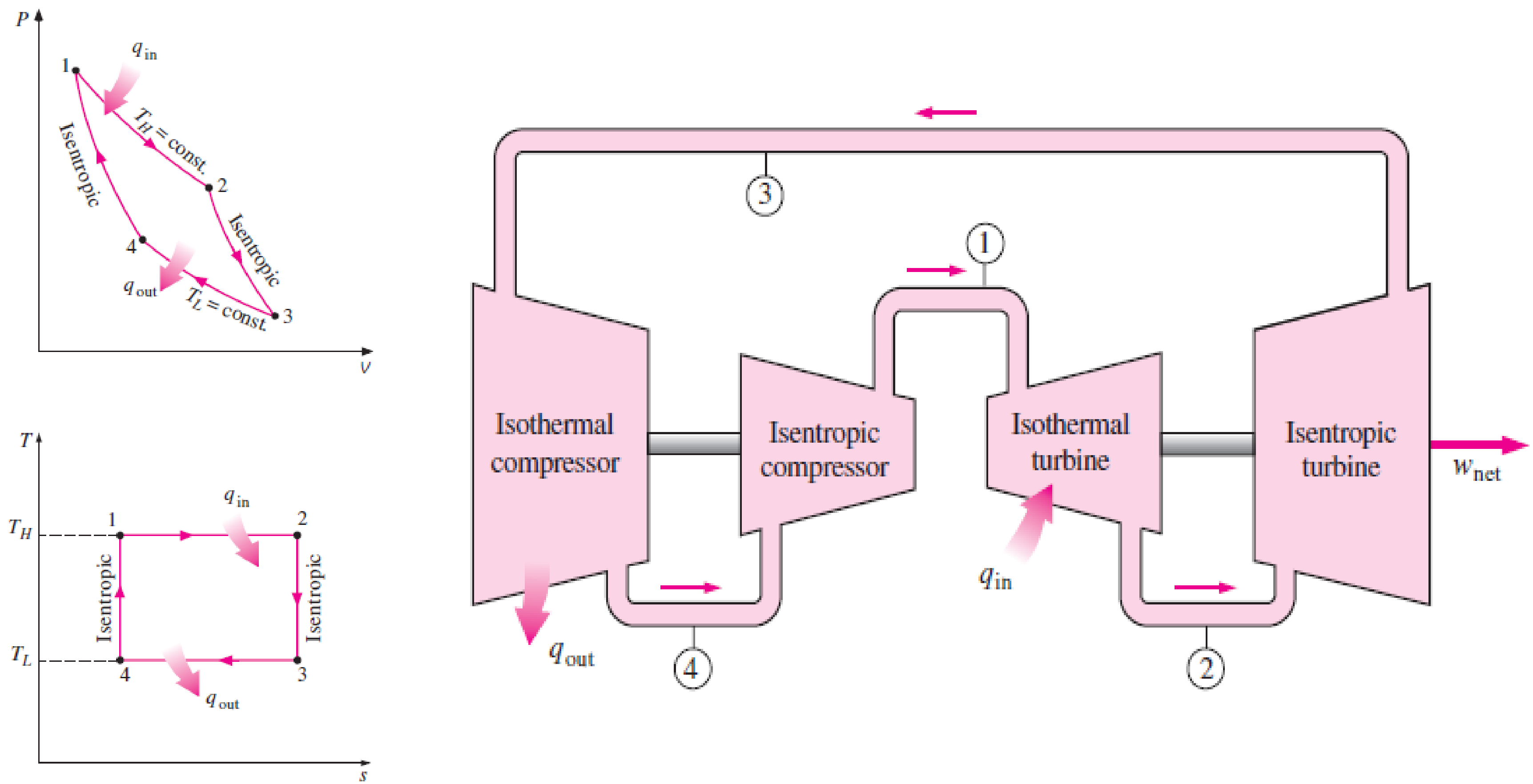
Fossil Energy Resources-Power Generation

