Energy Resources & Utilization

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Course Contents

I. Fossil Energy Resources and Technologies

Oil, Gas and Coal reserves, production technologies and trends, consumption trends, Technologies for conversion for heat, electricity and transport

II. Renewable Energy Resources and Technologies

Definition and types of Renewable Energies, Resource availability, technologies and applications Solar Energy (thermal and photovoltaics) Wind Energy (resources, turbines and applications), Hydropower (resources, turbines, small hydro power systems and applications), Biomass Energy (resources, thermal and non thermal applications of biomass, and biofuels), Geothermal Energy (resources, heat and electricity applications), Other Renewable Energy Resources (Tidal, Wave and Ocean Thermal Energy Conversion)

III. Outlook of future energy use, Towards a low carbon society, Energy access and energy conservation

Text Books

- I. JohnTwidell, TonyWeir, AnthonyD.Weir “Renewable Energy Resources”,Taylor&Francis.
- Godfrey Boyle, “Renewable Energy - Power for a Sustainable Future”. Oxford University Press, 2004
- Jefferson W. Tester, Elisabeth M. Drake, Michael J. Driscoll, Michael W. Golay, William A. Peters, “Sustainable Energy: Choosing Among Options”, The MIT Press.
- Anjaneyulu Yerramilli, Francis Tuluri “Energy Resources, Utilization and Technologies”

Lecture Plans

Fossil Energy Resources and Technologies (3-<u>4 Weeks</u>)

Coal, oil and gas reserves, production, trends, Energy modeling and demand forecasting

Renewable Energy Resources and Utilization (<u>7-8 Weeks</u>)

Solar, Wind, Hydropower, Biomass, Carbon Capture Storage (CCS), Geothermal, Tidal/Ocean Thermal Energy

Outlook of future energy use, Towards a low carbon society, Energy access and energy conservation (<u>2 Weeks</u>)

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.

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.

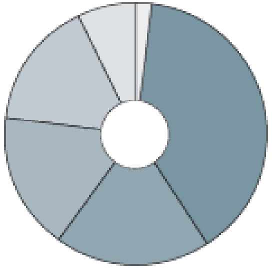
Coal formation began during the Carboniferous Period – known as the first coal age – which spanned 360 million to 290 million years ago

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.*

Coal Formation

Total World Electricity Generation (% by Fuel, 2002)

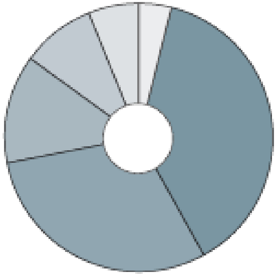


Coal	39%
Gas	19%
Nuclear	17%
Hydro	16%
Oil	7%
Other*	2%

**Other includes solar, wind, combustible r*

Source: IEA 2004

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

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.

Coal Characterization

TABLE 7-1
Carbon content and age of different coals

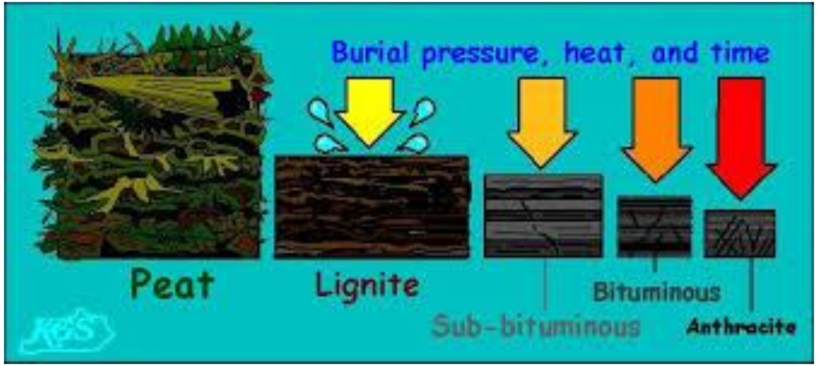
Coal type	Approximate age (years)	Approximate carbon content, %
Lignites	60,000,000	65-72
Subbituminous coals	100,000,000	72-76
Bituminous coals	300,000,000	76-90
Anthracites	350,000,000	90-95

Coal characterization

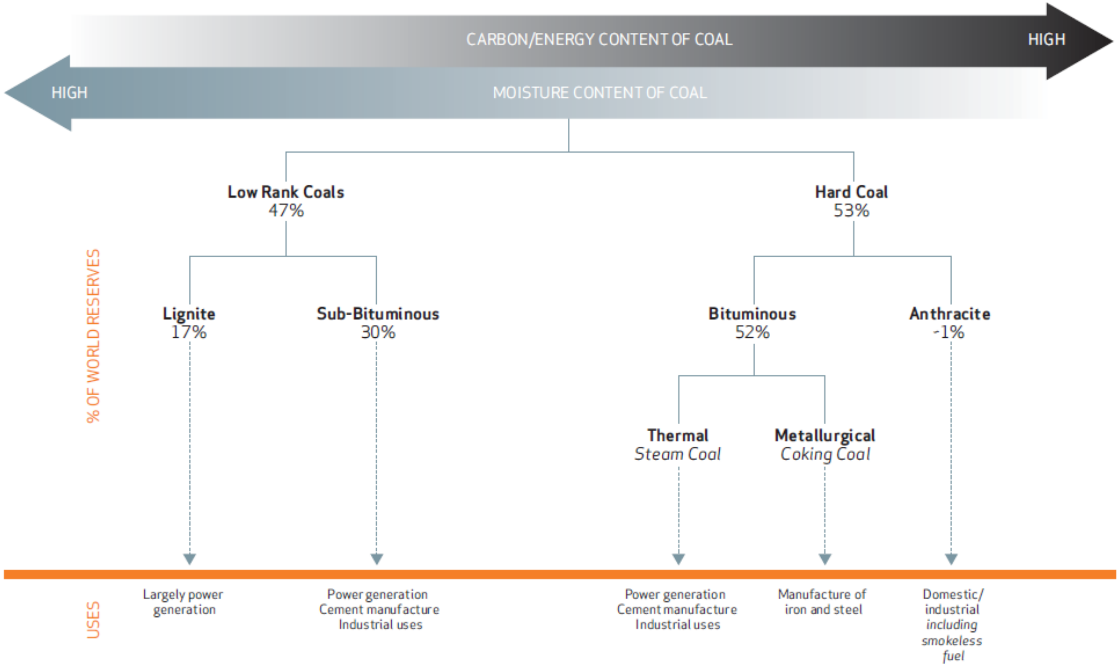
	<---------- Low Rank ------->		<---- High Rank ------------>	
Rank:	Lignite	Subbituminous	Bituminous	Anthracite
Age:	---------------------------------- increases --------------------------------->			
% Carbon:	65-72	72-76	76-90	90-95
% Hydrogen:	~5 ----------------------- decreases ----------------------- ~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.

Coal characterization



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


CARBON/ENERGY CONTENT OF COAL
HIGH
HIGH
MOISTURE CONTENT OF COAL
% OF WORLD RESERVES
Low Rank Coals
47%
Hard Coal
53%
Lignite
17%
Sub-Bituminous
30%
Bituminous
52%
Anthracite
-1%
Thermal
Steam Coal
Metallurgical
Coking Coal
USES
Largely power generation
Power generation
Cement manufacture
Industrial uses
Power generation
Cement manufacture
Industrial uses
Manufacture of iron and steel
Domestic/ industrial including smokeless fuel

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 lustre. 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

Coal Analysis

Ultimate (elemental) Analysis

Elemental or ultimate analysis encompasses the quantitative determination of Carbon, hydrogen, nitrogen, sulfur and oxygen within the coal.

