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Registered in England number 4050834

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Designed and printed by RAS Design, Chester 01244 346666

The Electricity Generation Mass Balance









A Biffaward Programme on Sustainable Resource Use

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Electricity Report - Forward

For the past 200 years society has become used to quantifying and understanding efficiency in 2 broad dimensions:

- labour and people input,
- financial costs.

Few have paused to think about the efficiency of the way we deliver goods and services in terms of physical resource inputs and outputs. This publication is an attempt to refocus our thoughts in that direction in relation to electrical power. Why bother? After all the environment is "free". We can use air or relatively low cost raw materials such as minerals, carbon or energy at will – it is the application and conversion of those resources that comes expensive.

We are now coming to terms with reality – that the profligate use of low "financially" priced resources has resulted in the introduction of large quantities of liquid, gaseous or solid waste into the world at a rate faster than the eco-system can return it to its original state – if at all. The consequences of this may not necessarily be as cheap as we thought – indeed we are yet to count the future cost in terms of health, climate change and biodiversity loss.

Few in society recognise that our developed economy is consuming in excess of 10 tonnes of raw material resources for every one tonne of output purchased at the point of sale by private individuals. Much the same ratios apply to specific sectors – and energy is no exception. Indeed – as a weightless product – the ratios for electrical power are infinite! In 1998 the Government introduced the means by which Biffa could fund work undertaken by those keen to explore the implications of this level of inefficiency. The Landfill Tax Credit Scheme has allowed us to commit over £8m in the last 4 years to more than 50 such sector studies which look at the dynamic of resource flows through different regions, industry sectors and resource lifecycles.

Environmental impacts come in the form of widespread use of non renewable materials sourced and disposed of in ways that don't necessarily represent the best deal for society in the long run. For the cynics among us, the dictum that it will be financial costs that drive the process is probably the right one and those costs are set to rise. Landfill Tax has risen at a mere £1 per tonne over the last 7 years and the Chancellor has announced a £35 cap for around 2011 – driven by higher levels of awareness on the workings of environmental taxation in the Government, as well as increased pressures resulting from the recent spending round. Additionally, a much wider range of materials being used are about to be reclassified as hazardous with the consequence that they will be banned from landfill and, of necessity, treated in ways which recover their constituent elements for reuse in other product cycles. Producer Responsibility, targets and Traded Pollution Permits are all adding to the emergent tapestry of Environmental instruments.

The energy sector is going to have to learn how to trade-off these new economic as well as environmental realities. Apart from the cost push pressures driven by European and UK legislation/regulation, there are also the expectations of your "market place". Generators are under increasing pressure to develop internal reporting guidelines on all aspects of their environmental track record. Unfortunately this report will create more questions than it answers – but that is always the case with such leading edge work. It certainly highlights the chronic absence of reliable data on resource generally. This should be no surprise given parallel paucity of data on mainstream areas under management – particularly waste – where policy-making is bedevilled by an absence of an integrated framework or sets of common definitional protocols. Indeed, in part, this publication should trigger questions in the context of the e-Government initiative. Today it is but a dream to believe that a comprehensive overview of resource inputs into and out of UK Plc could be obtained at the flick of a button!

This publication is designed to present the wider picture and inform the debate. If you wish to explore the issues outside your own industry, then find out more about the Biffa Mass Balance Programme on www.massbalance.org and see examples of some of the 50 odd commissioned studies which have reported thus far.

Peter Jones
Director - Development and External Relations
Biffa Ltd

Biffaward Programme on Sustainable Resource Use – Objectives

This report forms part of the Biffaward Programme on Sustainable Resource Use. The Programme aims to provide accessible, well researched information about the flows of different resources through the UK economy based either singly or in combination on regions, material streams and economic sectors. Information about material resource flows through the economy is of fundamental importance to the cost effective management of resource flows, especially at the stage when those resources become waste. In order to maximise the Programme's full potential, data will be generated and classified in ways which are consistent with each other and with the methodologies of other generators of resource flow/waste management data.

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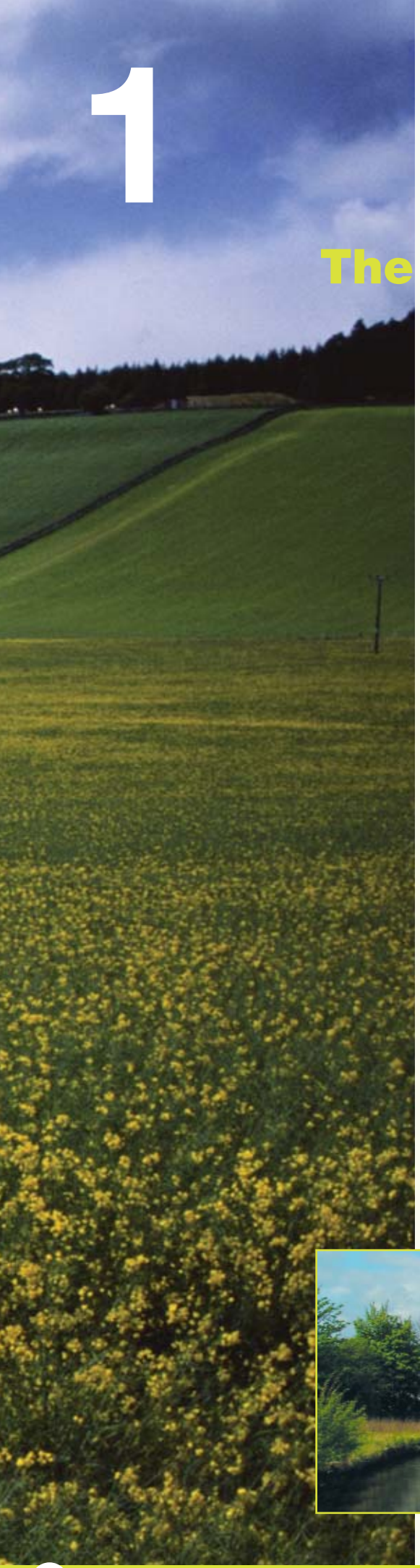
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1

This document sets out the key findings, conclusions and recommendations of the Biffaward Electricity Generation Mass Balance project.

The Electricity Generation Mass Balance

1.1 Introduction

The report sets out the total material resource requirement of the electricity generation industry and identifies the wastes and emissions associated with the industry. Information is presented as total mass (volume), and also as mass (volume)/kWh. This is further broken down into the four main electricity generation methods, namely, through the use of coal, oil, gas and nuclear power. The main recommendations are on the mass balance, information can be applied to the other Biffaward mass balances either completed or underway.

Information is also provided, in some detail, on the generation of electricity, the different methods, their associated emissions and wastes, and wherever possible a comparison is made between the UK and international situations. Regulatory influences are also examined, as is the market for renewable energy sources.

Wherever practical, existing definitions and classifications have been adopted to assist with the identification and categorisation, in order to maintain transparency and facilitate comparison with other electricity generation analyses.

1.2 The Electricity Generation Industry

The electricity generation industry has been defined as that industry, which is involved in the generation of electricity at power stations, located within the United Kingdom. Material flows are therefore concerned solely with the flow into and out of the different power stations, albeit in terms of the overall efficiency of the electricity generation process, account is made for transmission losses to the point of use.

No consideration has been made for energy consumption or material losses in the transport of material to the power stations etc. A number of studies have already quantified this.[1.1]

1.3 The Mass Balance

The underlying principle of a 'mass balance' is the physical law that within a closed system the total mass is constant.
This states that while there may be a movement of mass or a transformation of mass to different forms, for example solid to gas, it cannot be created or destroyed.
The purpose of a 'mass balance' is therefore to 'balance' the masses of all inputs to an activity with the outputs from an activity.

Further details of the mass balance approach to resource has been produced by Forum for the Future.[1.2]



1.4 The Choice of Indicators

The World Business Council for Sustainable Development has identified a limited set of 'eco-efficiency' indicators, which it proposes all companies could use for measuring their environmental performance.[1.3]

Some of these equate directly as indicators, others are more indirect.

The selected indicators are as follows:

- Annual material and product consumption.
- Material and product consumption per kilowatt-hour.
- Water consumption and usage.
- Greenhouse gas and ozone depleting substances emissions.
- Waste.

The greenhouse gas and ozone depleting substance emissions identified for this study are as following;

Water lost to steam

- CO_{2}* (carbon dioxide)
- CO (carbon monoxide)
- CH_{4}* (methane)
- NMHC (non-methane hydrocarbons)
- SO_{x} (sulphur oxides)
- PM10 (particulate materials)
- Benzopyrene
- HCl (hydrogen chloride)
- Hg (mercury)
- Rn & Ra (radon and other Radionucleides)

The gasses marked * are part of the 'basket of emissions' against which reduction targets were agreed at the Third Conference of the Parties of the United Nations Framework Convention on Climate Change in Kyoto, Japan, 1 December 1997 (United Nations, 1997).

1.5 The Structure of this Report

The report is presented in 16 chapters as follows.

Chapter 1: The Electricity Industry Mass Balance

Chapter 2: About the Electricity Industry.

A brief history of the electricity industry.

Defining what electricity is.

The generation and uses of electricity.

Chapter 3: The International Electricity Market.

Worldwide generation, consumption and gaseous emissions.

Chapter 4: The UK Generating Industry.

Key facts and figures.

Chapter 5: The Use of Coal to Generate Electricity.

Chapter 6: The Use of Oil to Generate Electricity.

Chapter 7: The Use of Gas to Generate Electricity.

Chapter 8: The Use of Nuclear Power to Generate Electricity.

Chapter 9: The Use of Air and Water to Generate Electricity.

Chapter 10: Emissions

Chapter 11: The Electricity Generation Mass Balance

Chapter 12: The Use of Emerging Technologies for Renewable Energy

Chapter 13: The Role of Effective Energy Efficiency

Chapter 14: Current and Pending Legislation

Chapter 15: The Future

Chapter 16: Conclusions and Recommendations

Further supporting information is given in the Appendices to this report.

Appendix 1: Glossary

Appendix 2: Definitions and terminology pertaining to the Electricity Industry

Appendix 3: References



2

This chapter looks at the discovery and study of electricity and the development of the electricity generation industry.

About the Electricity Industry



Alessandro Volta



Heinrich Rudolf Hertz

2.1 History of Electricity

The fact that amber acquires the power to attract light objects when rubbed may have been known to the Greek philosopher Thales of Miletus, who lived about 600 BC. Another Greek philosopher, Theophrastus, in a treatise written about three centuries later, stated that other substances possess this power. The first scientific study of electrical and magnetic phenomena, however, did not appear until AD 1600, when the English physician William Gilbert published his research. Gilbert was the first to apply the term electric (Greek elektron, "amber") to the force that such substances exert after rubbing. He also distinguished between magnetic and electric action.[2.1]

The first machine for producing an electric charge was described in 1672 by the German physicist Otto von Guericke. It consisted of a sulphur sphere turned by a crank on which a charge was induced when the hand was held against it. The French scientist Charles Francois de Cisternay Du Fay was the first to make clear the two different types of electric charge: positive and negative. The earliest form of condenser, the Leyden jar, was developed in 1745. It consisted of a glass bottle with separate coatings of tinfoil on the inside and outside. If either tinfoil coating was charged from an electrostatic machine, a violent shock could be obtained by touching both foil coatings at the same time.

Benjamin Franklin spent much time in electrical research. His famous kite experiment proved that the atmospheric electricity that causes the phenomena of lightning and thunder is identical with the electrostatic charge on a Leyden jar. Franklin developed a theory that electricity is a single "fluid" existing in all matter, and that its effects can be explained by excesses and shortages of this fluid.