Heat Engine: Energy to Mechanical Energy



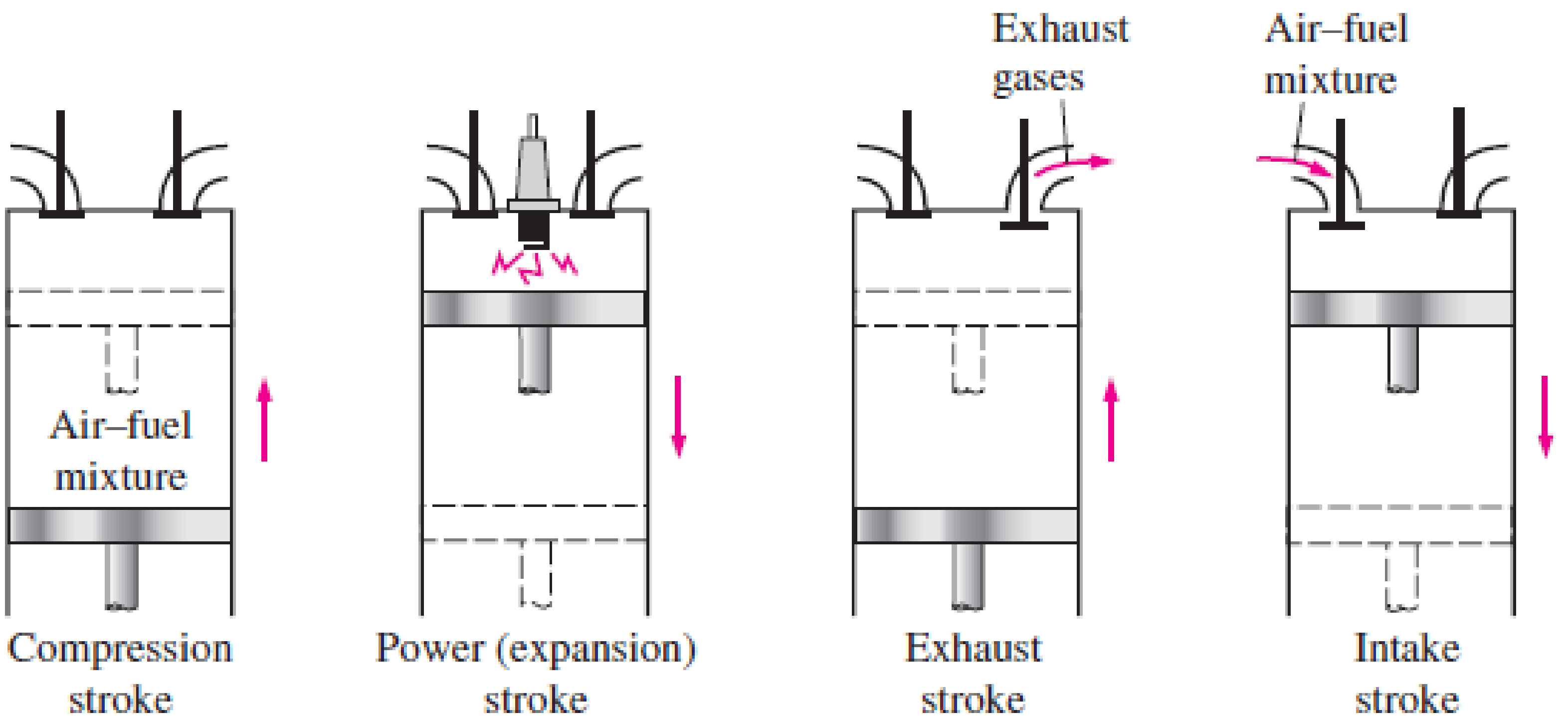
Fossil Energy Resources-Power Generation