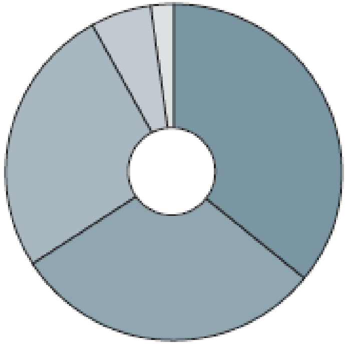
Proximate Analysis

moisture, volatile matter, ash, and fixed carbon.

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

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

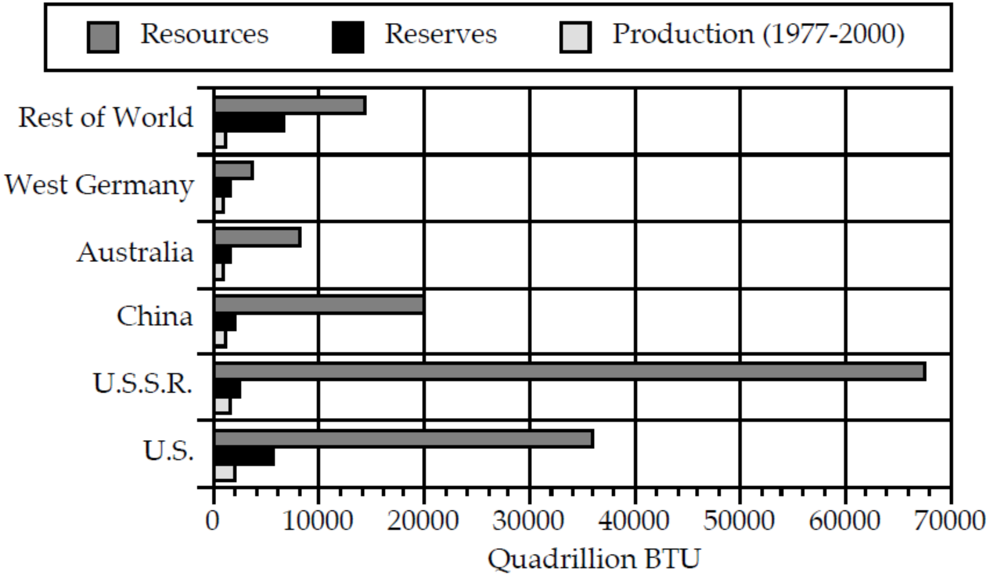


FIGURE 7-1. World distribution of coal resources and reserves.
[Source: W. Fulkerson et al., *Scientific American*, September 1990, p. 129.]

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.

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)

Coal Utilization

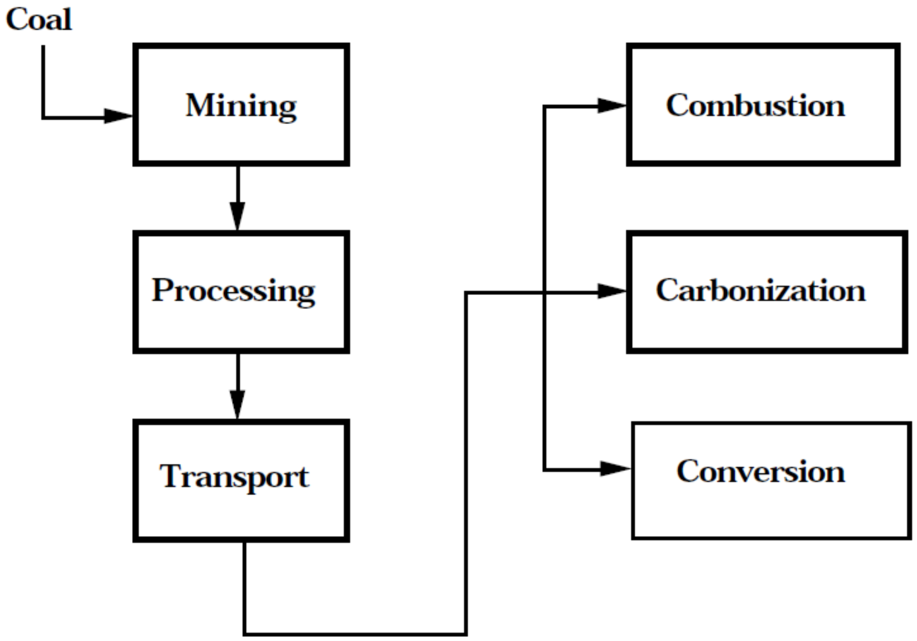


FIGURE 7-4
Pathways to coal utilization.

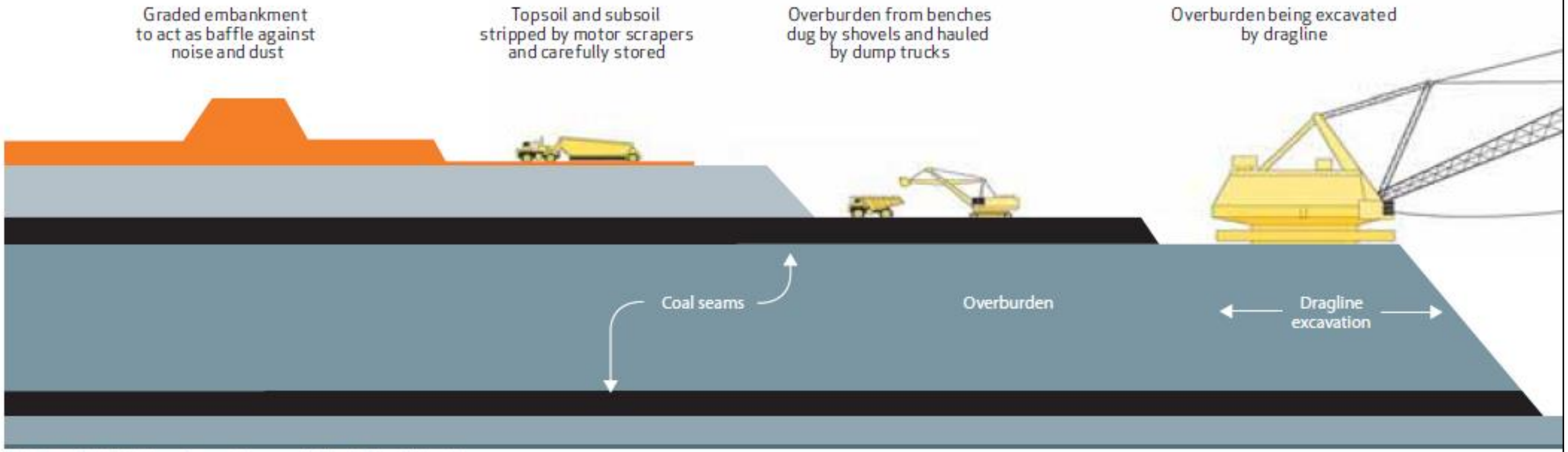
Coal Mining

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



Surface Coal Mining Operations and Mine Rehabilitation

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

Coal processing

Coal straight from the ground, known as runof-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.

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.