In c1766 the law that the force between electric charges varies inversely with the square of the distance between the charges was proved experimentally by the British chemist Joseph Priestley. Priestley also demonstrated that an electric charge distributes itself uniformly over the surface of a hollow metal sphere, and that no charge and no electric field of force exists within such a sphere. Charles Augustin de Coulomb invented a torsion balance to measure accurately the force exerted by electrical charges. With this apparatus he confirmed Priestley's observations and showed that the force between two charges is also proportional to the product of the individual charges. Faraday, who made many contributions to the study of electricity in the early 19th century, was also responsible for the theory of electric lines of force.

The Italian physicists Luigi Galvani and Alessandro Volta conducted the first important experiments in electrical currents. Galvani produced muscle contraction in the legs of frogs by applying an electric current to them. Volta in 1800 announced the first artificial electrochemical source of potential difference, a form of electric battery.

The fact that a magnetic field exists around an electric current flow was demonstrated by the Danish scientist Hans Christian Oersted in 1819, and in 1831 Faraday proved that a current flowing in a coil of wire can electromagnetically induce a current in a nearby coil. About 1840 James Prescott Joule and the German scientist Hermann Ludwig Ferdinand von Helmholtz demonstrated that electric circuits obey the law of the conservation of energy and that electricity is a form of energy.

An important contribution to the study of electricity in the 19th century was the work of the British mathematical physicist James Clerk Maxwell, who investigated the properties of electromagnetic waves and light and developed the theory that the two are identical.

His work paved the way for the German physicist Heinrich Rudolf Hertz, who produced and detected electric waves in the

atmosphere in 1886, and for the Italian engineer Guglielmo Marconi, who in 1896 harnessed these waves to produce the first practical radio signalling system.

The Dutch physicist Hendrik Antoon Lorentz first advanced the electron theory, which is the basis of modern electrical theory, in 1892. The American physicist Robert Andrews Millikan first accurately measured the charge on the electron in 1909.

From Faraday's experiment developments happened at a fast rate. The race was on to develop generators that could be of industrial use. As a new source of energy its full potential was not realised. A lot of development went into electric motors and lighting. This was in strong competition with the well established steam engines and gas lighting. This initially caused much mistrust and rejection of electricity's possibilities. Claims were made of the harmful effects of using electricity; causing headaches, skin disorders and the onset of allergies. Most of this negative feeling came from the gas and steam industries. They were realising that electricity was going to provide stiff competition.

There were many private companies that set up to provide electric lighting for streets, theatres and galleries but by 1881, 14 years after Faraday's death, Godalming became the first town to combine public and private use of electricity.[2.2] The town council considered electricity as an alternative to gas when their contract for gas lighting expired. What probably swayed their opinion was that when the gas and electric contractors offered their quotes to light the town for 1 year the electric bid was £195, £15 less than the gas bid. The source of power for the generator was one of the waterwheels at a local leather dressing mill, half a mile from the town centre.

The next year was an important one in the history of electricity generation with the birth of purpose built power stations. On the 12th of January Thomas Edison opened the 'Edison Electric Light Station' at no. 57 Holborn Viaduct. Soon after, on the 27th of February, the Hammond Electric Light Company opened the Brighton power station, which claims to be the first permanent and viable public power supply.

For consumers of electricity the important year was 1884. Various metering systems where introduced and charging began. The usual cost would be 1/2d per lamp hour.

By 1892 it was realised that electricity could be used for heating and two years later it was possible to 'cook electric'. In 1918 electric washing machines became available and in the next year the refrigerator appeared. By this time electricity had been accepted as the energy of the future and the word was getting around, everyone wanted electricity. The dream of electricity for all in England, Scotland and Wales did not start to be realised until the middle of 1928 when construction on a national grid system began. It took 17 years before the system was in operation. Even then that did not include the north east of England.

On the 13th August 1947 the 'Electricity Bill' received the Royal assent and the electricity supply of England, Wales and Southern Scotland came under Public ownership. Under this new ownership, on the 17th of October 1956, the world's first large-scale Nuclear power station opened at Calder Hall in Cumbria, although its primary purpose was to produce Plutonium for military use.

On the 1st of January 1958 the Electricity Act 1957 came into effect and the Central Electricity Generating Board (C.E.G.B.) was set up. This situation remained until 1990 when the electricity supply was privatised and National Power, PowerGen and Nuclear Electric were formed.

2.2 Electricity Generation

The production of bulk electric power is for industrial, residential, and rural use. Electric power generation generally implies large-scale production of electric power in stationary plants designed for that purpose. The generating units in these plants convert energy from falling water, coal, natural gas, oil, and nuclear fuels to electric energy. Electric power generating plants are normally interconnected by a transmission and distribution system to serve the electric loads in a given area or region.

An electric load (or demand) is the power requirement of any device or equipment that converts electric energy into light, heat, or mechanical energy, or otherwise consumes electric energy as in aluminium reduction, other power requirements of electronic and control devices. The total load on any power system is seldom constant; rather, it varies widely with hourly, weekly, monthly, or annual changes in the requirements of the area served. The minimum system load for a given period is termed the "base load component". Maximum loads, resulting usually from temporary conditions, are called peak loads, and the operation of the generating plants must be closely co-ordinated with fluctuations in the load. The peaks, usually being of only a few hours' duration are frequently served by gas or oil combustion-turbine or pumped-storage hydro generating units.



The pumped-storage type utilises the most economical off-peak (typically 10pm to 7am) surplus generating capacity to pump and store water in elevated reservoirs to be released through hydraulic turbine generators during peak periods. This type of operation improves the capacity factors or relative energy outputs of base-load generating units and hence their economy of operation.

A study of annual load graphs and forecasts indicates the rate at which new generating stations must be built; they are an inseparable part of utility operation and are the basis for decisions that profoundly affect the financial requirements and overall development of a utility.

Generating Unit Sizes

The size and capacity of electric utility generating units varies widely, depending upon type of unit; duty required, that is, base-, intermediate-, or peak-load service; and system size and degree of interconnection with neighbouring systems.

Power Plant Circuits:

Both main and accessory circuits in power plants can be classified as follows:

1 Main power circuits to carry the power from the generators to the step-up transformers and on to the station high-voltage terminals.

2 Auxiliary power circuits to provide power to the motors used to drive the necessary auxiliaries.

3 Control circuits for the circuit breakers and other equipment operated from the plant's control room.

4 Lighting circuits for the illumination of the plant and to provide power for portable equipment required in the upkeep and maintenance of the plant. Sometimes special circuits are installed to supply the portable power equipment.

5 Excitation circuits, which are so installed that they will receive good physical and electrical protection because reliable excitation is necessary for the operation of the plant.

6 Instrument and relay circuits to provide values of voltage, current, kilowatts, reactive kilovoltamperes, temperatures, pressures, flow rates, and so forth, and to serve the protective system.

7 Communication circuits for both plant and system communications. Telephone, radio, transmission-line carrier, and microwave radio may be involved.



It is important that reliable power service is provided for the plant itself, and for this reason station service is usually supplied from two or more sources. To ensure adequate reliability, auxiliary power supplies are frequently provided for start-up, shutdown, and communications services.

Generator Protection

Necessary devices are installed to prevent or minimise other damage in cases of equipment failure. Using differential-current and ground relays, over-current relays and loss-of-excitation relays, the generator is immediately de-energised for electrical failure and shut down for any over-limit condition, all usually automatically.

Voltage Regulation

This term is defined as the change in voltage for specific change in load (usually from full load to no load) expressed as percentage of normal rated voltage.

Generation Control

Computer-assisted (or on-line controlled) load and frequency control and economic dispatch systems of generation supervision are being widely adopted, particularly for the larger new plants.

Synchronisation of Generators
Synchronisation of a generator to a power system is the act of matching, over an appreciable period of time, the instantaneous voltage of a power system of one or ore other generators (running source), then connecting them together.

Fossil Fuel Plants
Fossil fuels are of plant or animal origin and consist of hydrogen and carbon (hydrocarbon) compounds. The most common fossil fuels are coal, oil, and natural gas.

The less common ones include peat, oil shale, and biomass (wood and so forth), as well as various waste or by-products such as steel mill blast furnace gas, coke-oven gas, and refuse-derived fuels. Fossil fuel electric power generation uses the combustion heat energy from these fuels to produce electricity.

Steam Power Plants
A fossil fuel steam plant operation essentially consist of four steps:

(1) Water is pumped at high pressure to a boiler, where

(2) it is heated by fossil-fuel combustion to produce steam at high temperature and pressure.

(3) This steam flows through a turbine, rotating an electric generator (connected to the turbine shaft) which converts the mechanical energy to electricity.

(4) The turbine exhaust steam is condensed by using cooling water from an external source to remove the heat rejected in the condensing process. The condensed water is pumped back to the boiler to repeat the cycle.

A given power plant's size is determined by the utility company's need for power as dictated by the electrical demand growth forecast. A typical large fossil-fuel power plant consists of several major facilities and equipment, including fuel handling and processing, boiler (including furnace), turbine and electric generator, condenser and condenser heat removal system, feed water heating and pumping system, flue gas-cleaning system, and plant controls and control system.

Gas Turbine Plants
Power plants with gas turbine-driven electric generators are often used to meet short-term peaks in electrical demand. Gas turbine power plants use atmospheric air as the working medium, operating on an open cycle where air is taken from and discharged to the atmosphere and is not recycled. In a simple gas turbine plant, air is compressed and fuel is injected into the compressed air and burned in a combustion chamber. Variations of this basic operation to increase cycle efficiency include regeneration, where exhaust from the turbine is used to preheat the compressed air before it enters the combustion chamber.

Hydroelectric Plants
Hydroelectric operation is an attractive source of electric power because it is a renewable resource and a non-consumptive use. In the broadest sense, hydroelectric power is a form of solar power; the resource is renewed by the solar cycle in which water is evaporated from the oceans, transported by clouds, and falls as precipitation on the landmasses. It then returns through rivers to the ocean, generating power on the way. Hydroelectric power can be defined as the generation of electricity by flowing water; potential energy from the weight of water falling through a vertical distance is converted into electrical energy.

Power Failures
In most parts of the world, local or national electric utilities have joined in grid systems. The linking grids allow electricity generated in one area to be shared with others. Each pooling company gains an increased reserve capacity, use of larger, more efficient generators, and compensation, through sharing, for local power failures. These interconnected grids are large, complex machines that contain elements operated by different groups. These complex systems offer the opportunity for economic gain, but increase the risk of widespread failure. For example, a major grid-system breakdown occurred on November 9, 1965, in eastern North America, when an automatic control device that regulates and directs current flow failed in Queenston, Ontario, causing a circuit breaker to remain open. A surge of excess current was transmitted through the northeastern United States. Generator safety switches from Rochester, New York, to Boston, Massachusetts, were automatically tripped, cutting generators out of the system to protect them from damage. Power generated by more southerly plants rushed to fill the vacuum and overloaded these plants, which automatically shut themselves off. The power failure enveloped an area of more than 200,000 sq. km (80,000 sq. miles), including the cities of Boston, Buffalo, Rochester, and New York. Similar grid failures, usually on a smaller scale, have troubled systems in North America and elsewhere. In some areas the outage lasted 25 hours as restored high voltage burned out equipment. These major failures are termed blackouts. The term brownout is often used for partial shutdowns of power, usually deliberate, either to save electricity or as a wartime security measure. To protect themselves against power failures, hospitals, public buildings, and other facilities that depend on electricity have installed backup generators.

Voltage Regulation
Long transmission lines have considerable inductance and capacitance as well as resistance. When a current flows through the line, inductance and capacitance have the effect of varying the voltage on the line as the current varies. Thus the supply voltage varies with the load. Several kinds of devices are used to overcome this undesirable variation, in an operation called regulation of the voltage. They include induction regulators and three-phase synchronous motors (called synchronous condensers), both of which vary the effective amount of inductance and capacitance in the transmission circuit. Inductance and capacitance react with a tendency to nullify one another. When a load circuit has more inductive than capacitive reactance, as almost invariably occurs in large power systems, the amount of power delivered for a given voltage and current is less than when the two are equal. The ratio of these two amounts of power is called the power factor. Because transmission-line losses are proportional to current, capacitance is added to the circuit when possible, thus bringing the power factor as nearly as possible to 1. For this reason, large capacitors are frequently inserted as a part of power-transmission systems.