Carnot cycle-Ideal cycle for Heat Engines



Fossil Energy Resources-Power Generation

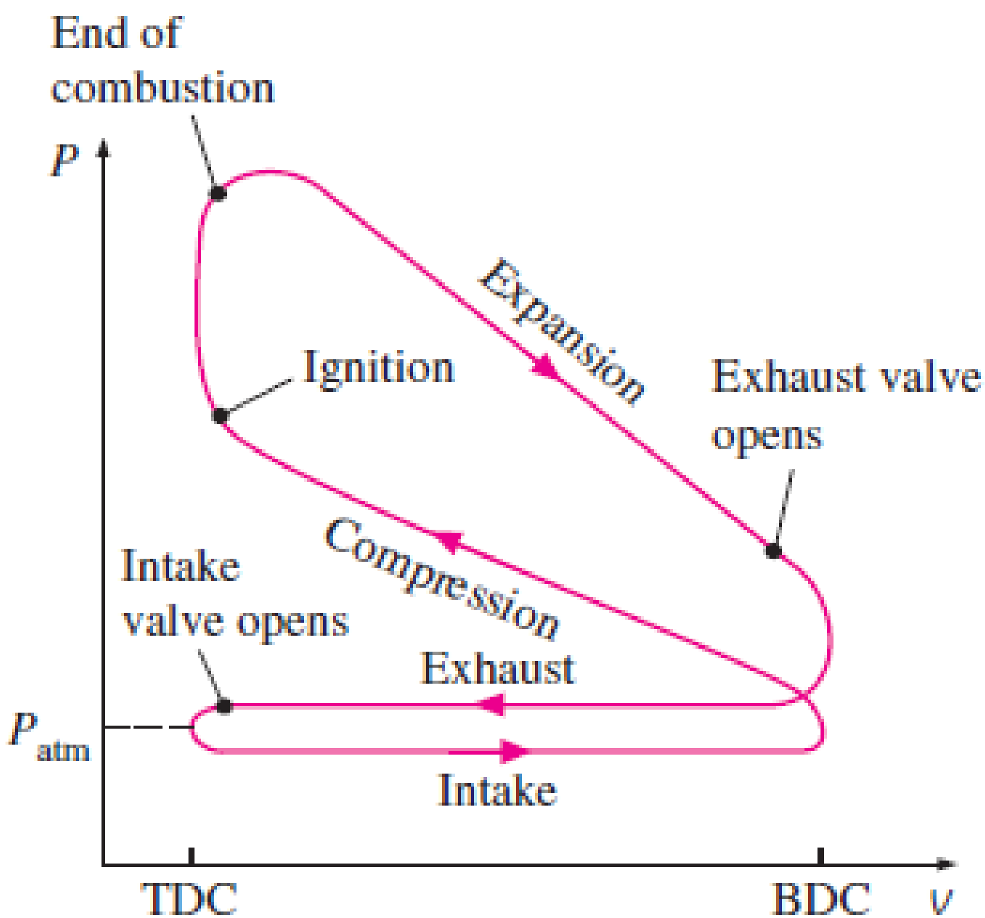
Otto Cycle-Reciprocating Engines



(*a*) Actual four-stroke spark-ignition engine

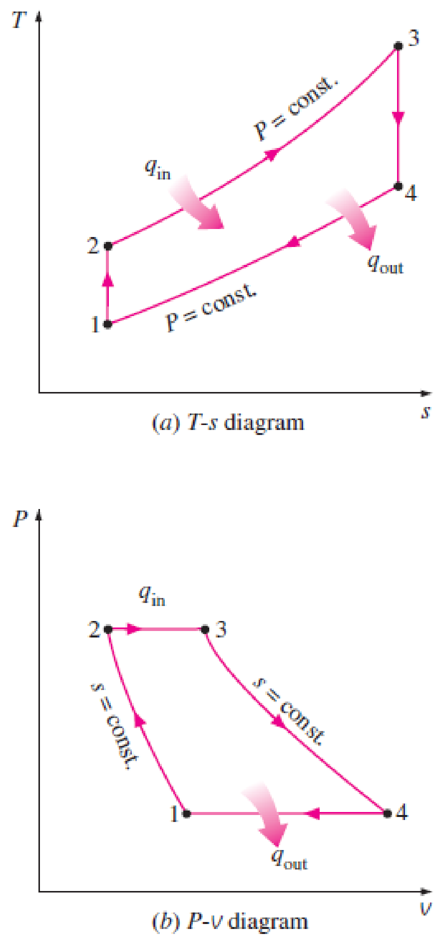
Fossil Energy Resources-Power Generation

Otto Cycle-Reciprocating Engines



Fossil Energy Resources-Power Generation

Brayton cycle-Gas turbine power plants



(a) T-s diagram

(b) P-v diagram

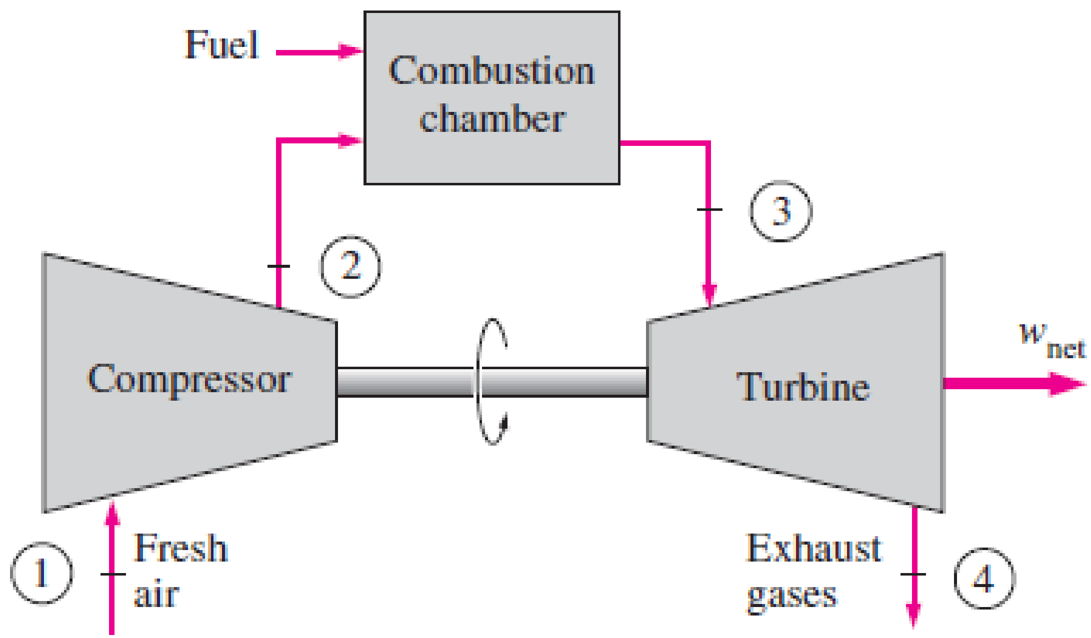
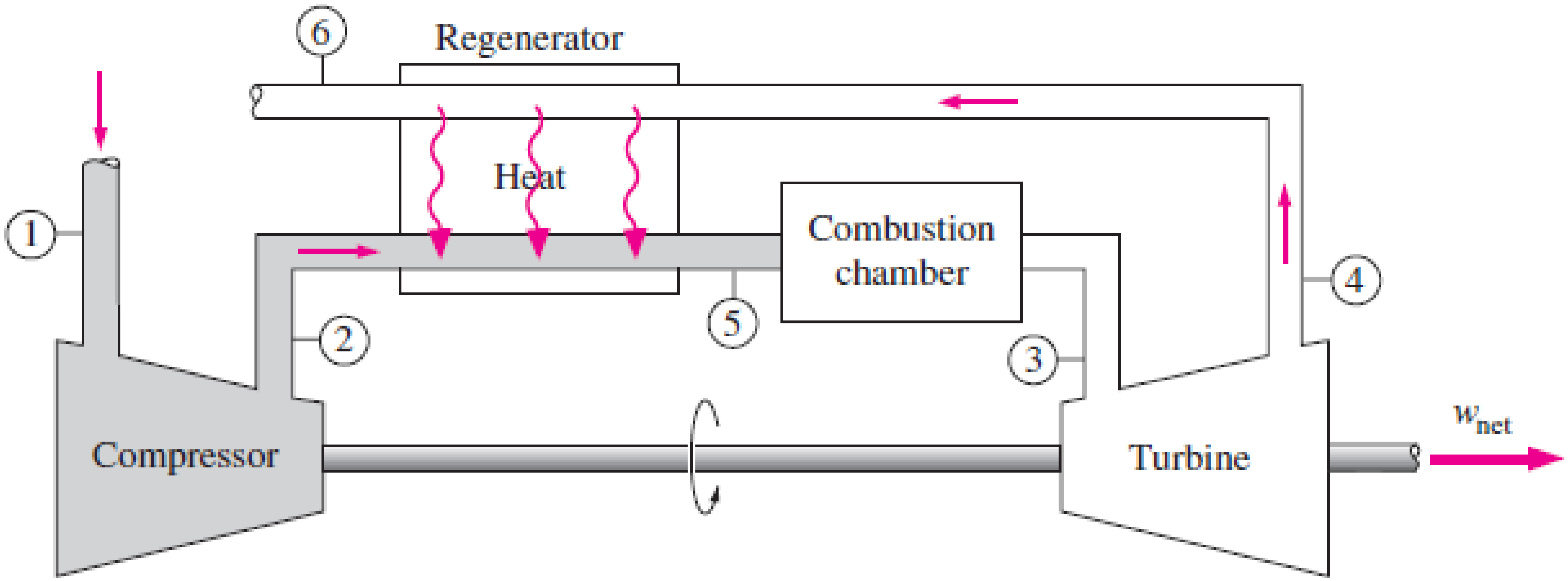