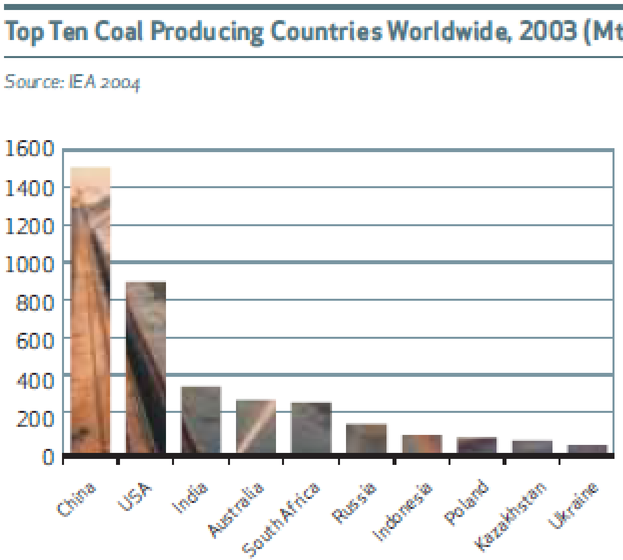
Coal is generally transported by conveyor or truck over short distances. Trains and barges are used for longer distances

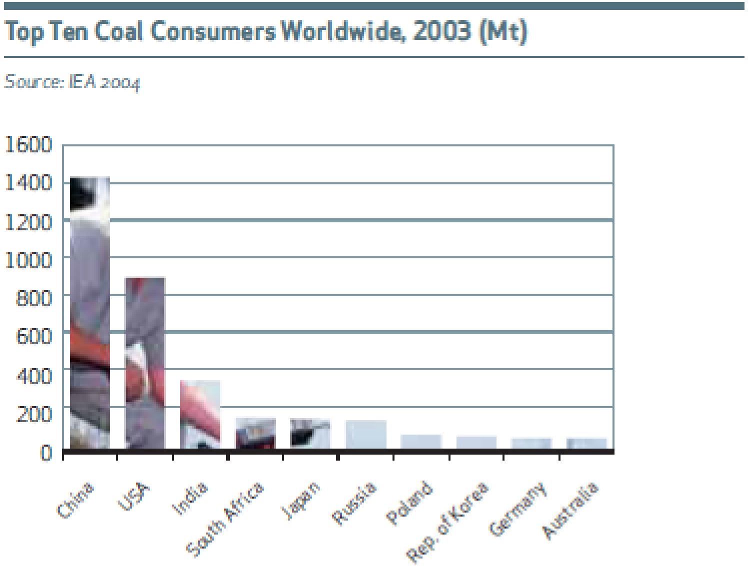
within domestic markets, or alternatively coal can be mixed with water to form a coal slurry and transported through a pipeline.

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.

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.

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.

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.

Coal Utilization

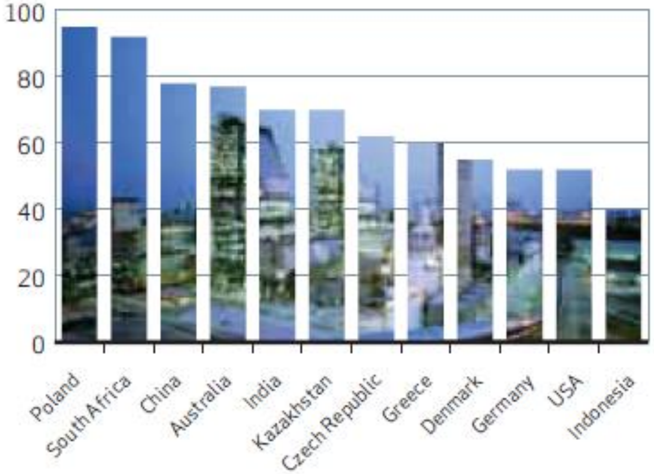
Coal still plays a vital role in the world's primary energy mix, providing 23.5% of global primary energy needs in 2002, 39% of the world's electricity, more than double the next largest source, and an essential input into 64% of the world's steel production.

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

Coal Utilization

Percentage of Electricity Generated from Coal in Selected Countries (mixture of 2003 & 2002 data)

Source: IEA 2004



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 pulverised 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.

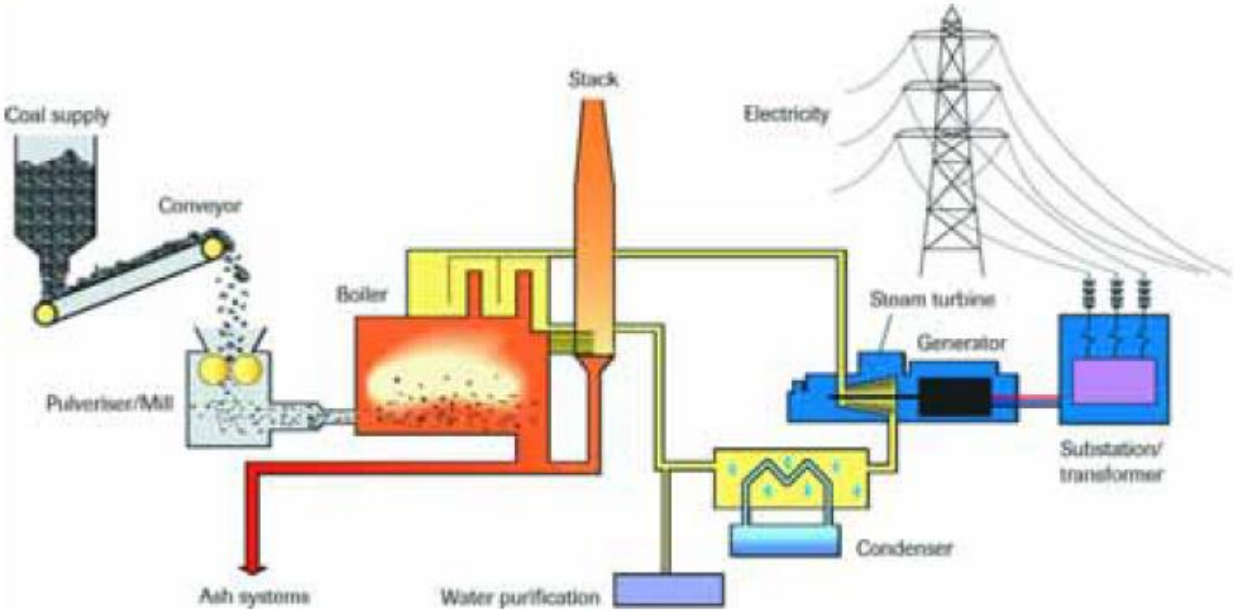
Coal Utilization-Power Production

Top Five Coking Coal Producers (Mt)