3

This chapter gives a brief overview of the international electricity generation market, while chapter 4 focuses on the UK generation capability

The International Electricity Market



3.1 World wide Generation

In the International Energy Outlook 2003 [3.1] (IEO2003) reference case, world wide electricity consumption is projected to increase at an average annual rate of 2.4% from 2001 to 2025. The most rapid projected growth in electricity use by region is 3.7% per year for developing Asia, where robust economic growth is expected to increase demand for electricity to run newly purchased home appliances for air conditioning, refrigeration, cooking, space and water heating. By 2025, developing Asia as a whole is expected to consume almost 2.5 times as much electricity as it did in 2001. In China, electricity consumption is projected to grow by an average of 4.3% per year, nearly tripling over the forecast period.

In Central and South America, as in developing Asia, high rates of economic growth are expected to improve standards of living and increase electricity use for industrial processes and in homes and businesses. The expected growth rate for electricity use in Central and South America is 3.3% per year. In Brazil, the region's largest economy and largest consumer of electricity, electricity consumption is projected to increase by 3.2% per year, with electrification coming to rural populations that previously have not had access to the National Grid. Electricity consumption in the industrialised world is expected to grow at a more modest pace than in the developing world, at 1.7% per year. In addition to expected slower growth in population and economic activity in the industrialised nations, market saturation and efficiency gains for some electronic appliances are expected to slow the growth of electricity consumption from historical rates.

There have been two important developments in the electricity sector in recent years that may affect the way the industry works in the future. The first is the increasing role of foreign investment in the developing regions of the world. Greater access to foreign investment in the electricity sector had allowed developing nations to construct the infrastructure needed for substantial increases in access to electricity.

A second important development is electricity reform. Many developing countries have implemented reforms to the rules governing electricity generation and distribution in an effort to secure the direct foreign investment they need to modernise and improve the electricity infrastructure. In industrialised countries many nations have undertaken electricity reforms to introduce greater competition in domestic markets in an effort to reduce the cost of electricity to consumers. These two factors are driving the changes in the electricity sector and are expected to have a profound effect in the development of the electricity industry over the next two decades.

Table 3-1
World Net Electricity Consumption in 3 Cases from 1970 to 2025

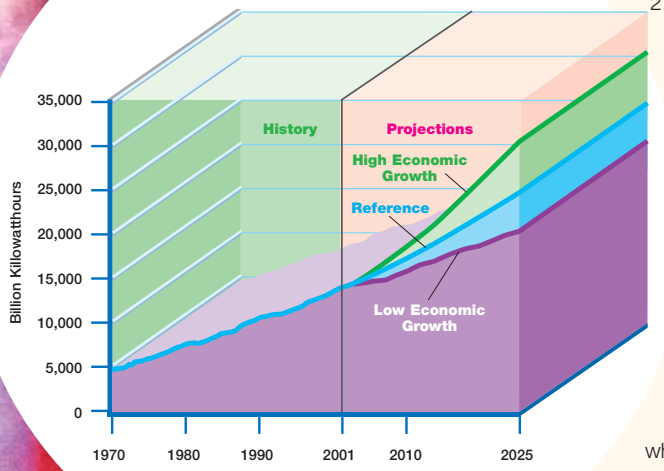


Figure 3-2
World Energy Consumption for Electricity Generation

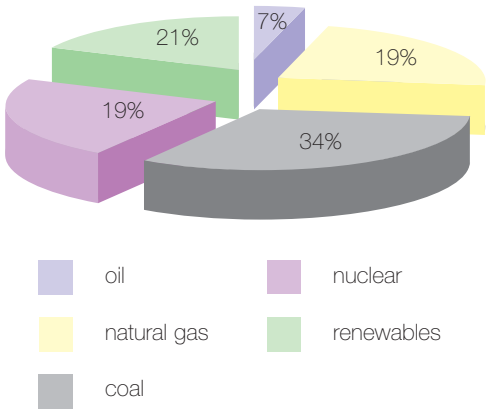


Table 3-1

World Energy Consumption for Electricity Generation by Region and Fuel, 2000-2025

(Quadrillion Btu)

	History			Projections			
Region and Fuel	**2000**	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**
Industrialized	**89**	**89.6**	**92.1**	**99.9**	**106.4**	**113.3**	**120.1**
Oil	5.0	4.9	4.5	4.6	5	5.2	5.5
Natural Gas	14.3	14.7	16.6	19.4	23.5	28.4	33.5
Coal	30.5	30.9	32.3	34.8	35.4	36.1	37.7
Nuclear	22.6	22.4	21.6	22.3	22.4	21.9	20.4
Renewables	16.5	16.7	17.2	18.9	20	21.7	23
EE/FSU	**23.2**	**22.6**	**20.6**	**22.8**	**25.3**	**26.3**	**27**
Oil	1.5	1.3	0.4	0.5	0.9	1.2	0.8
Natural Gas	7.9	8	8.5	9.5	12	13.7	16.1
Coal	6.3	6	4.9	4.1	3.6	2.7	1.6
Nuclear	4.3	4.1	3.2	3.3	3.3	3	2.6
Renewables	3.2	3.2	3.6	5.5	5.6	5.7	5.8
Developing	**39.8**	**41.2**	**47**	**55**	**64.1**	**74.1**	**85**
Oil	5	5.3	6.2	6	6.8	7.6	8.2
Natural Gas	6.3	6.5	7.2	9.8	13.4	16.7	21.0
Coal	14.4	15.1	18.1	21.4	23.8	28.3	32.7
Nuclear	2.6	2.7	2.7	3.1	4.2	4.5	5.0
Renewables	11.4	11.7	12.8	14.6	15.9	17.0	18.0
Total World	**151.9**	**153.4**	**159.7**	**177.7**	**195.7**	**213.7**	**232**
Oil	11.6	11.5	11.1	11.1	12.7	14.0	14.5
Natural Gas	28.4	29.2	32.3	38.7	48.8	58.9	70.6
Coal	51.2	52	55.2	60.3	62.9	67.1	72.0
Nuclear	29.5	29.1	27.5	28.7	29.8	29.4	28.0
Renewables	31.1	31.6	33.5	38.9	41.5	44.4	46.9

3.1.1 Primary Fuel Use for Electricity Generation

The mix of primary fuels used to generate electricity has changed a great deal over the past three decades on a world wide basis. Coal has remained the dominant fuel, although electricity generation from nuclear power increased rapidly from the 1970s through the mid-1980s, and natural-gas-fired generation has grown rapidly in the 1980s and 1990s. In contrast, in conjunction with the high world oil prices brought on by the oil price shocks resulting from the OPEC oil embargo of 1973-1974 and the Iranian Revolution of 1979, the use of oil for electricity generation has been slowing since the mid-1970s. In the IEO2003 reference case, continued increases in the use of natural gas for electricity generation are expected world wide. Coal is projected to continue to retain the largest market share of electricity generation, but its importance is expected to be diminished somewhat by the rise in natural gas use. The role of nuclear power in the world's electricity markets is projected to lessen as reactors in industrialised nations reach the end of their life spans and few new reactors are expected to replace them. Generation from hydropower and other renewable energy sources is projected to grow by 56% over the next 24 years, but their share of total electricity generation is projected to remain near the current level of 21%.

Natural Gas

19%

Electricity markets of the future are expected to depend increasingly on natural gas-fired generation. Industrialised nations are intent upon using combined-cycle gas turbines, which usually are cheaper to construct and more efficient to operate than other fossil-fuel-fired generation. Natural gas is also seen as a much cleaner fuel than other fossil fuels. World wide, natural gas use for electricity generation is projected to be almost 2.5 times greater in 2025 than it was in 2001 as technologies for natural-gas-fired generation continue to improve and ample gas reserves are exploited. In the developing world, natural gas is expected to be used to diversify electricity fuel sources, particularly in Central and South America, where heavy reliance on hydroelectric power has led to shortages and blackouts during periods of severe drought.

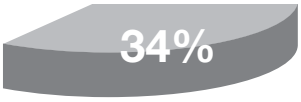
The former Soviet Union (FSU) accounted for more than one-third of natural gas usage for electricity generation world wide in 2001, and natural gas provided 42% of the energy used for electricity generation in the FSU. By 2025, natural gas is projected to account for 63% of the electricity generation market in the FSU. Relying increasingly on imports from Russia, the nations of Eastern Europe are also expected to increase their use of natural gas for electricity generation, from a 9% share of total generation in 2001 to 50% in 2025.

In North America, the natural gas share of the electricity fuel market in the United States is projected to increase from 18% in 2001 to 24% in 2025, with Canadian exports expected to provide a growing supply of natural gas to US generators. The natural gas share of electricity generation in Canada is also projected to grow, from 3% in 2001 to 11% in 2025. Natural gas consumption for electricity generation in Western Europe is projected to nearly triple over the forecast period, and its share of the region's electricity fuel market is projected to grow from 17% in 2001 to 38% in 2025 as the nuclear power and coal shares are reduced. After the oil crisis of 1973, European nations actively discouraged the use of natural gas for electricity generation (as did the United States) and instead favoured domestic coal and nuclear power over dependence on natural gas imports. The European Commission's 1975 directive, 75/404/EEC restricted the use of natural gas in new power plants.

The natural gas share of the electricity market in Western Europe fell from 9% in 1977 to 5% in 1981, where it remained for most of the 1980s. In the early 1990s, the growing availability of reserves from the North Sea and increased imports from Russia and North Africa lessened concerns about gas supply in the region, and the EU directive was repealed. In Central and South America natural gas accounted for 9% of the electricity fuel market in 2001. Its share is projected to grow to 46% in 2025. Hydropower is the major source of electricity supply in South America at present, but environmental concerns, cost overruns on large hydropower projects in the past, and electricity shortfalls during periods of drought have prompted South American

governments to view natural gas as a means of diversifying their electricity supplies. A continent-wide natural gas pipeline system is being built in South America, which will transport Argentine and Bolivian gas to Chile and Brazil.

Per capita consumption of natural gas in Asia and Africa is relatively small when compared with Europe and North America. In 2001, Japan accounted for one-fourth of natural gas consumption in Asia. Almost all natural gas consumed in Japan is imported as liquefied natural gas (LNG). Japan is expected to maintain its dependence on natural gas at around 20% of the electricity fuel market through 2025.



Coal

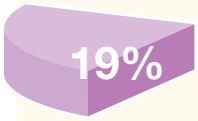
In 2025, coal is expected to account for 31% of the world's electricity fuel market, slightly lower than its 34% share in 2001. The United States accounted for 40% of all coal use for electricity generation in 2001, and China and India together accounted for 27%.

In the IEO2003 forecast, the coal share of US electricity generation is expected to remain at roughly 50% through 2025. China's coal share is projected to rise slightly, to 73% in 2025 from 72% in 2001. Over the same period, coal's share of India's electricity market is expected to decline from 72% to 63%.

Although coal remains a relatively cheap source of electricity production, natural gas is viewed as being environmentally superior, and the economics of natural gas generation technology are improving, particularly in countries with access to gas pipelines.

Reliance on coal for electricity generation is also expected to be reduced in other regions. In Western Europe, for example, coal accounted for 20% of the electricity fuel market in 2001 but is projected to have only a 12% share in 2025. Similarly, in Eastern Europe and the FSU (EE/FSU), coal's 27% share of the electricity fuel market in 2001 is projected to fall to 6% in 2025. For years, massive state subsidies were all that kept many coal mines operating in Western and Eastern Europe. In many cases, electricity consumers underwrote the subsidies.

The EU has adopted policy measures to eliminate or reduce state subsidies for domestic coal production, and only four EU member states (the United Kingdom, Germany, Spain, and France) continue to produce hard coal.