FIGURE 9–29

An open-cycle gas-turbine engine.

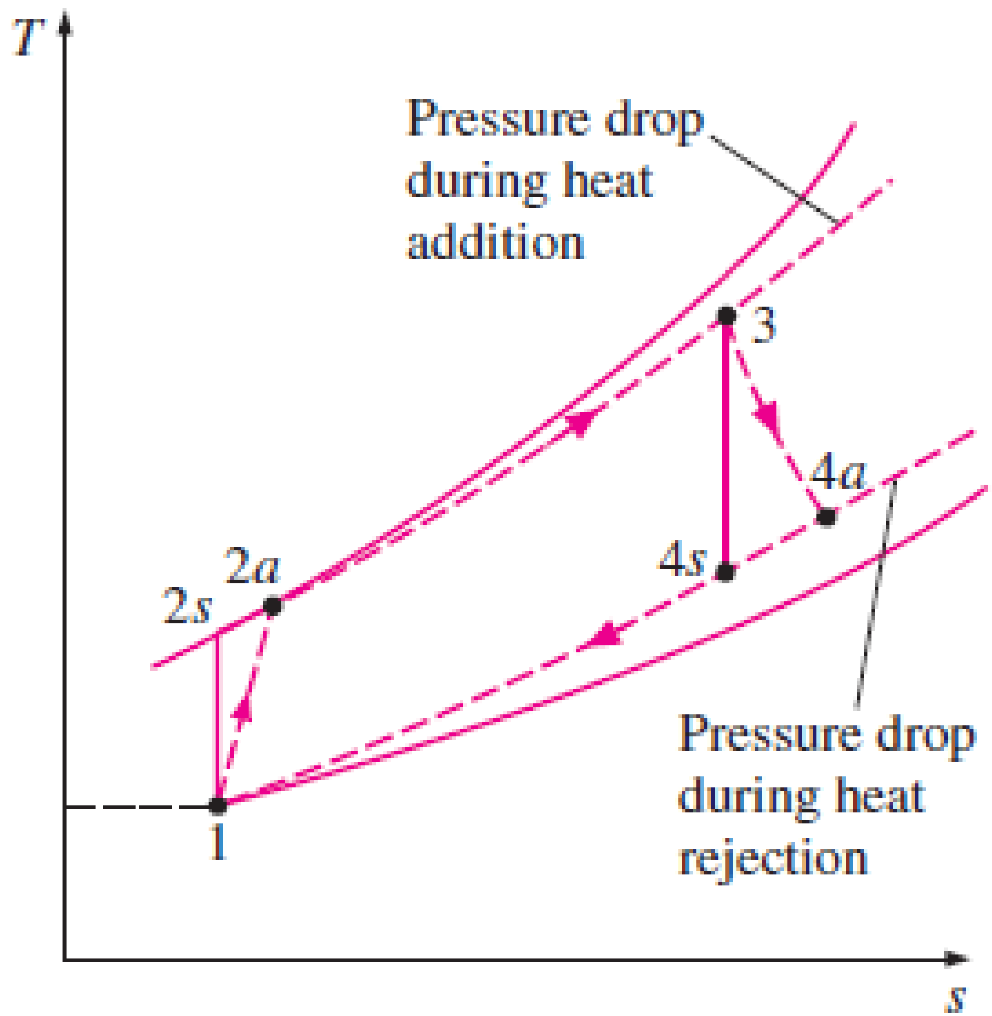
Fossil Energy Resources-Power Generation