China	159
Australia	112
Russia	55
USA	40
Canada	23

Source: IEA 2004

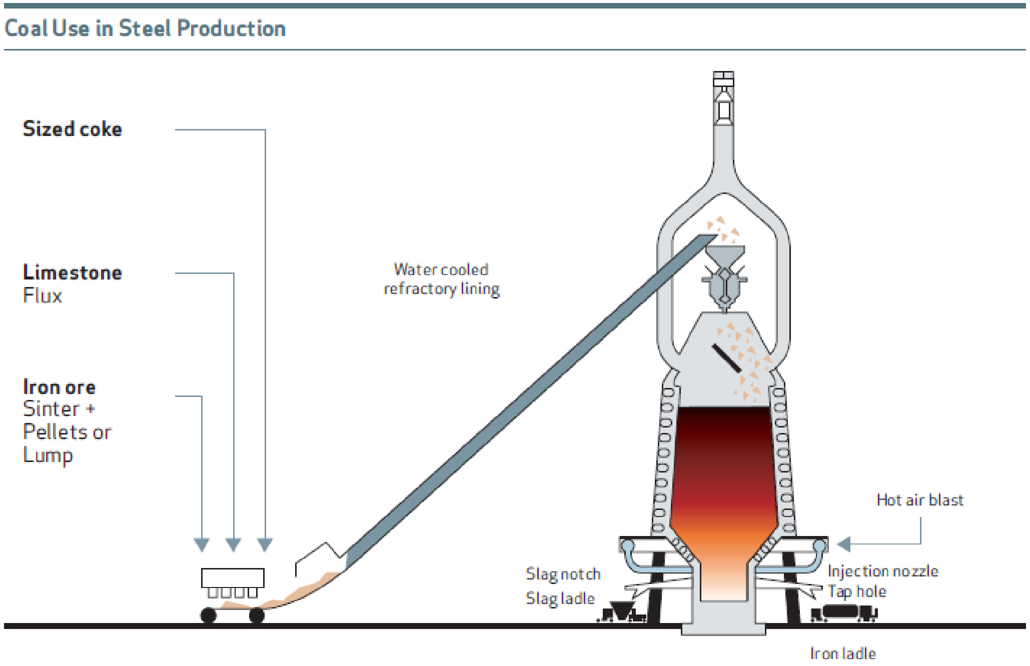
Converting Coal to Electricity



Coal Utilization-Steel Mills

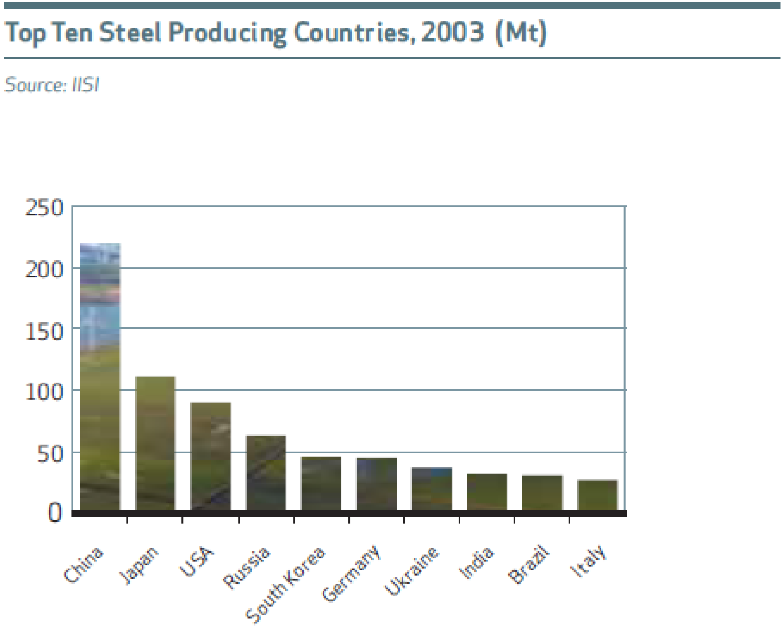
Some 64% of steel production worldwide comes from iron made in blast furnaces

A blast furnace uses iron ore, coke (made from specialist coking coals) and small quantities of limestone.



Coal Utilization-Steel Mills

Coke has certain physical properties that cause them to soften, liquefy and then resolidify 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.



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.

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 fuelled 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.

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.

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”.

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

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

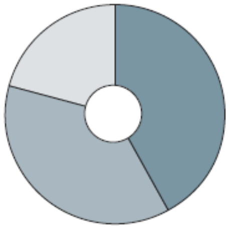
Coal and the environment

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.