Nuclear Power

The nuclear share of energy use for electricity production is expected to decline in most regions of the world as a result of public opposition, waste disposal issues, concerns about nuclear arms proliferation, and the economics of nuclear power. The nuclear share of electricity generation world wide is projected to drop to 12% in 2025 from 19% in 2001.

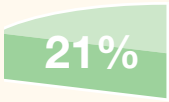
In the United States, the nuclear share is projected to decline from 19% of the electricity fuel market in 2001 (second behind coal) to 15% in 2025. In Canada, where the nuclear share of the market has been declining since 1984, its 22% share in 2001 is projected to fall to 11% in 2025. In Western Europe, where Finland is the only country projected to build new nuclear units, the nuclear share of the region's electricity fuel market is projected to fall from 34% in 2001-more than any other energy source-to 21% in 2025. In Japan, nuclear power accounted for 39% of the energy used for electricity generation in 2001. That share is expected to decline to 31% by 2025 in the IEO2003 forecast. In the EE/FSU region, the nuclear share is projected to decline from 18% in 2001 to 10% in 2025. Nuclear power contributes very little to electricity generation in the developing nations of Central and South America, Africa, and the Middle East, and it is expected to contribute little in 2025. In Central and South America, only Argentina and Brazil were nuclear power producers in 2001. In Africa, only South Africa generated electricity from nuclear power in 2001. There are no nuclear power plants in operation in the Middle East, although two are under construction in Iran.

In contrast to the rest of the world's regions, in developing Asia nuclear power is expected to play a growing role in electricity generation. China, India, Pakistan, South Korea, and Taiwan currently have nuclear power programs, and the nuclear share of the region's electricity fuel market is expected to remain stable at roughly 9% from 2001 through 2025. China is expected to account for most of the region's nuclear power capacity additions.



Oil

The role of oil in the world's electricity generation market has been on the decline since the 1979 oil price shock. Oil accounted for 23% of electricity fuel use in 1977, in 2001 its share stood at 7%. Energy security concerns, as well as environmental considerations, have already led most nations to reduce their use of oil for electricity generation. In regions where oil continues to hold a significant share of the generation fuel market, such as the FSU and the Middle East, it generally is expected to maintain its position. As a result, the oil share of world energy use for electricity production is projected to remain stable at between 6 and 7% through 2025. Developing Asia accounted for 18% of the world's consumption of oil for electricity generation in 2001, when 7% of its electricity fuel use consisted of oil down from 29% in 1977). The oil share of electricity fuel consumption in developing Asia is expected remain stable through 2025. In the petroleum-rich Middle East, oil supplied 38% of the energy used for electricity generation in 2001, and its share is projected to decline slightly, to 34% in 2025.



Hydroelectricity and Other Renewables

Renewable energy, predominantly hydropower, accounted for one-fifth of the world's energy use for electricity generation in 2001, where it is expected to remain through 2025. Of the world's consumption of renewable energy for electricity production in 2001, the United States and Canada together accounted for almost 29% of the total, Western Europe for 20%, and Central and South America 19% (despite consuming just 5 percent of the world's electricity). In 2001, renewables accounted for 9% of electricity production in the United States and 56% in Canada, both nations where hydroelectric power has been extensively developed. Their shares are expected to grow slightly by 2025. In North America and throughout the world, generation

technologies using non-hydroelectric renewables are expected to improve over the forecast period, but they still are expected to be relatively expensive in the low price environment assumed for energy fuels in the IEO2003 reference case.

Hydroelectricity is used the most for electricity generation in Central and South America, and renewables accounted for 73% of the region's electricity fuel market in 2001. Recent experiences with drought, cost overruns, and the negative environmental impacts of several large-scale hydroelectric projects have reduced the appeal of hydropower in South America. The renewable share of electricity generation in the region is expected to decline to 45% by 2025 as countries work to diversify their electricity fuel mix.

Most of Western Europe's renewable energy consumption consists of hydroelectricity. Renewables in total accounted for 24% of the region's electricity market in 2001, and their share is expected to increase to 25% by 2025. Some European nations, particularly Denmark and Germany, are actively developing their non-hydroelectric renewable energy resources, most notably wind.

Some near-term growth in renewable energy use is expected in developing Asia, particularly in China, where the 18,200-megawatt Three Gorges Dam and a number of other major hydropower projects are expected to become operational during the forecast period. Developing Asia relied on renewables for 18% of its electricity production in 2001, and that share is expected to shrink slightly, to 16% in 2025.

3.2 World Wide Consumption

The IEO2003 reference case projects that consumption of every primary energy source will increase over the 24-year forecast horizon. Much of the increment in future energy demand in the reference case is projected to be for fossil fuels (oil, natural gas, and coal), because it is expected that fossil fuel prices will remain relatively low, and that the cost of generating energy from other fuels will not be competitive. It is possible, however, that as environmental programs or government policies – particularly those designed to limit or reduce greenhouse gas emissions – are implemented, the outlook might change, and non-fossil fuels (including nuclear power and renewable energy sources such as hydroelectricity, geothermal, biomass, solar, and wind power) might become more attractive. The IEO2003 projections assume that government policies or programs in place as of October 1, 2002 will remain constant over the forecast horizon.

Oil is expected to remain the dominant energy fuel throughout the forecast period, with its share of total world energy consumption falling only slightly from 39% in 2001 to 38% in 2025. In the industrialised world, increases in oil use are projected primarily in the transportation sector, where there are currently no available fuels to compete significantly with oil products.

The IEO2003 reference case projects declining oil use for electricity generation, with other fuels (especially natural gas) expected to be more favourable alternatives to oil-fired generation. In the developing world, oil consumption is projected to increase for all end uses. In some countries where non-commercial fuels have been widely used in the past such as fuel wood for cooking and home heating), diesel generators are now sometimes being used to dissuade rural populations from decimating surrounding forests and vegetation. This is most notably in Sub-Saharan Africa, Central and South America, and Southeast Asia. Because the infrastructure necessary to expand natural gas use has not been as widely established in the developing world as it has in the industrialised world, natural gas use is expected to grow in the developing world, but not enough to accommodate all of the increase in demand for energy.

Natural gas is projected to be the fastest growing primary energy source world wide, maintaining growth of 2.8% annually over the 2001-2025 period, nearly twice the rate of growth for coal use. Natural gas consumption is projected to rise from 90 trillion cubic feet in 2001 to 176 trillion cubic feet in 2025, primarily to fuel electricity generation. Gas is increasingly seen as the desired option for electric power, given the efficiency of combined-cycle gas turbines relative to coal- or oil-fired generation. Gas also burns more cleanly than either coal or oil, making it a more attractive choice for countries interested in reducing greenhouse gas emissions.

Coal use world wide is projected to increase by 2.2 billion short tons (at a rate of 1.5% per year) between 2001 and 2025. Substantial declines in coal use are projected for Western Europe and the EE/FSU countries, where natural gas is increasingly being used to fuel new growth in electric power generation and for other uses in the industrial and building sectors. In the developing world, however, even larger increases in coal use are expected. The largest increases are projected for China and India, where coal supplies are plentiful. Together these two countries account for 86% of the projected rise in coal use in the developing world over the forecast period.

World wide, consumption of electricity generated from nuclear power is expected to increase from 2,521 billion kilowatt-hours in 2001 to 2,737 billion kilowatt-hours in 2025. Until very recently, nuclear electricity consumption was expected to decline sharply by the end of the forecast. The prospects for nuclear power have been reassessed, however, in light of the higher capacity utilisation rates reported for many existing nuclear facilities and the expectation that fewer retirements of existing plants will occur than previously projected. Further extensions of operating licenses (or the equivalent) for nuclear power plants are expected to be granted among the countries of the industrialised world, slowing the decline in nuclear generation. In many of the industrialised countries, extending the operating life of a nuclear power plant is a decision left primarily to the owner and thus is essentially a question of economic viability. In the IEO2003 reference case, world nuclear capacity is projected to rise from 353 gigawatts in 2001 to 393 gigawatts in 2015 before falling to 366 gigawatts in 2025. In contrast, in last year's IEO, world nuclear capacity was projected to rise to 363 gigawatts in 2010 and then fall to 359 gigawatts in 2020.

The highest growth in nuclear generation is projected for the developing world, where consumption of electricity from nuclear power is projected to increase by 4.1% per year between 2001 and 2025. In particular, developing Asia is expected to see the greatest expansion in new nuclear generating capacity. As of February 2003, the nations of developing Asia accounted for 17 of the 35 reactors currently under

construction world wide, including 8 in India, 4 in China, 2 each in South Korea and Taiwan, and 1 in North Korea accounting for 12 of the 30 gigawatts currently under construction. Consumption of electricity from hydropower and other renewable energy sources is projected to grow by 1.9% annually in the IEO2003 forecast. With fossil fuel prices projected to remain relatively low in the reference case, renewable energy sources are not expected to be widely competitive, and the renewable share of total energy use is not expected to increase. Over the 2001-2025 forecast horizon, renewables maintain their share of total energy consumption at 8%.

Moreover, despite the high rates of growth projected for alternative renewable energy sources, such as wind power in Western Europe and biomass and geothermal power in the United States, much of the growth in renewable energy sources will result from large-scale hydroelectric power projects in the developing world, particularly among the nations of developing Asia.

China, India, Malaysia, and Vietnam are already constructing or have plans to construct ambitious hydroelectric projects over the projection period.

3.3 World wide CO_2 Emissions

World carbon dioxide emissions are expected to increase by 3.8 billion metric tons carbon equivalent over current levels by 2025-growing by 1.9% per year - if world energy consumption reaches the levels projected in the IEO2003 reference case.

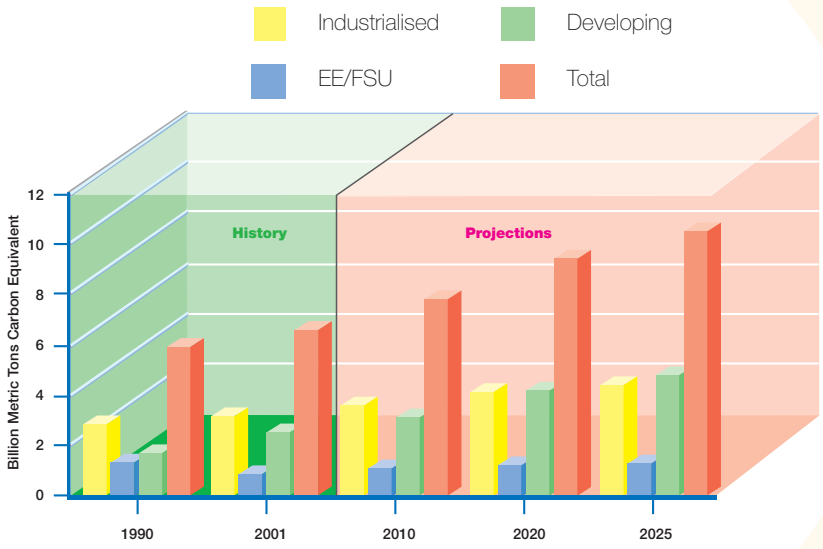
According to this projection, world carbon dioxide emissions in 2025 would exceed 1990 levels by 76%. Oil and natural gas contribute about 1.5 and 1.3 billion metric tons, respectively, to the projected increase from 2001, and coal provides the remaining 1.1 billion metric tons carbon equivalent. Carbon dioxide emissions from energy use in the industrialised countries are expected to increase by 1.2 billion metric tons carbon equivalent to 4.3 billion metric tons in 2025, or by about 1.3% per year. Emissions from the combustion of petroleum products account for more than 44% of the total increment expected for the industrialised world, and the increase in emissions from natural gas is expected to be more than twice as large as that from coal.

By 2020, carbon dioxide emissions in the developing world (including China and India) are expected to surpass those in the industrialised countries, even though developing countries are projected to use less energy than industrialised countries at that time. Total emissions in developing nations are expected to increase by 2.3 billion metric tons to a total of 4.7 billion metric tons carbon equivalent in 2025, representing about 59% of the projected increment world wide.