Brayton cycle-Gas turbine power plant



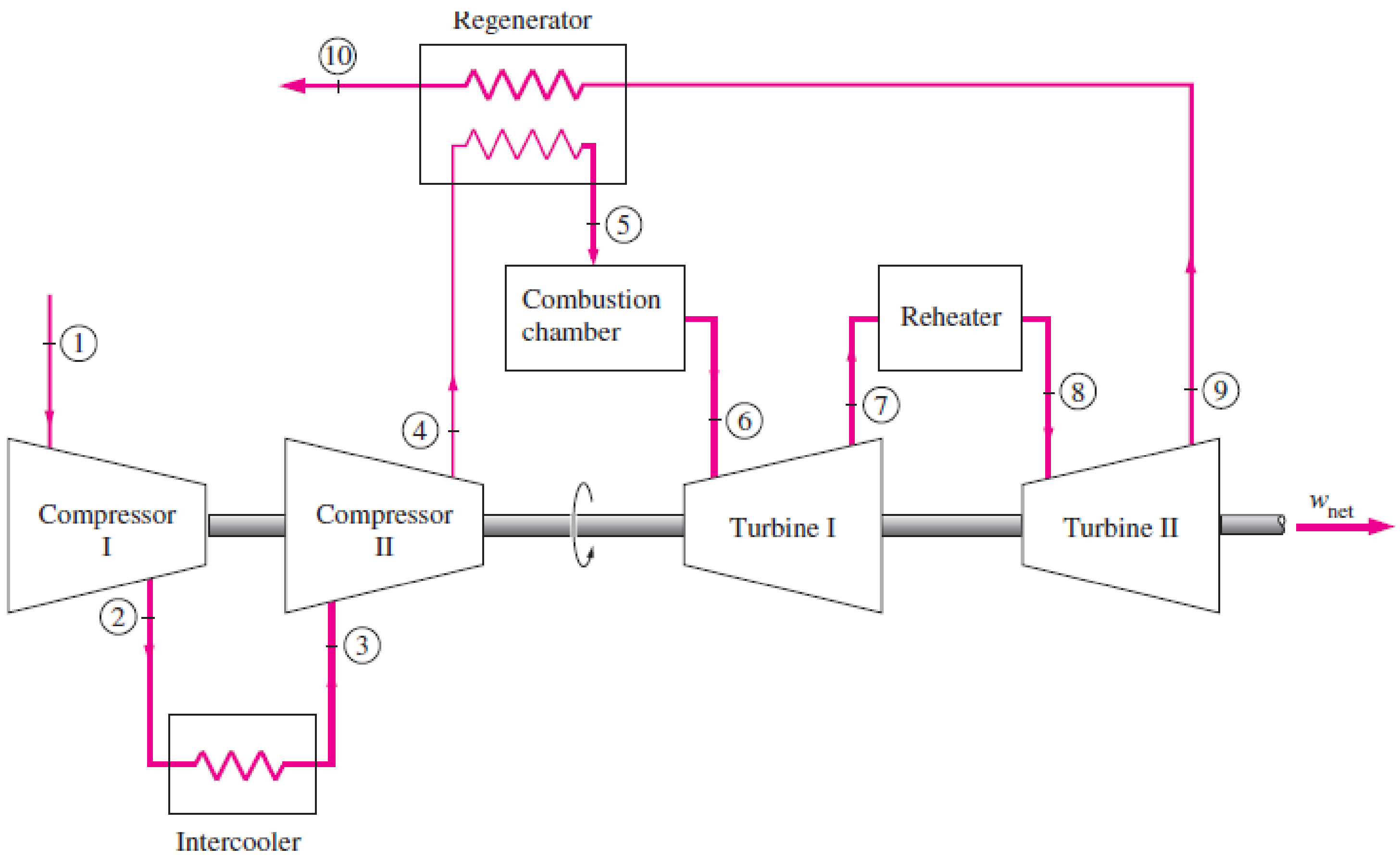
Fossil Energy Resources-Power Generation