Coal and the environment

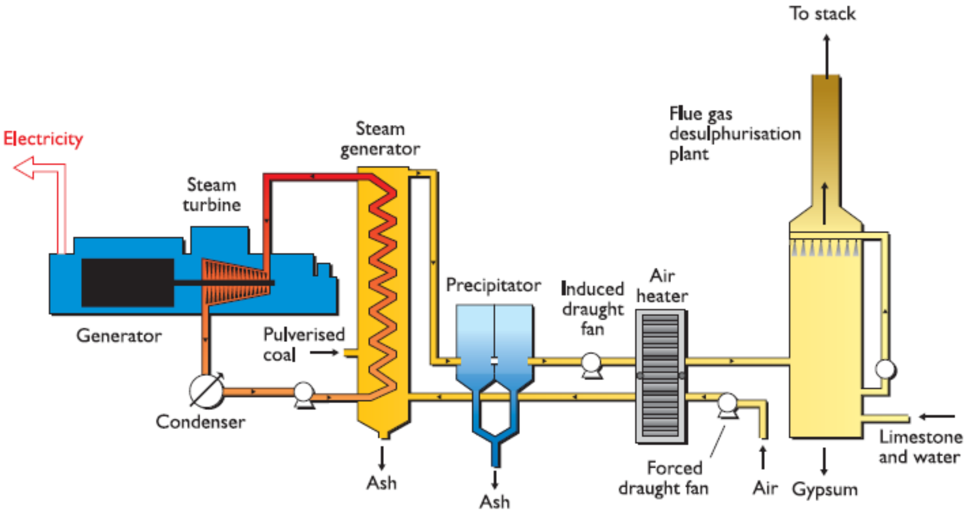
CO_2 Emissions from Fossil Fuels



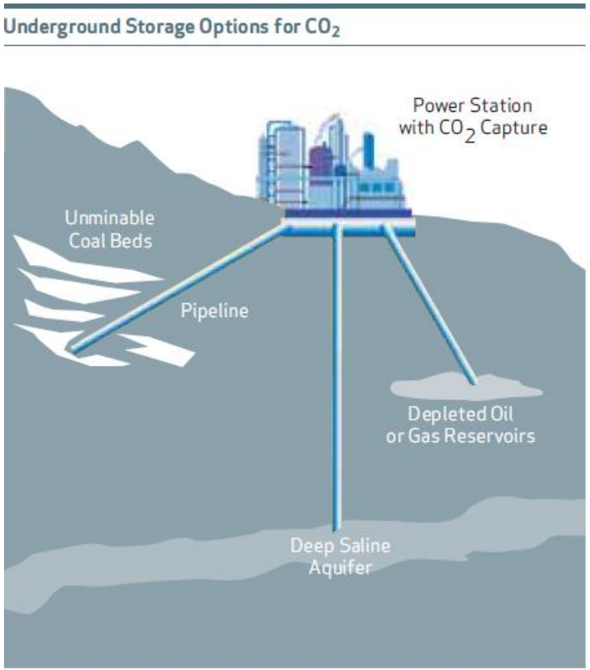
Oil	41%
Coal	38%
Gas	21%

Source: IEA 2004

A Flue Gas Desulphurisation System



Coal and the environment



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

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**	

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**	

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

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

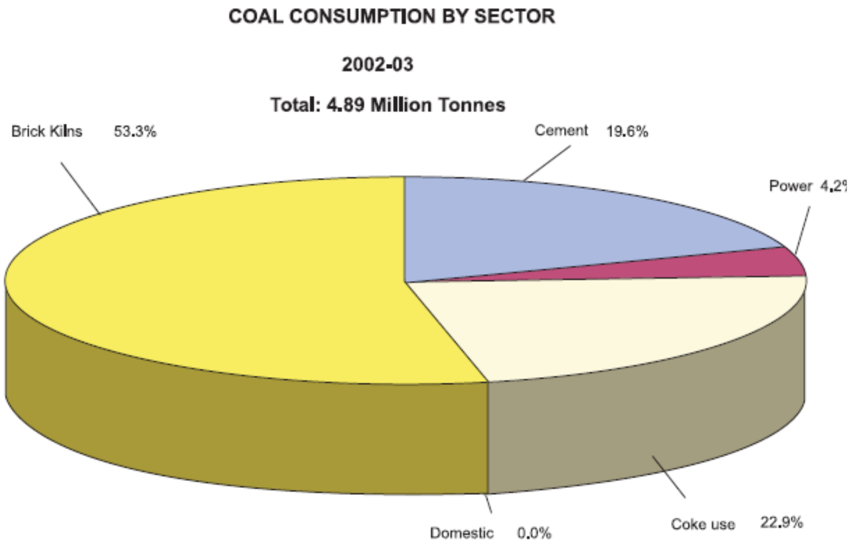
Coal-Local context

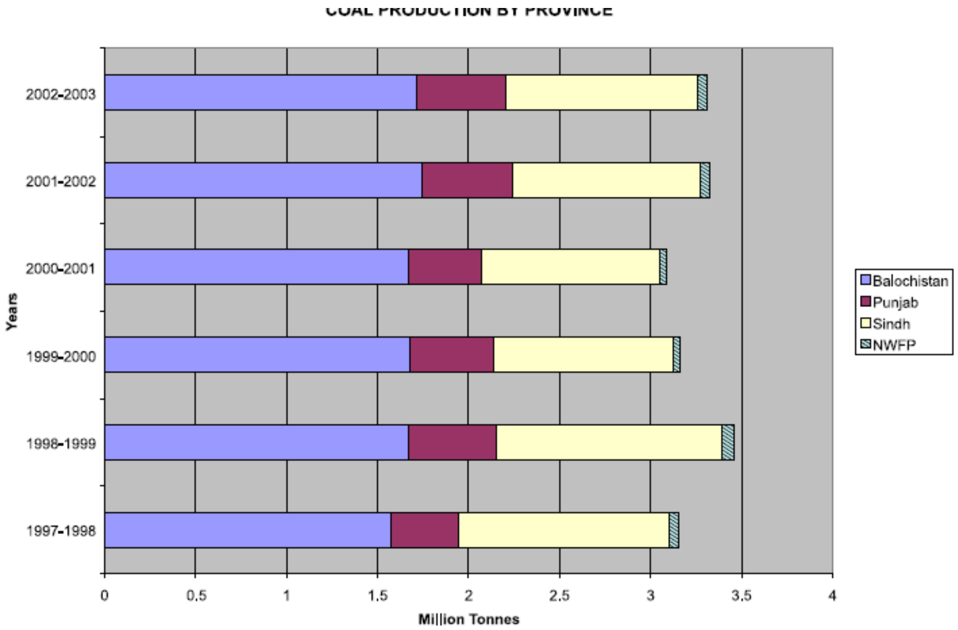
a) The power station must be located at the mine site, because the low energy and high moisture content of lignite coal do not justify the transportation cost.

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.

Coal-Local context





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

Chapter 5 World Energy Assessment Report

BP Statistical Review of World Energy

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**

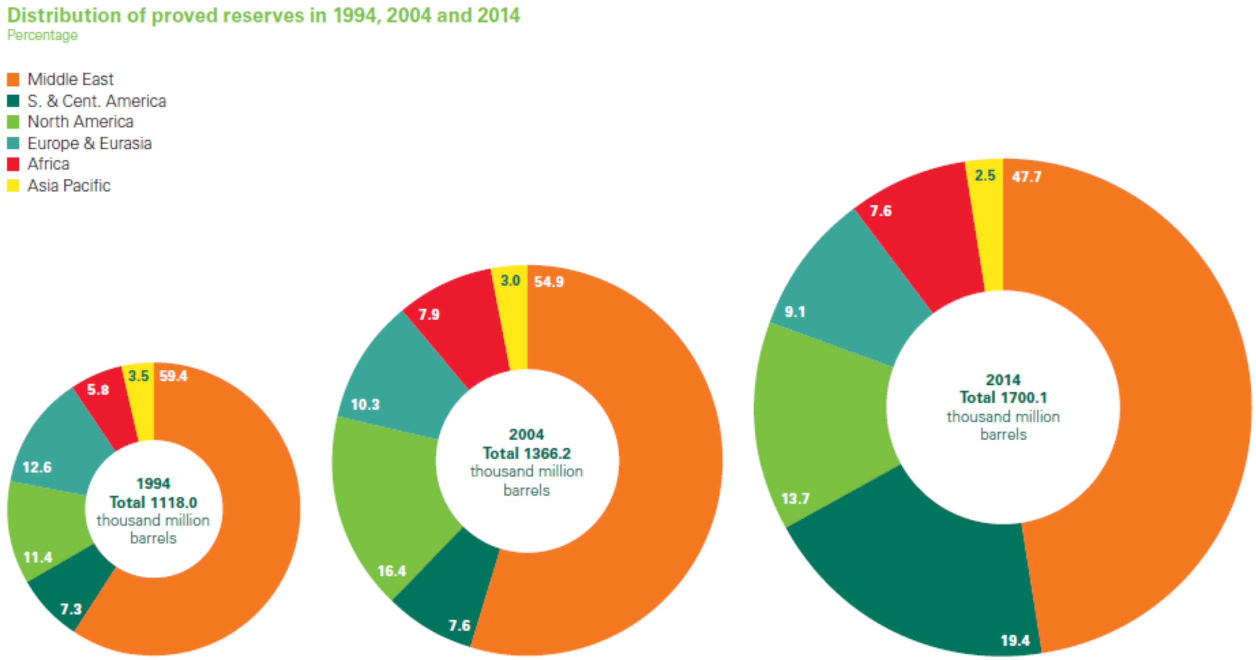
Estimated oil reserves

Oil

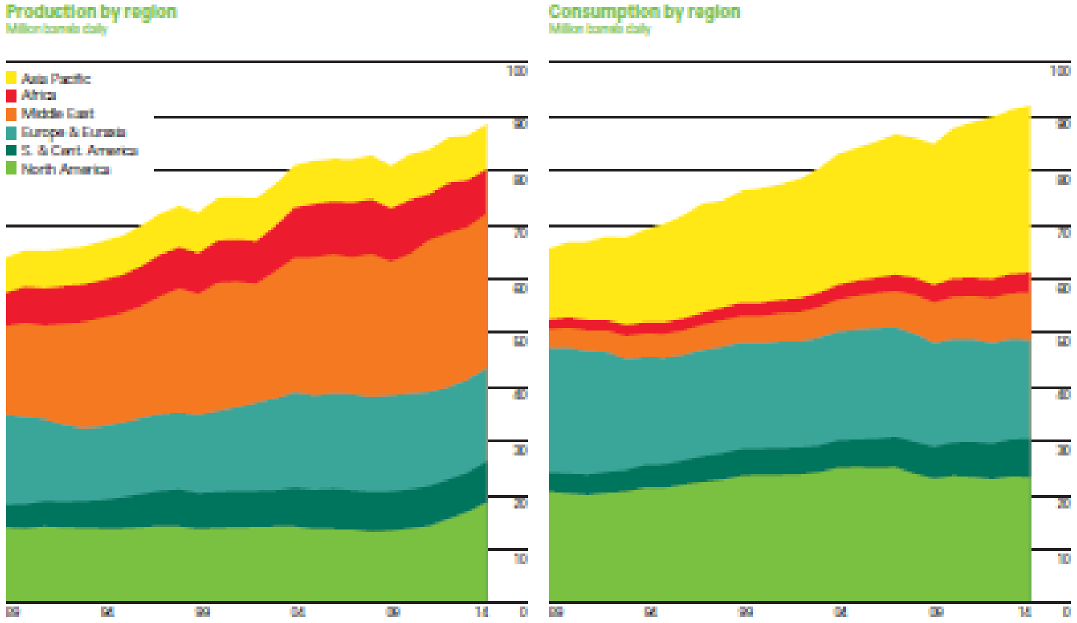
Total proved reserves

	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%	*

Estimated oil reserves



Oil production and consumption



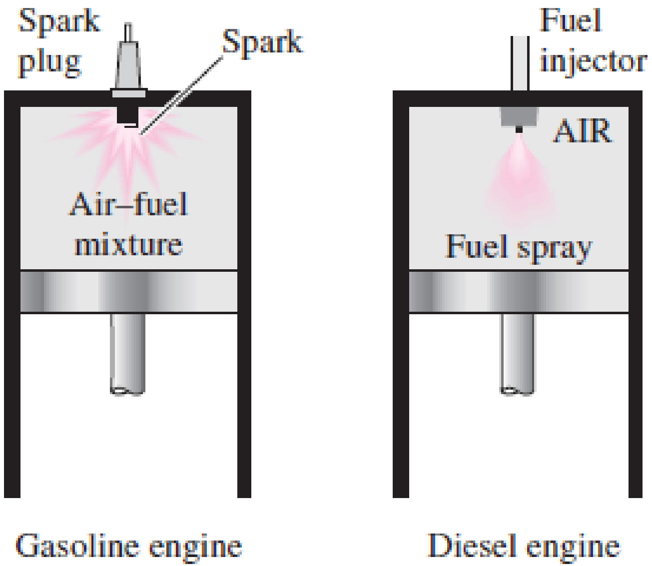
Estimated gas reserves

TABLE 5.3. ESTIMATED NATURAL GAS RESERVES

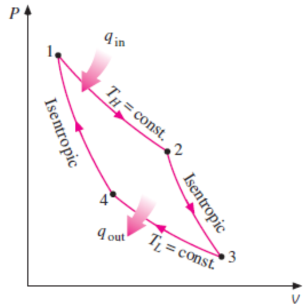
Region	Proven recoverable reserves (WEC, 1998)		Total recoverable reserves (WEC, 1998)		Proven and additional reserves (IGU, 2000)		Proven reserves (BP, 1999)		Enhanced gas recovery	
	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3	Exajoules	Tm^3
North America	252	6.8	389	10.5	2,307	63.0	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