The sizeable rise in emissions among the developing nations is partially a result of their continued heavy reliance on coal, the most carbon-intensive of the fossil fuels.

Coal is used extensively in the developing Asia region, which has the highest expected rate of economic and energy growth in the forecast.

Figure 3-3
World Carbon Dioxide Emissions by Region



Carbon dioxide emissions in developing Asia alone are projected to increase from 1.6 billion metric tons carbon equivalent in 2001 to 3.3 billion metric tons in 2025. In the EE/FSU region as a whole, carbon dioxide emissions are not expected to return to their Soviet-era levels during the projection period. This year's reference case projection has been revised to reflect the expectation that coal use will not decline as precipitously as was projected in previous editions of this report, particularly among the FSU countries. The region appears to be in the midst of sustained economic recovery after the political, social, and economic upheavals that followed the break up of the Soviet Union in the early 1990s. Emissions are not expected to increase as quickly as energy use because of gains in energy efficiency resulting from the replacement of old, inefficient capital stock, and because in many countries in the region natural gas is expected to displace coal, particularly for new electricity generation capacity.

The region may also be able to take advantage of its lower emissions levels should a world wide carbon trading system be enacted in the future.

World wide, carbon dioxide emissions per person are projected to increase from about 1.1 metric tons in 1990 to 1.3 metric tons in 2025. Per capita emissions in the industrialised countries remain much higher than those in the rest of the world throughout the projection period, increasing from 3.2 to 3.6 metric tons per person between 1990 and 2010 and then to 4.2 metric tons per person in 2025 in the IEO2003 reference case. In December 2002 Canada and New Zealand ratified the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). As of February 24, 2003, 104 countries plus the European Community had ratified the treaty. Thirty of the ratifying nations are the so-called Annex I countries, which are required to limit or reduce their greenhouse gases relative to 1990 levels under the terms of the Protocol.[3.2] These 30 countries accounted for around 44% of the total Annex I emissions in 1990. The Kyoto Protocol enters into force 90 days after it has been ratified by at least 55 of the parties to the UNFCCC, including a representation of Annex I countries accounting for at least 55% of the total 1990 carbon dioxide emissions from the Annex I group.

Although the United States had the largest share of Annex I emissions in 1990 at 35%, even without US participation the Protocol could enter into force for other signatories. Russia has publicly announced plans to advance ratification of the Kyoto Protocol. Because Russia accounted for 17% of the 1990 Annex I carbon dioxide emissions, its ratification would bring the Protocol into force as long as Russia meets the Protocol's requirements for verifying and monitoring emissions levels.

China and India also ratified the Kyoto Protocol in 2002. Although both countries account for significant amounts of the world's carbon dioxide emissions, their ratification does not affect the implementation of the Protocol, because neither country is an Annex I member. In 2001, China and India together accounted for 17% of total world carbon dioxide emissions, as compared with the 24% share made up by US emissions in 2001.

In the United States, the Bush Administration has introduced initiatives aimed at reducing greenhouse gas intensity as an alternative to the Kyoto Protocol. Under the President's Clear Skies and Global Climate Change Initiatives, the United States will work to reduce greenhouse gas intensity by 18% by 2012. Carbon dioxide intensity is defined as the amount of carbon dioxide emitted per dollar of gross domestic product (GDP). This measurement illustrates the relationship between emissions and the expansion of economic activity. The Administration argues that reducing the amount of greenhouse gases emitted per dollar of GDP will slow the rate of increase in emissions without sacrificing needed economic growth.

World carbon dioxide intensity has improved (decreased) substantially over the past three decades, falling from 302 metric tons carbon equivalent per million 1997 dollars of GDP in 1970 to 202 metric tons per million 1997 dollars in 2001. Although the pace of improvement in emissions intensity is expected to slow over the forecast period, it still continues to improve in the reference case projections, dropping to 154 metric tons per million 1997 dollars in 2025.

On a regional basis, the most rapid improvements in carbon dioxide intensity are expected to occur among the transitional economies of the EE/FSU and in China and India. In the FSU, economic recovery from the upheaval of the 1990s is expected to continue throughout the forecast. The FSU nations are also expected to replace old and inefficient capital stock and increasingly use less carbon-intensive natural gas for new electricity generation and other end uses rather than the more carbon-intensive oil and coal. Eastern European nations have been in economic recovery longer than has the FSU, and natural gas is expected to continue to displace coal use in the region, resulting in an average 2.8% annual improvement (decrease) in carbon intensity for Eastern Europe as a whole.

In developing Asia, fairly rapid improvements in carbon dioxide intensity are expected for China and India over the projection period, primarily as a result of rapid economic growth rather than a switch to less carbon-intensive fuels. Both China and India are projected to remain heavily dependent on fossil fuels, particularly coal, in the IEO2003 reference case, but their annual GDP growth is projected to average 5.9%, compared with an expected 3.4% annual rate of increase in fossil fuel use from 2001 to 2025.

Figure 3-4
World Carbon Dioxide Emissions by Fuel

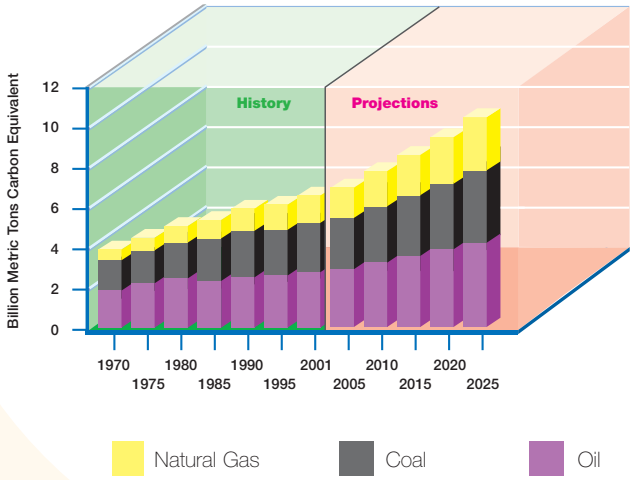
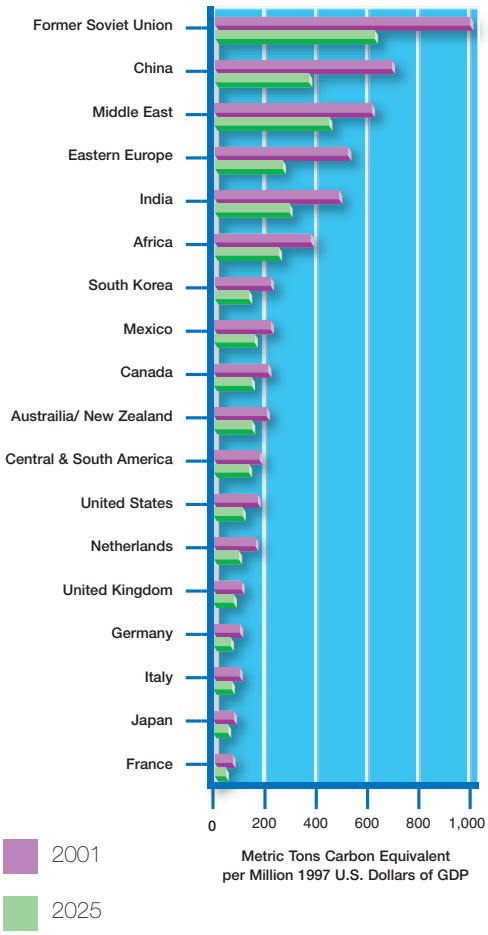


Figure 3-5
World Carbon Dioxide Intensity by Selected Countries & Regions



4

This chapter gives a brief overview of the United Kingdom electricity generation market.

The UK Electricity Market

The electricity industry in the UK plays a key role in the economy by transforming, producing and supplying electricity to all sectors. Electricity consumption has increased steadily rising from 11% of the total final energy consumption in 1970 to 18% in 2000.[4.1]

The electricity sector contributed 1.3% to the Gross Domestic Product in 2000, and is very capital intensive with total capital assets of approximately £35 billion.

The total turnover from the sale of electricity in 2000 was £15.6 billion, with two thirds of the total profit, namely £3.3 billion reinvested in the business, amounting to 12% of all industrial investment made in the UK.

On average each customer is off supply for 75 minutes a year, which equates to 99.98% availability, largely as a result of significant investment in the distribution networks since privatisation. In 2001 the price paid by the UK consumer for electricity was the fourth lowest in Europe.

Figure 4-1
Percentage of Energy Consumed as Electricity Per Sector

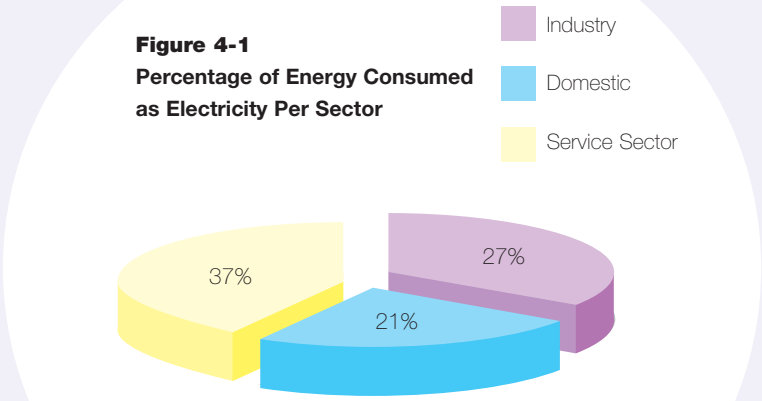


Table 4-1

Electricity prices for Households,
US Dollars per Kilowatthour[4.2]

Country	1994	1995	1996	1997	1998	1999
OECD[1]	0.116	0.127	0.121	0.114	0.110	n.a.
OECD Europe	0.135	0.150	0.147	0.131	0.131	n.a.
United Kingdom	0.122	0.127	0.125	0.125	0.121	0.117
USA[2]	0.084	0.084	0.084	0.084	0.083	0.081

[1] Organisation for Economic Co-operation and Development

[2] Price excluding tax n.a. Not Available

Table 4-2

Electricity Prices for Industry,
US Dollars per Kilowatthour[4.3]

Country	1994	1995	1996	1997	1998	1999
OECD[1]	0.073	0.079	0.074	0.068	0.063	n.a.
OECD Europe	0.071	0.077	0.074	0.065	0.065	n.a.
United Kingdom	0.067	0.068	0.065	0.065	0.065	0.064
USA[2]	0.047	0.047	0.046	0.044	0.040	0.039

[1] Organisation for Economic Co-operation and Development

[2] Price excluding tax n.a. Not Available

Table 4-3

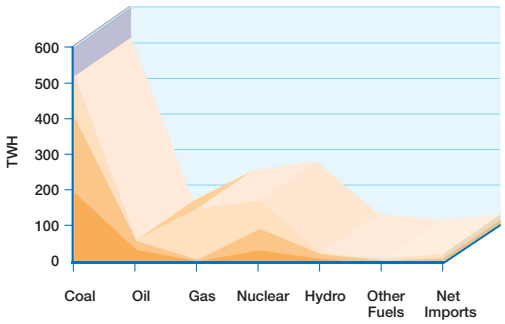
Key UK Electricity Industry Figures

Generating capacity (MW) (1)	79,562
Generation Output (GWh) (1)	385,826
System load factor (%) (1)	70.8
Plant load factor (%) (1)	53.1
Thermal efficiency (%) (1):	
Conventional steam stations	35.7
CCGTs	46.4
Nuclear stations	37.3
Maximum demand (MW)(1)	57,052
Electricity supply (net) (GWh)(1)	365,241
Net imports (GWh)(1)	10,399
Sales of electricity (GWh) (1)	321,751
Revenue from sales of electricity (£m) (1)	14,850
Average revenue from sales of electricity (p/kWh)(1)	4.584
Transmission network (circuit km)	25,529
Units transmitted (TWh)	349
Distribution network (circuit km)	808,209
Units distributed (GWh)	317,460
Number of customers' (000s)	28,160
Number of employees	7,240
System frequency (Hz)	50 +/- 1%
System voltage (V)	230 +10% -6%

Notes:

1. Figures are for calendar year 2001. The difference in the amount of electricity generated versus that supplied is accounted for by system losses.