Brayton cycle-Gas turbine power plant



Fossil Energy Resources-Power Generation

Brayton cycle-Gas turbine power plant



Fossil Energy Resources-Power Generation

Rankine cycle-Steam Turbine power plant

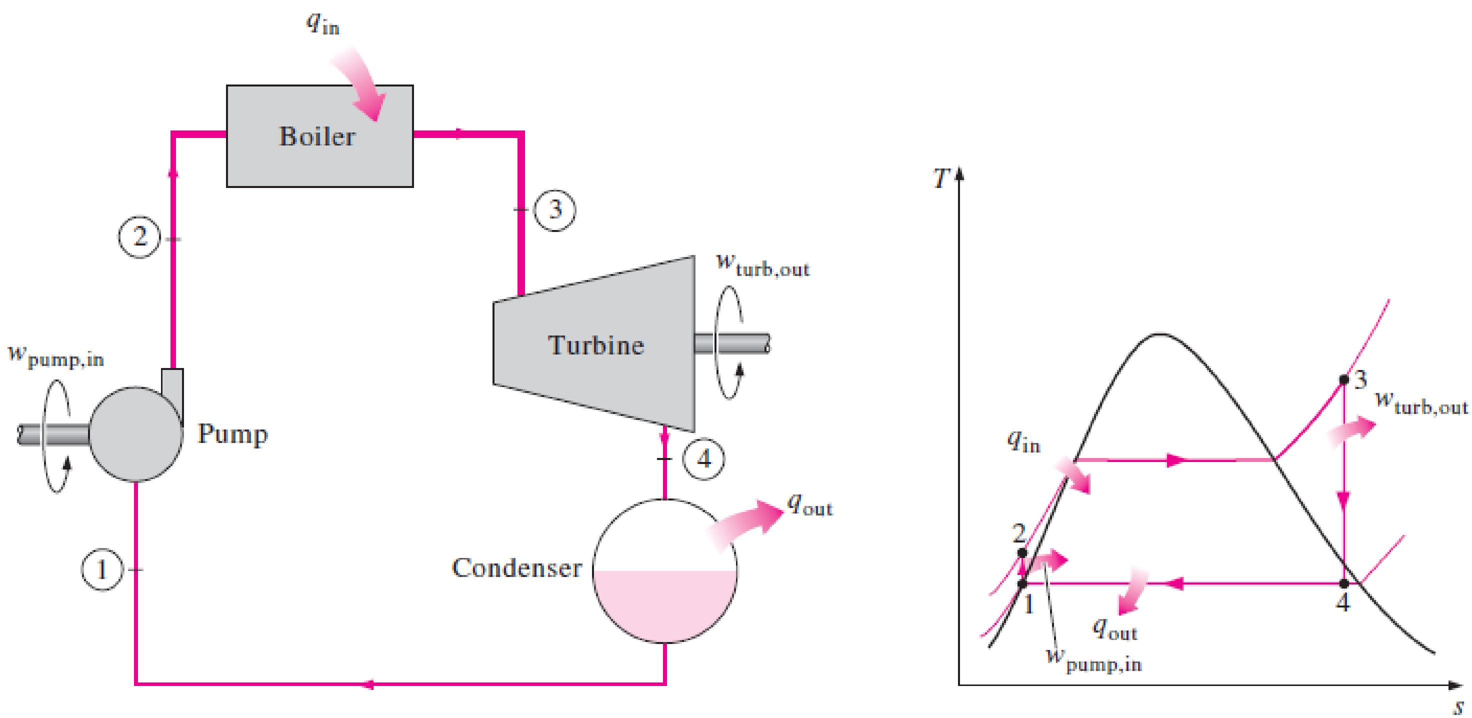
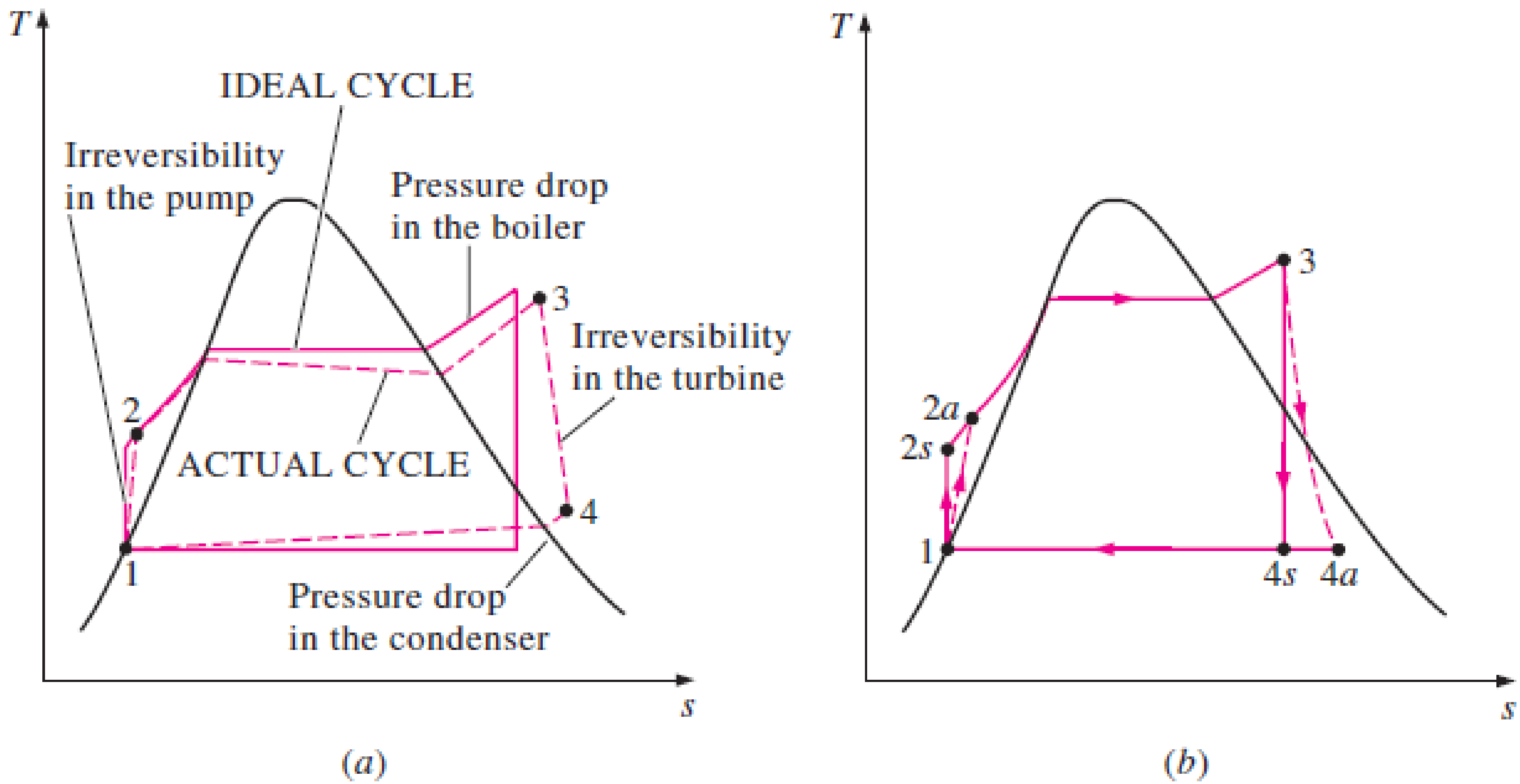


FIGURE 10–2

The simple ideal Rankine cycle.