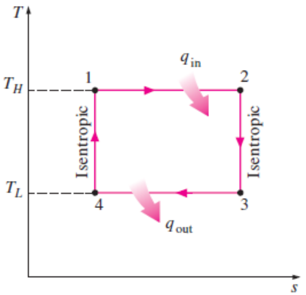
Heat Engine

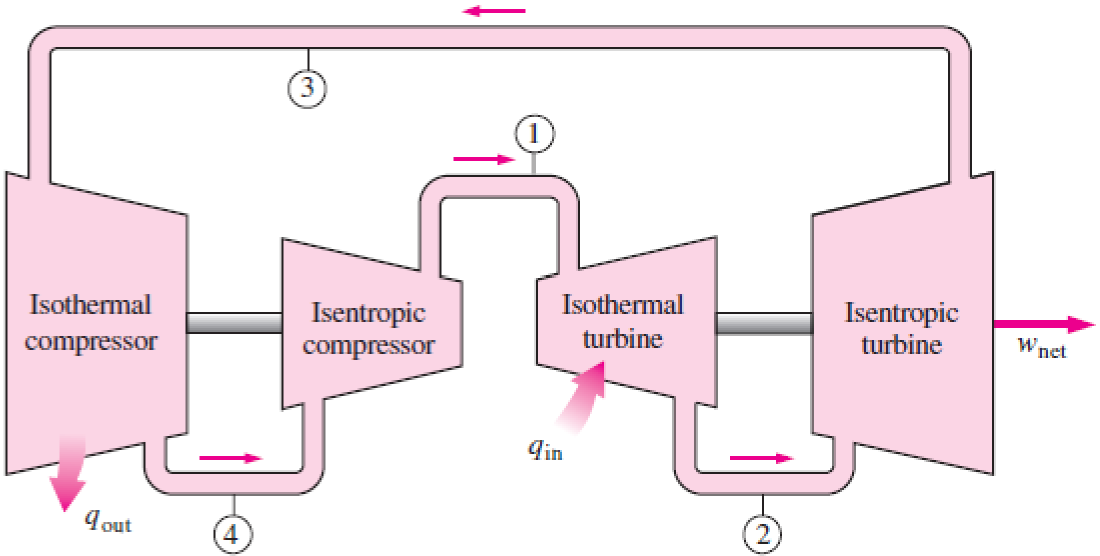
Heat Energy to Mechanical Energy



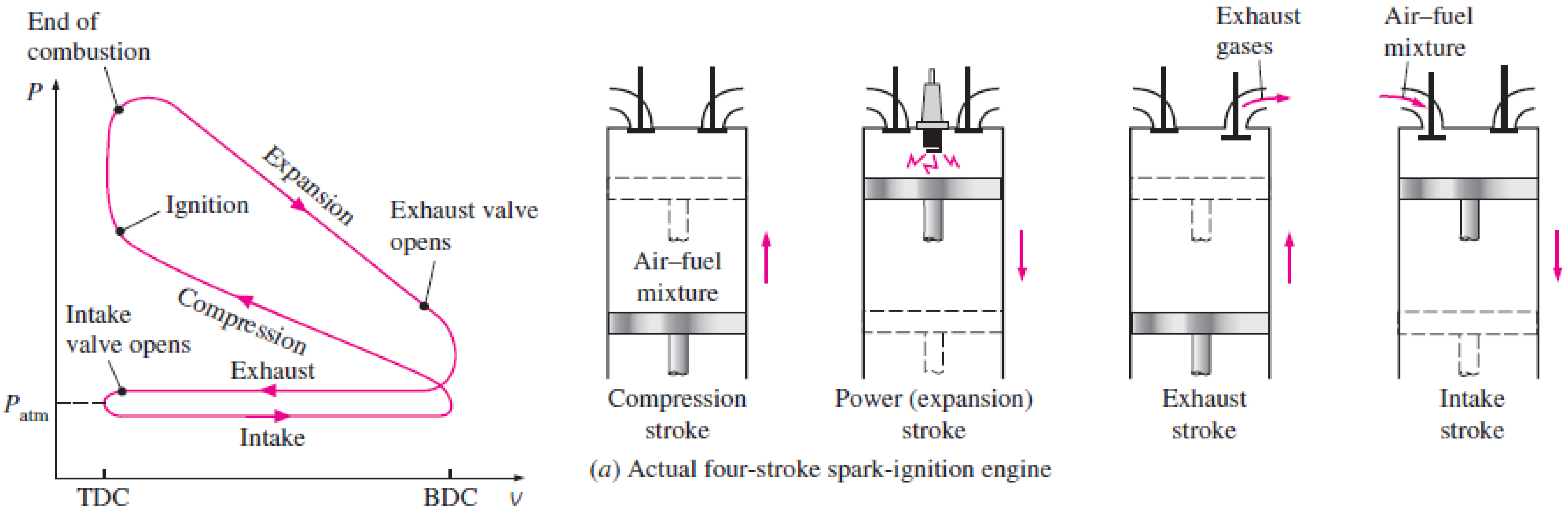
Carnot cycle-Ideal cycle for Heat Engines