Figure 4-2
Electricity Generation Methods 1980 to 2000



	Coal	Oil	Gas	Nuclear	Hydro	Other Fuels	Net Imports
2000	114.6	5.1	143.7	78.3	5.1	8.3	14.2
1990	208	21.3	1.6	58.7	11.9	-	7.9
1980	190	33.9	1.6	32.3	7.3	-	0

4.1 UK Generation

In May 2002 there were 163 power stations operating in the United Kingdom, with a generating capacity of 73, 455 megawatts (MW). If one includes 'other' power stations using renewable or combustible wastes, and combined heat and power schemes (CHP) (see Chapter 13 for more details) the generating capacity rises to 79753 MW.

Table 4-4

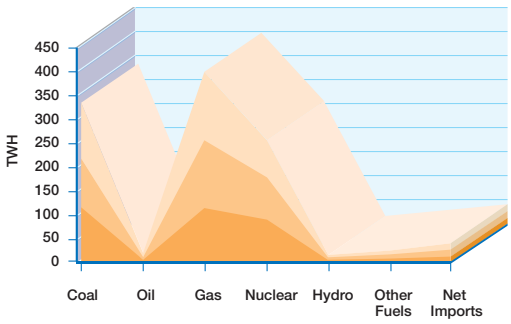
The UK generation mix

Type of generation	Capacity (MW)	Percentage
Coal	30272	38%
Gas	24989	31%
Oil	5816	7%
Nuclear	12242	15%
Hydro	4128	5%
Other	2306	3%
Total	79753	100%

The main source for the generation of electricity in the UK is still coal, followed by gas, with nuclear power generated electricity at 15%. For more details on the generation of electricity by these different methods, see Chapters 4 to 8.

The following table shows the electricity availability by fuel type for 1980, 1990 and 2000, and for the period 1998 through to 2000 which has shown significant change.

Figure 4-3
Generating Capacity Method Changes, 1998 to 2000



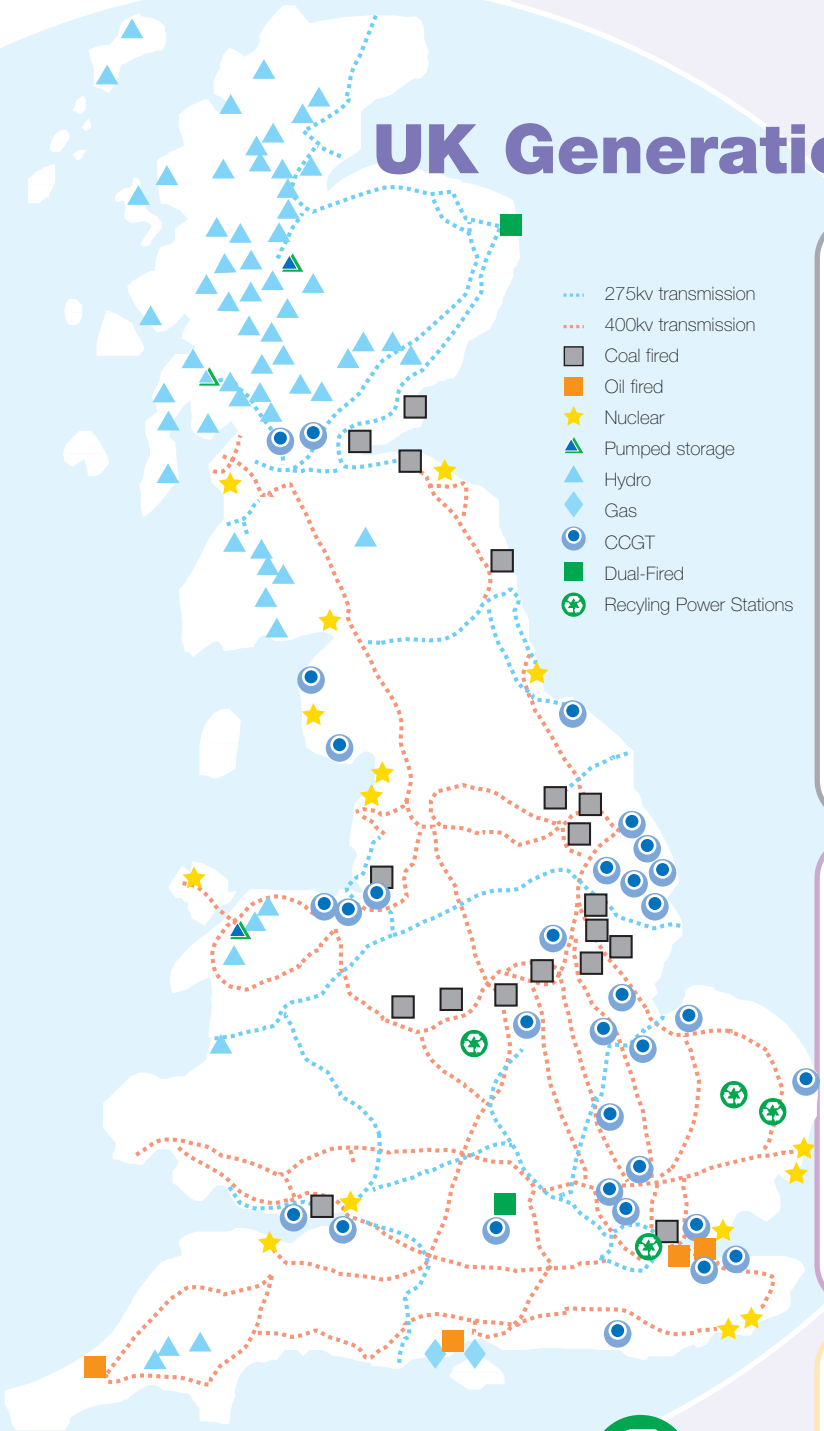
	Coal	Oil	Gas	Nuclear	Hydro	Other Fuels	Net Imports
2000	114.6	5.1	143.7	78.3	5.1	8.3	14.2
1990	101.2	5.3	139.8	87.7	5.3	8.6	14.2
1980	117	5.9	116.3	90.6	5.1	7.8	12.5



Tables detailing the number of power stations operating within the UK.

73,455 (MW) Total installed capacity.

UK Generation Stations



Coal Fired Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Drax	3,870	1974
Fifoots Point (2)	393	2000
Ferrybridge C	1,955	1966
Fiddler's Ferry	1,961	1971
Lynemouth	248	1995
Eggborough	1,960	1968
Aberthaw B	1,506	1971
Rugeley	1,006	1972
Cottam	2,008	1969
West Burton	1,932	1967
Ratcliffe	2,000	1968
High Marnham	945	1959
Ironbridge	970	1970
Didcot A *Coal /gas*	2,040	1972
Kilroot *Coal/oil*	520	1981
Tilbury B *Coal /oil*	1,071	1968
Kingsnorth *Coal /oil*	1,455	1970

Nuclear Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Dungeness B	1,110	1985
Hartlepool	1,210	1989
Heysham1	1,150	1989
Heysham 2	1,250	1989
Hinkley Point B	1,220	1976
Sizewell B	1,188	1995
Hunterston B	1,190	1976
Torness	1,250	1988
Calder Hall	194	1956
Sizewell A	420	1966
Wylfa	980	1971

Oil, Oil/Gas, Diesel, Diesel/Gas Kerosene Fired Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Indian Queens	140	1996
Coolkeeragh	293	1959
Fawley	518	1969
Littlebrook D	790	1982
Grain	1,350	1979
Ballylumford *Oil/gas*	1,080	1968
Peterhead *Oil/gas*	1,550	1980
Thatcham *Diesel*	9.6	1994
Five Oaks *Diesel*	11.5	1995
Lerwick *Diesel/gas*	66	1953
Princetown *Kerosene*	3	1959
Roseland *Kerosene*	5	1963

Recycling Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Suffolk *Poultry litter*	13	1992
Thetford *Poultry litter*	39	1998
Wolverhampton *Waste*	20	1994
Landmann Way, London *Waste*	32	1994
Glanford *Meat & bone meal*	13	1993

Combined Heat and Power Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Derwent	236	1994
Fellside	168	1993

CCGT Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Barry	250	1998
Barking	1,000	1994
Kings Lynn	350	1996
Peterborough	380	1993
Corby	401	1993
Coryton	750	2001
Brimsdown	406	1999
Saltend	1,200	2000
Damhead Creek	792	2000
Westfield Development Centre	120	1998
South Humber Bank 1	785	1996
South Humber Bank 2	527	1998
Didcot B	1,370	1998
Little Barford	655	1995
Rocksavage	750	1997
Deeside (4)	250	1994
Roosecote	229	1991
Sutton Bridge	803	1999
Medway	688	1995
Killingholme	650	1994
Connahs Quay	1,380	1996
Killingholme (4)	450	1992
Cottam Development Centre	400	1999
Glanford Brigg	240	1993
Keadby	720	1994
Rye House	715	1993
Seabank 1	812	1998
Seabank 2	410	2000
Shoreham	400	2000
Teesside Power Station	1,875	1992

Gas Fired Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Bridgewater District Energy	10	2000
Solutia District Energy	10	2000
Sevington District Energy	10	2000
Charterhouse St, London	32	1995
Chickerell	45	1998
Burghfield	45	1998
Drax GT *Gas/oil*	75	1971
Ferrybridge GT Gas/oil	34	1966
Fiddler's Ferry GT *Gas/oil*	34	1969
Cowes *Gas/oil*	70	1982
Rugeley GT *Gas/oil*	50	1972
Grain GT *Gas/oil*	55	1978
Kingsnorth GT *Gas/oil*	34	1967
Ratcliffe GT *Gas/oil*	34	1966
Taylor's Lane GT *Gas/oil*	132	1979
Knapton *Gas/oil*	40	1994
St Marys *Gas/oil*	6	1958
Lynton *Gas/oil*	2	1961

Hydro Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Maentwrog	30	1928
Cwm Dyli	10	1989 (3)
Dolgarrog	37	1924
Kielder	5.5	1984
Rheidol	50	1961
Mullardoch Tunnel	2.4	1955
Fasnakyle	69	1951
Deanie	38	1963
Culligran	24	1962
Aigas	20	1962
Kilmorack	20	1962
Lubreoch	4	1958
Cashlie	11	1959
Lochay	47	1958
Finlarig	30	1955
Lednock	3	1961
St. FillansHydro	21	1957
Dalchonzie	4	1958
Achanalt	3	1956
Grudie Bridge	24	1950
Mossford	24	1957
Foyers Falls	5.2	1968
Mucomir	2	1962
Ceannacroc	20	1956
Livishie	15	1962
Glenmoriston	37	1957
Quoich	22	1955
Ivergarry	20	1956
Cassley	10	1959
Lairg Hydro	3.5	1959
Shin	24	1958
Sloy	160	1950
Sron Mor	5	1957
Clachan	40	1955
Alt-na-Lairgie	6	1956
Nant	15	1963
Inverawe	25	1963
Kilmelfort	2	1956
Loch Gair	6	1961
Lussa	2.4	1952
Striven	8	1951
Gaur	6.4	1953
Cuaich	2.5	1959
Loch Ericht	2.2	1962
Rannoch	42	1930
Tummel	34	1933
Errochty	75	1955
Clunie	61.2	1950
Pitlochry	15	1950
Chliostair	1.1	1960
Kerry Falls	1.3	1951
Loch Dubh	1.2	1954
Nostie Bridge	1.3	1950
Storr Lochs	2.4	1952
Galloway (6 stations)	106	1935
Lanark (2 stations)	17	1927
Foyers Hydro/pumped	300	1974