Fossil Energy Resources-Power Generation

Rankine cycle-Steam Turbine power plant



Fossil Energy Resources-Power Generation

Rankine cycle-Steam Turbine power plant

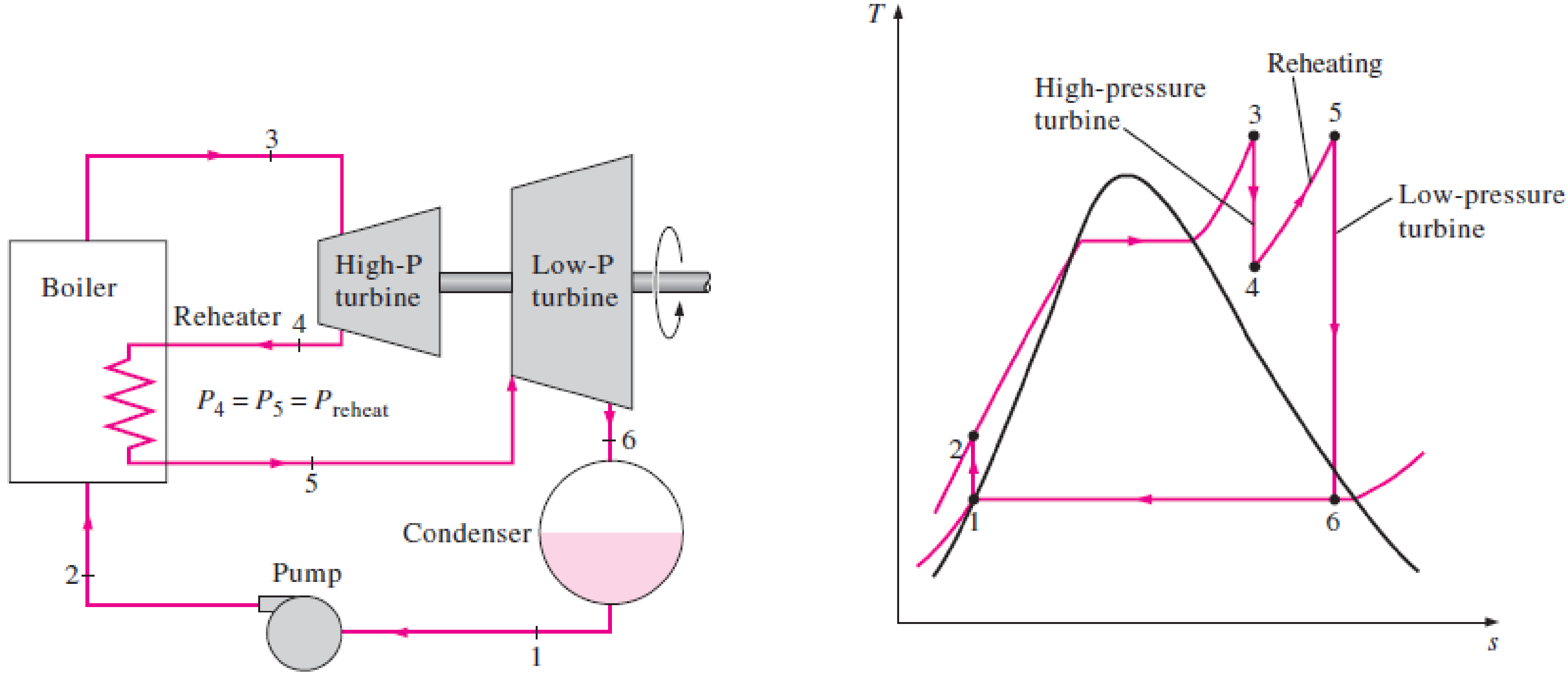


FIGURE 10–11
The ideal reheat Rankine cycle.