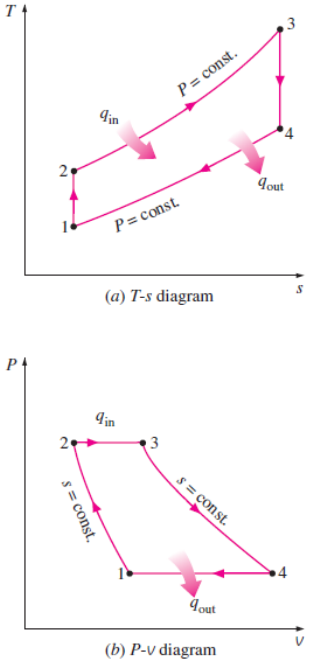


Otto Cycle-Reciprocating Engines



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

Brayton cycle-Gas turbine power plants



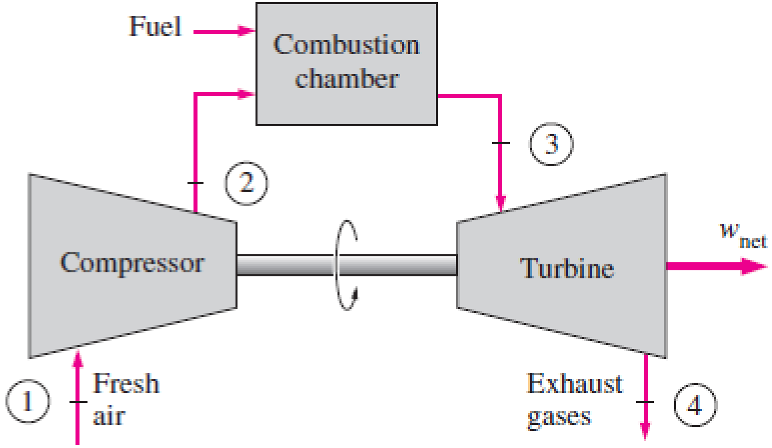
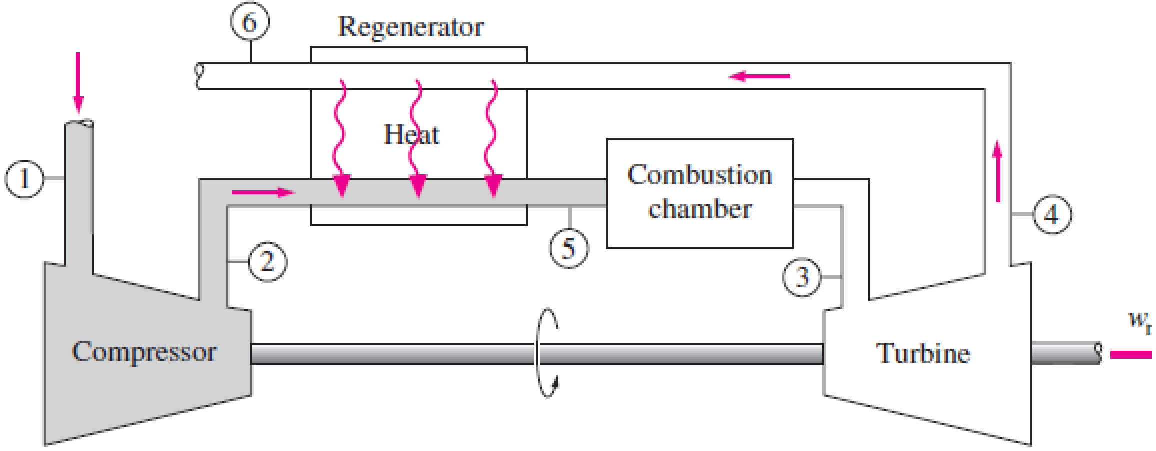
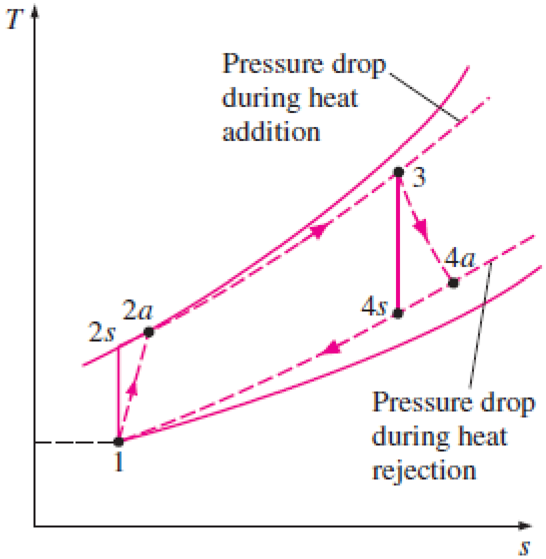


FIGURE 9–29

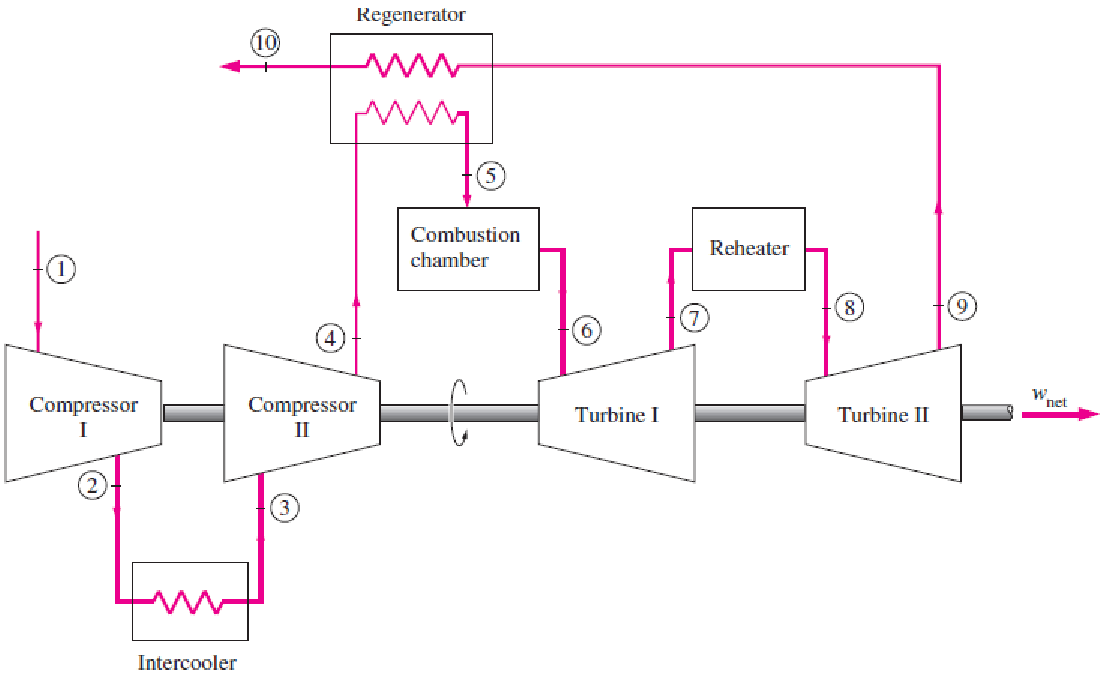
An open-cycle gas-turbine engine.