Pumped Storage Power Stations in the UK

(operational at the end of May 2002)

Station Name	Installed Capacity (MW)	Year of Commission or Year Generation Began
Dinorwig	1,728	1983
Ffestiniog	360	1961
Cruachan	399	1966

Figure 4-5
Generation Capacity in England & Wales

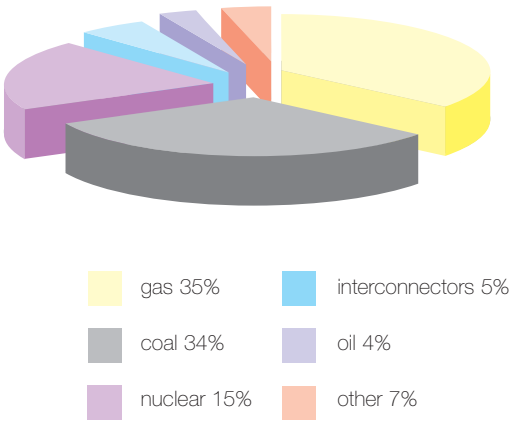


Figure 4-6
Generation Capacity in Scotland

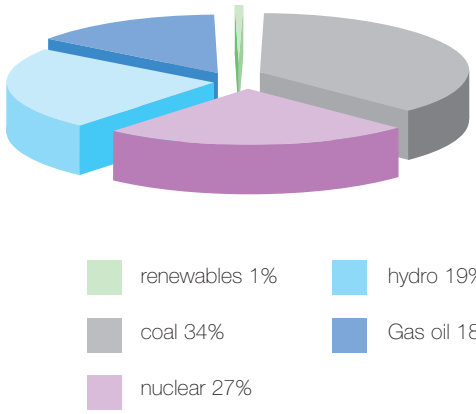
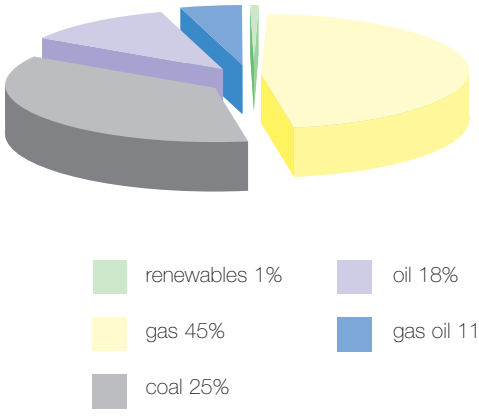


Figure 4-7
Generation Capacity in Northern Ireland



4.2 The Structure of the Electricity Industry in the United Kingdom

The electricity industry in the United Kingdom has undergone a radical restructuring since 1990 with aim of creating through liberalisation a highly competitive market where suppliers can sell nation-wide the customer can also choose their supplier.

Privatisation was carried out in stages, beginning in England and Wales and then in Scotland and finally in Northern Ireland. This has resulted in different structural, commercial and legislative arrangements for the three regions.

4.2.1 England and Wales

In England and Wales the monopoly elements of the business, that is the transmission and distribution have been separated from those, which are subject to competition, that is supply and generation. At present the generation market in England and Wales is very diverse with many generating companies, including merchant companies often owing one plant. There are at least 36 companies now regarded as major power producers. The following chart shows the generation capacity in England and Wales.

4.2.2 Scotland

The Scottish electricity industry had an integrated structure prior to privatisation, and this continued on afterwards with two companies, Scottish Power and Scottish and Southern Energy. These two companies cover the full range of electricity provision from generation through to supply. Each of the two companies has access to each others generation, while a third company, British Energy is a nuclear generator and is contracted to supply its full output to the other two companies.

The first two companies schedule generation in their own areas from the plant available to them, while British Energy provide the bulk of the base load in Scotland accounting for some 50% of the output. Through a 1,600MW interconnector the Scottish electricity system is connected to the national grid in England and Wales permitting selling or buying of power from each area.

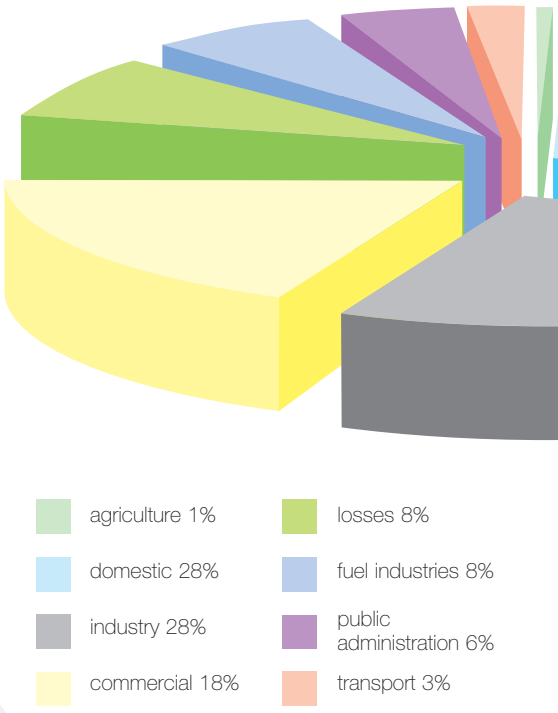
4.2.3 Northern Ireland

The industry in Northern Ireland differs from the rest of the UK in a number of important ways, in that there are a small number of customers in a relatively small area and until the mid-1990's had been isolated from the other networks.
There are only four major power stations, with two of them, Ballylumpford and Kilroot supplying more than 90% of the electricity generated in Northern Ireland.

4.3 Electricity Consumption in the UK

Consumption by end users accounts for most of the total demand for electricity in the UK. In 2000, end users' consumption represented 85% of the total demand, while consumption by the energy industries was 7.5% of the total. The remaining 7.5% were losses from the transmission and distribution system and losses due to theft or meter fraud. The electricity industry itself consumes more than half of the total electricity used by the energy industries, with oil refineries the next most significant consumer.

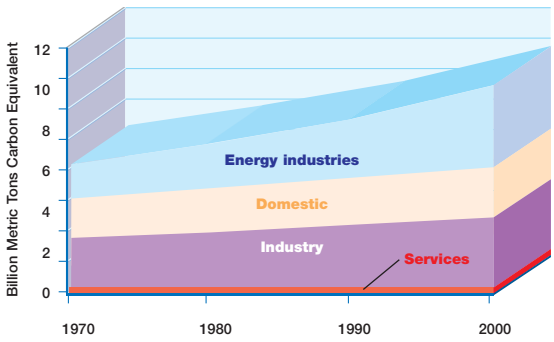
Figure 4-8
Electricity Consumption by Sector



Industry accounted for 34.5% of the total end users consumption in 2000, the domestic sector for 34%, transport and other services sector for 30.5% and agriculture for the remaining 1%. Most of the electricity consumed by final users is delivered through the public distribution system. In 2000 only 6% of electricity consumption did not pass through the public distribution system, as it was self-generated.[4.6]

Figure 4-9
Electricity Consumption, 1970 through to 2000

Charting how demand has varied over the past thirty years.



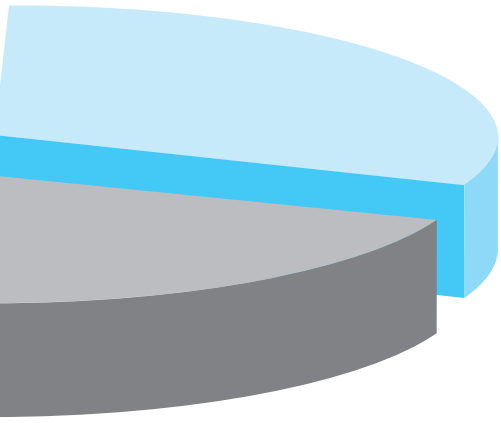
4.4 UK CO_2 Emissions

Environmental conditions in the United Kingdom have improved in recent years[4.7]. While some pollutants, such as nitrogen oxides, have not decreased substantially, sulphur dioxide emissions have. As a major component of acid rain, this reduction in sulphur dioxide has produced noticeable environmental benefits. Furthermore, the United Kingdom finds itself in the company of only three other Western European countries-Finland, Germany and Luxembourg-in experiencing a decline in carbon dioxide emissions since 1990.

The United Kingdom is an Annex I country under the United Nations Framework Convention on Climate Change. (Annex I countries include the countries of the Organisation of Economic Co-operation and Development, as well as the countries designated as Economies in Transition). The European Union, as a whole, agreed to an 8% reduction below 1990 levels of a "basket" of greenhouse gases by the 2008-2012 commitment period. Among countries of the European Union, the United Kingdom agreed to a more challenging target of 12.5% below 1990 levels. The government went even further and suggested a domestic goal of 20% below 1990 levels by 2010.

Reductions of carbon emissions in the United Kingdom, as well as reductions in other pollutants, such as sulphur dioxide, have resulted primarily from deregulation of the country's electricity industry. Privatisation led to a reduction in coal subsidies, thus narrowing the price differential between coal and natural gas. As a result, consumers are switching to natural gas, and the benefits of burning this "cleaner" fuel are being realised.

In 1999, the United Kingdom accounted for 2.6% of total world energy consumption and was responsible for 2.5% of total world carbon emissions. Under the Kyoto Protocol, the United Kingdom has set a target of reducing greenhouse gas emissions by 12.5% on 1990 levels by 2008-2012, and to cut carbon emissions 20% by 2010. Energy related carbon emissions in the United Kingdom have fallen from 167.4 million metric tons of carbon in 1990 to 152.4 million metric tons in 1999, a 9% reduction. The decline in carbon emissions has been due to a decrease in the share of coal (the most carbon intensive fossil fuel) in the total fuel mix. Coal has been replaced by less carbon intensive energy sources such as natural gas, nuclear and renewable energy. Likewise there has been a steady decline in energy intensity over the past twenty years (see chapter 3 for details).







5

The use of Coal to Generate Electricity

5.1 What is Coal?

Coal is the altered remains of prehistoric vegetation that originally accumulated as plant material in swamps and peat bogs[5.1]. The accumulation of silt and other sediments, together with movements in the earth's crust (tectonic movements) buried these swamps and peat bogs, often to great depth. With burial, the plant material was subjected to elevated temperatures and pressures, which caused physical and chemical changes in the vegetation, transforming it into coal.

Initially the peat, the precursor of coal, was converted into lignite or brown coal – coal-types with low organic 'maturity'. Over many more millions of years, the continuing effects of temperature and pressure produced additional changes in the lignite, progressively increasing its maturity and transforming it into the range known as sub-bituminous coals. As this process continued, further chemical and physical changes occurred until these coals became harder and more mature, at which point they are classified as bituminous or hard coals. Under the right conditions, the progressive increase in the organic maturity continued, ultimately to form anthracite.

The degree of 'metamorphism' or coalification undergone by a coal, as it matures from peat to anthracite, has an important bearing on its physical and chemical properties, and is referred to as the 'rank' of the coal. Low rank coals, such as lignite and sub-bituminous coals, are typically softer, friable materials with a dull, earthy appearance; they are characterised by high moisture levels and a low carbon content, and hence a low energy content. Higher rank coals are typically harder and stronger and often have a black vitreous lustre. A rise in the carbon and energy contents and a decrease in the moisture content of the coal accompany increasing rank. Anthracite is at the top of the rank scale and has a correspondingly higher carbon and energy content and a lower level of moisture.

Bituminous coal can be metallurgical (also known as coking coal) and used predominantly in the steel making process, or thermal (also known as steam coal) a term used to distinguish coals considered particularly suitable for boiler steam generation.

Large coal deposits only started to be formed after the evolution of land plants in the Devonian period, some 400 million years ago. Significant accumulations of coal occurred during the Carboniferous period (350-280 million years ago) in the Northern Hemisphere, the Carboniferous/Permian period (350-225 million years ago) in the Southern Hemisphere and, more recently, the late Cretaceous period to early Tertiary era (approximately 100-15 million years ago). It is found in areas as diverse as the USA, South America, Indonesia and New Zealand.