Fossil Energy Resources-Power Generation

Rankine cycle-Steam Turbine power plant

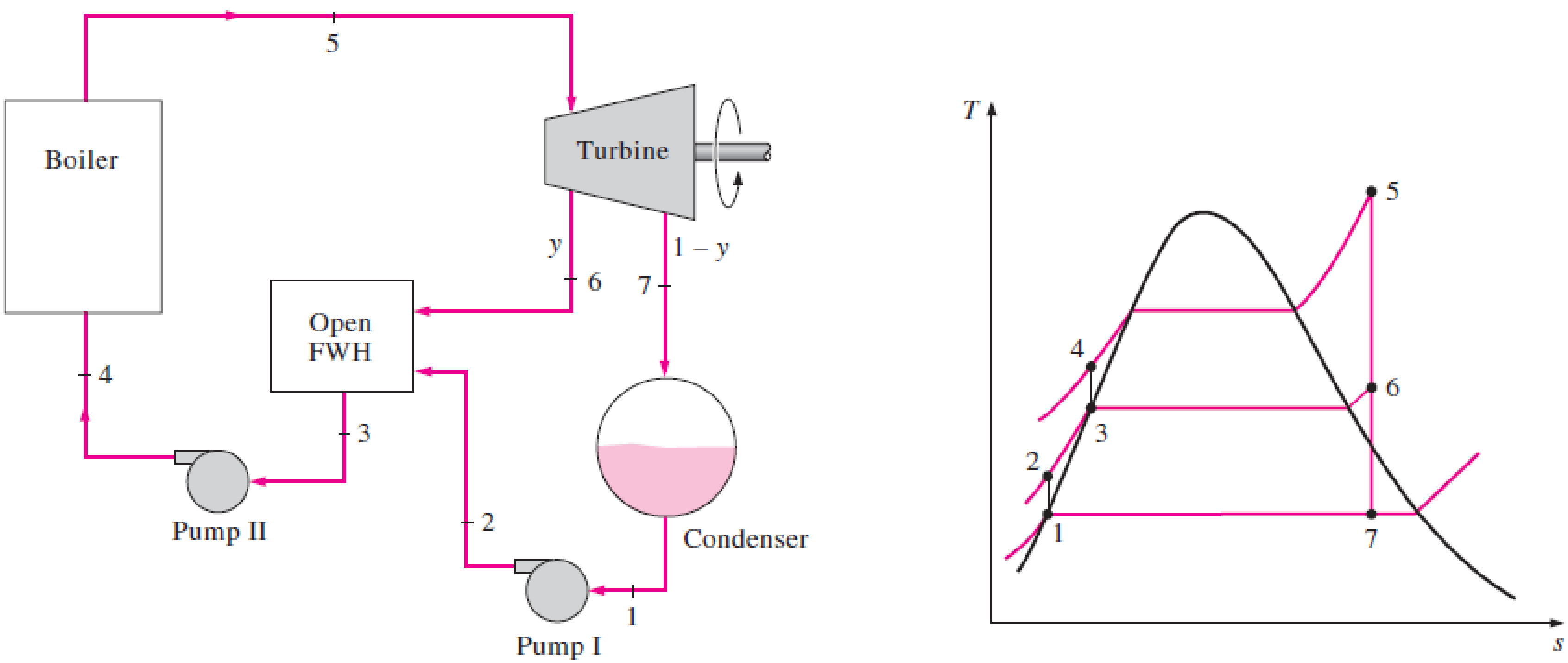


FIGURE 10–15
The ideal regenerative Rankine cycle with an open feedwater heater.

Fossil Energy Resources-Power Generation

Combined cycle for power plant

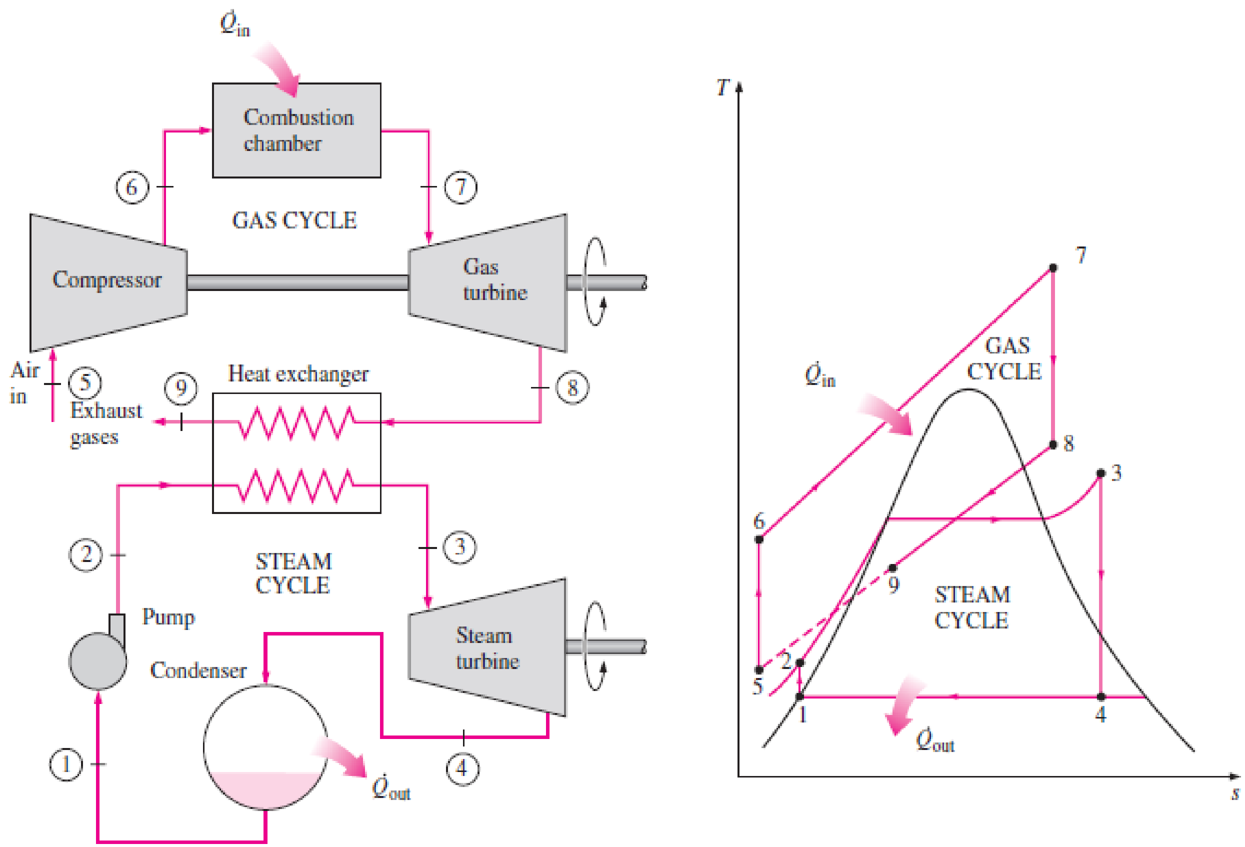


FIGURE 10–24
Combined gas–steam power plant.

Home Work

- Chapter 07: Handouts_Chapter7_Coal classification
- Problem Sheet 01: Non Renewable Energy

Thank You