Brayton cycle-Gas turbine power plant

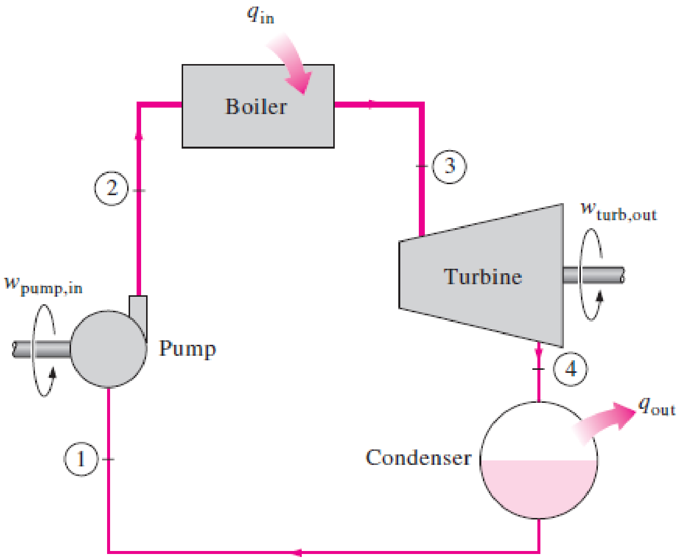




Brayton cycle-Gas Turbine power plants



Rankine cycle-Steam Turbine power plant



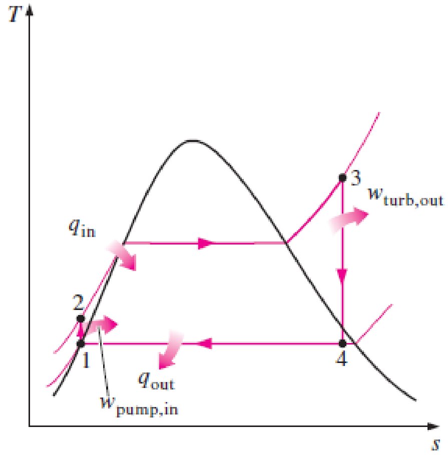
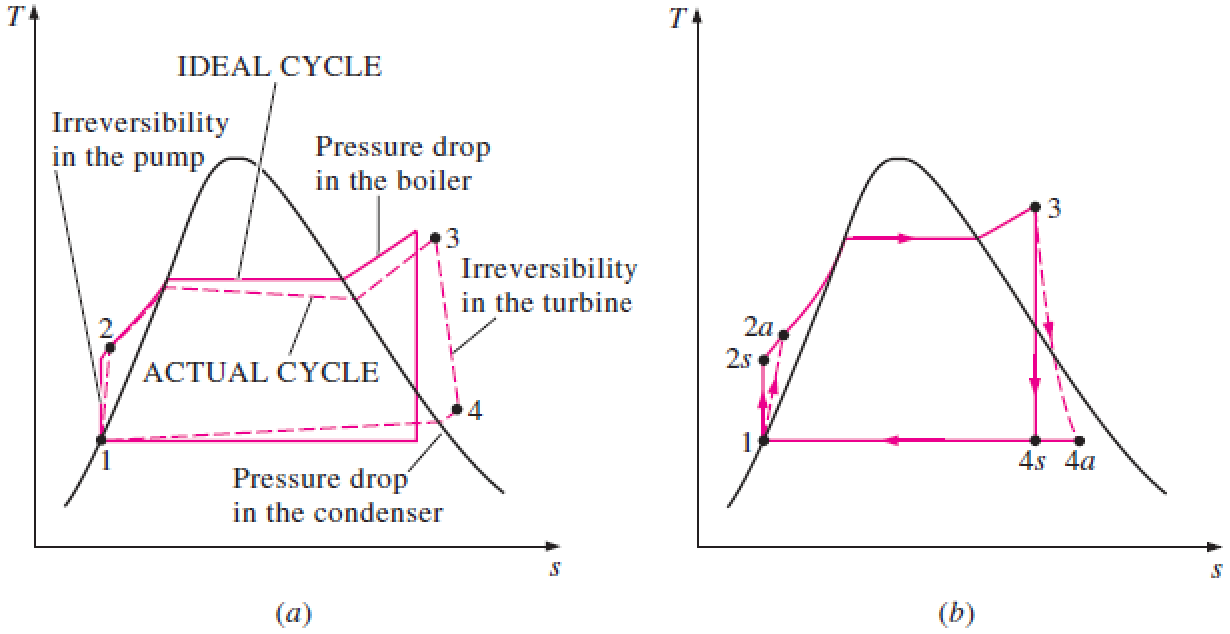


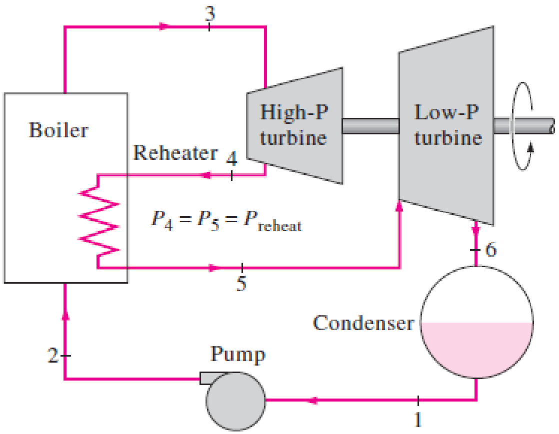
FIGURE 10–2

The simple ideal Rankine cycle.

Rankine cycle-Steam turbine power plant



Rankine cycle-Steam turbine power plant



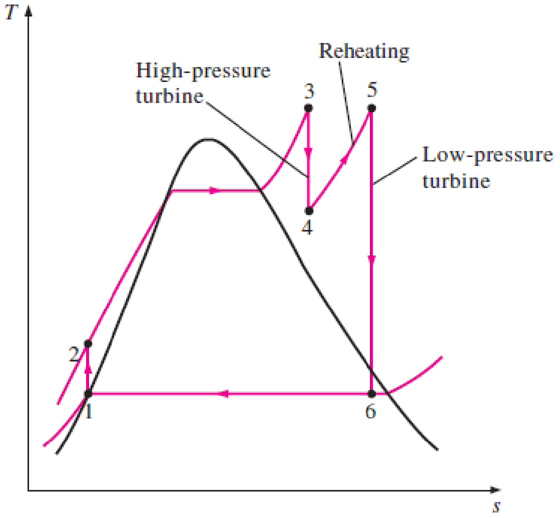


FIGURE 10–11

The ideal reheat Rankine cycle.

Rankine cycle-Steam turbine power plant

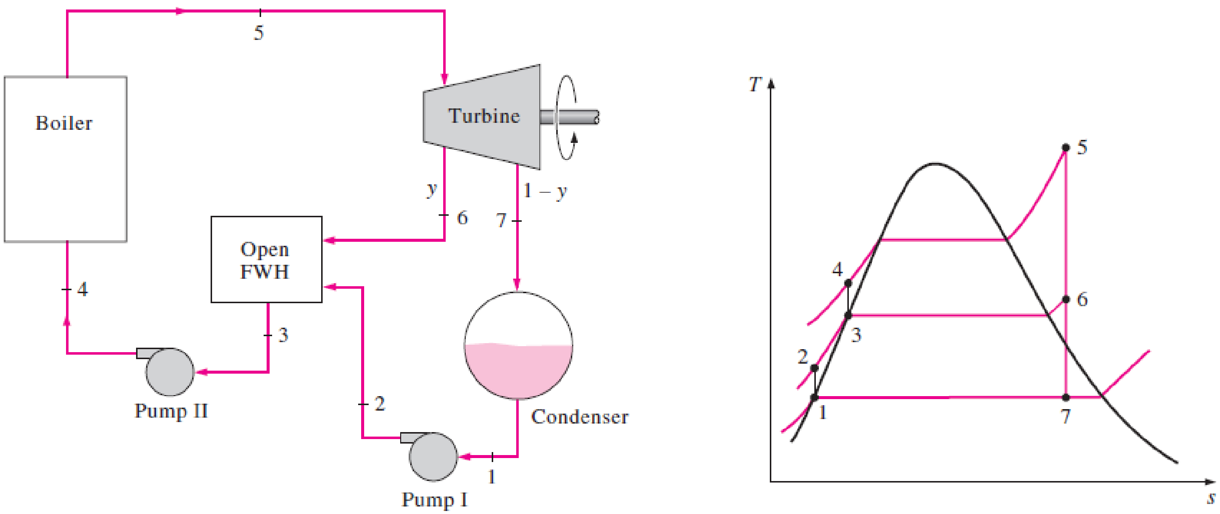


FIGURE 10–15

The ideal regenerative Rankine cycle with an open feedwater heater.

Combined cycle for power plant

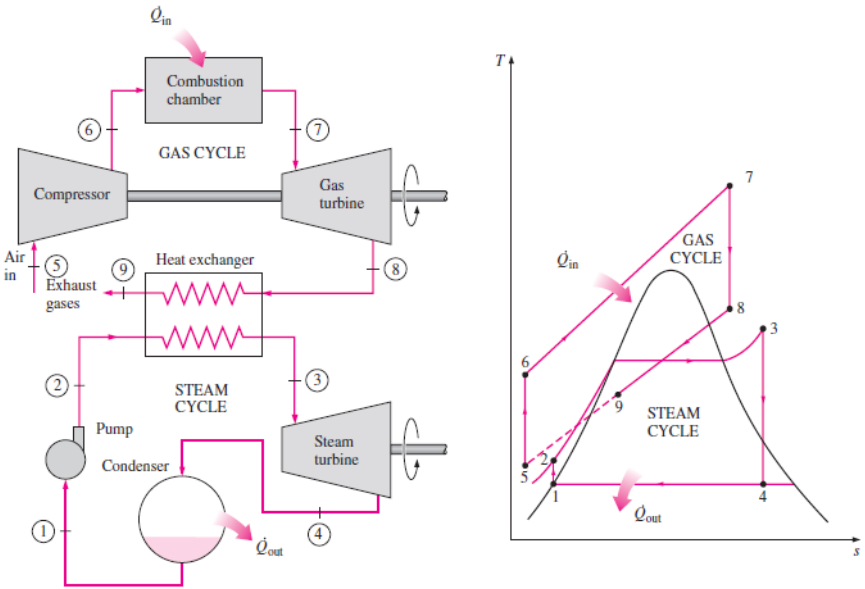


FIGURE 10–24
Combined gas–steam power plant.