Coal is currently produced in over 50 countries world wide, with approximately two-thirds of hard coal production being extracted by underground mining and one third by surface mining. Preparation techniques are then used to reduce the ash, mineral, and sulphur and moisture contents of many coals. Approximately 12% of all coals produced world wide are traded internationally. Some 37% of the world's electricity is coal fired, with approximately 70% of global steel production dependant on coal.

The following is a typical coal analysis taken from the EM database[5.2], which has been subsequently used in the coal mass balance, to cross check, in particular, the amount of carbon released into the environment in the form of carbon dioxide emissions, versus that obtained by other methods (see later).

The Environmental Manual for Power Development, which includes the EM database, was developed for and is maintained by the German government. The EM database for coal technologies distinguishes between hard coals, and lignite. Hard coals represent anthracite and

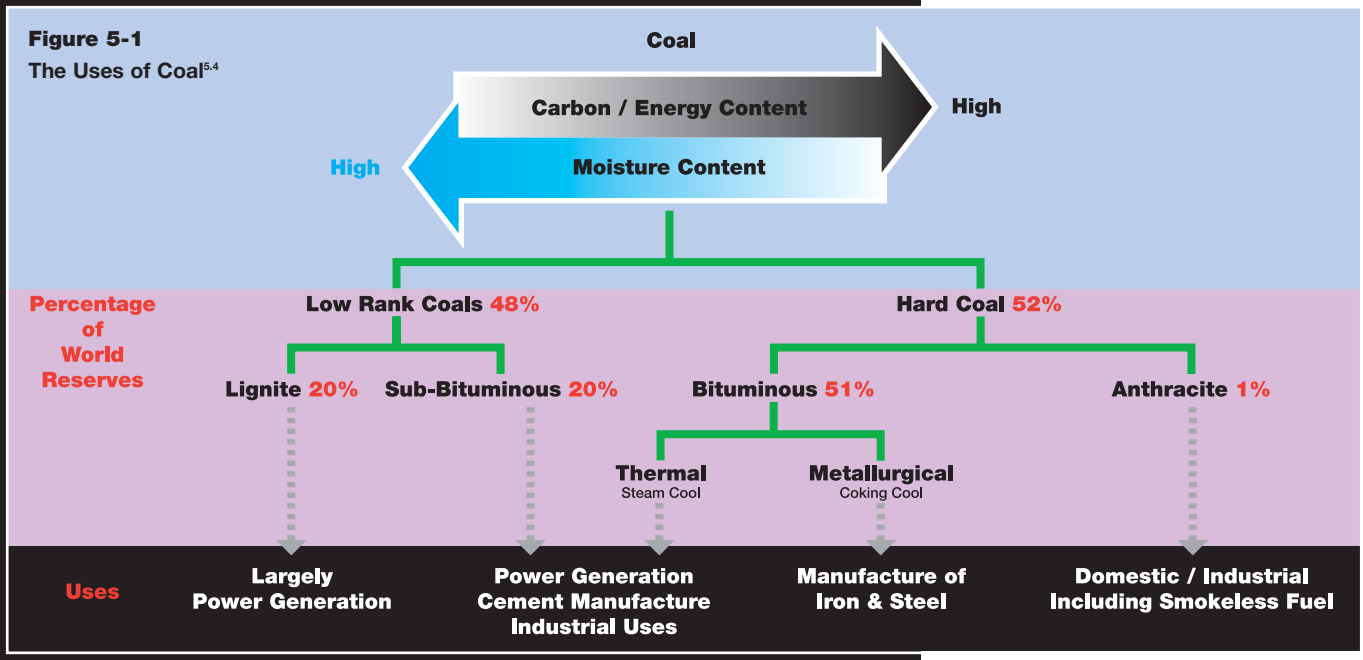
bituminous coals, while lignites cover sub-bituminous and brown coals.

The EM contains pre-defined fuels for several countries, which deliver hard coals to the world market. The ultimate analyses of these typical fuels are taken directly from files of the German Association of Coal Importers (VdKol 1992). Based on this data, a generic hard coal composition was estimated for the EM (see following Table 5-1). The equivalent lignite generic coal composition is not given as the UK burns only hard coal[5.3].

Table 5-1 The EM Database: Coal

Component	Unit	Australia	Poland	South Africa	USA	EM generic
Carbon	wt%	67.0	67.0	65.0	73.0	67.0
Hydrogen	wt%	3.0	3.9	3.0	3.0	3.0
Sulphur	wt%	0.5	1.0	0.7	1.0	1.0
Oxygen	wt%	7.5	10.1	7.5	7.5	8.0
Nitrogen	wt%	1.4	1.5	1.4	1.4	1.0
Chlorine	wt%	0.1	0.1	0.1	0.1	0.1
Fluorine	wt%	0.01	0.01	0.01	0.01	0.01
Water	wt%	8.0	7.0	9.0	6.5	7.9
Ash	wt%	12.5	9.4	13.3	7.5	12.0
HHV	MJ/kg	26.1	27.0	26.0	28.3	26.0

Figure 5-1
The Uses of Coal[5.4]



5.2 The Use of Coal for Generating Electricity

Coal is currently the single largest fuel source for the generation of electricity world wide with currently approximately 38% of the world's electricity being generated using coal[5.4].

However coal was the only primary energy source to experience a production decline between 1991 and 2000. Production decreased by 57 million short tons, over the period. China was the leading producer in 2000 at 1.3 billion short tons (Bst), with the United States the second leading producer in 2000 with 1.1 Bst. India was ranked a distant third at 345 million short tons (Mmst), followed by Australia, at 337 Mmst, and South Africa at 326 Mmst. Together, these five countries accounted for 67 percent of world coal production in 2000[5.5].

However, while the production of coal fell, world coal consumption grew by 1.2% 2.2 Bst, with demand in the US rising by 3.3% and Europe experiencing its first increase in coal consumption for over a decade. However, China, the worlds second largest coal consumer, saw another sharp fall in demand, down by 6.4%[5.6].

The world reserves of coal are an estimated 227 years (expressed as a multiple of annual production at the end-2000). Proven coal reserve total some 984 billion tonnes, of which 509 are hard coal (anthracite and bituminous). The US has the largest percentage at 25.1% of known reserves, followed by Russia (15.9%), China (11.6%), Australia (9.2%), India (7.6%), Germany (6.8%) and South Africa (5.6%).[3]

In terms of supply and demand, Europe is the only trading block whose demand for coal significantly exceeds its ability to supply. America, the former Soviet Union and Africa all supply more than they consume, while the Asian Pacific region has a marginal demand for coal supply.

Coal production and consumption in the United Kingdom have decreased dramatically since 1986. UK coal production fell from 119 Mmst in 1986 to 40.9 Mmst in 1999. Production fell again in 2000, but demand rose, increasing imports. In 2000, steam coal accounted for 80% of coal demand, coking coal for 15% and anthracite for 5%. Electricity demand accounted for 95% of demand for steam coal and 46.5% of demand for anthracite[5.7]. Approximately 47 million tonnes of coal were used in 2000 to produce some 119960 GWh of electricity, which is equivalent to 396g per kWh of electricity. The average efficiency of a coal fired power station in the OECD countries has been taken as 35%[5.8].

In the late 1980s, coal accounted for about two-thirds of the United Kingdom's thermal electricity production. Currently, less than half of UK thermal electricity is coal-fired (around 34% in 2000), and the figure is expected to fall below one-third by the end of the decade.

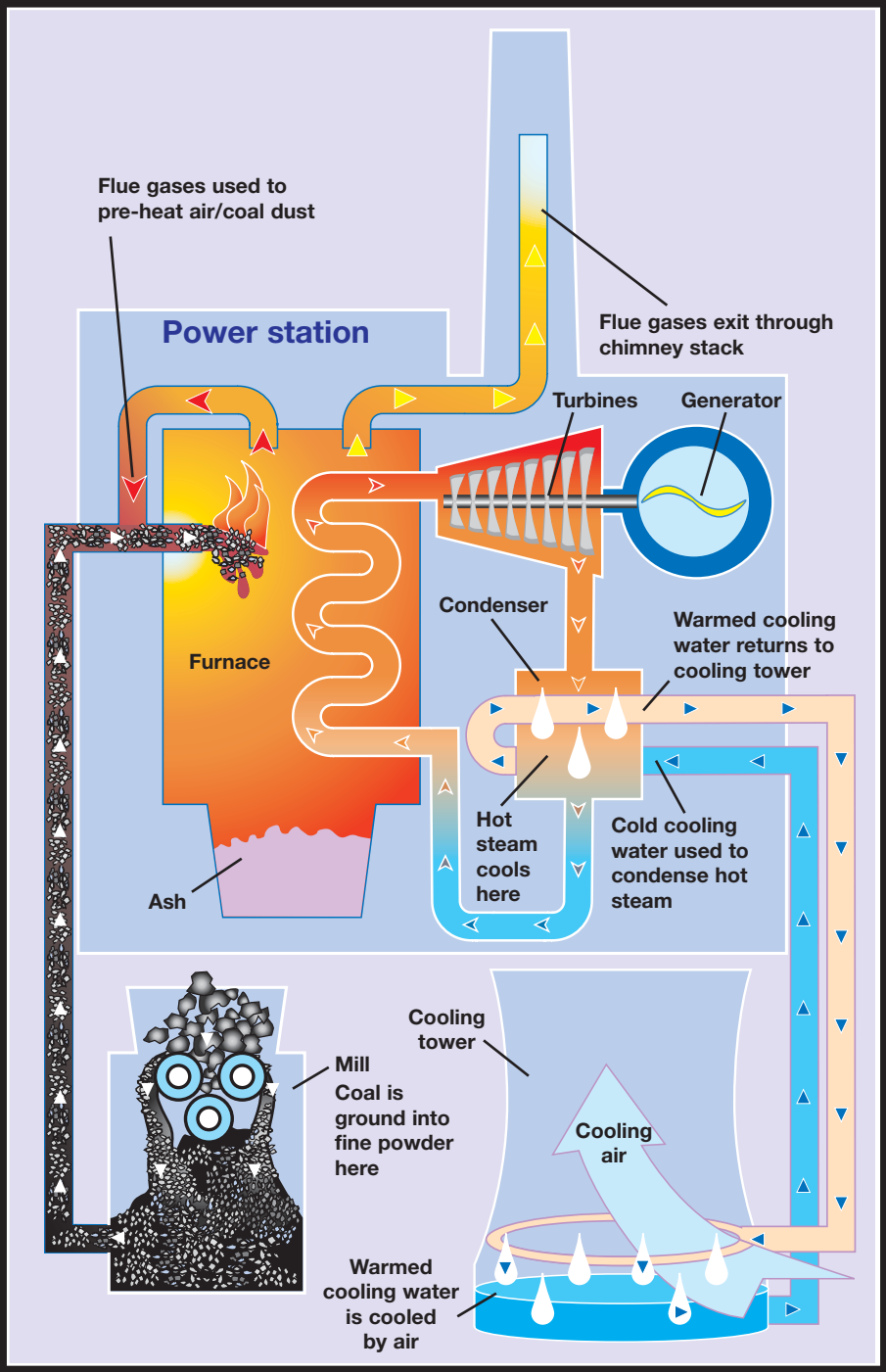
However more recently, government figures have shown that in the first quarter of 2001 coal consumption rose 17.4 percent against 3.6 percent for gas. In 2000 the amount of coal burned in power stations rose 15 percent compared with 1999 levels. In contrast gas use rose only 0.7 percent over the same period. But the "dash for gas" - a defining characteristic of the last decade's electricity generation trends which saw gas-use shoot up - has stalled in the face of soaring wholesale gas prices. Therefore, analysts say the reason is simple - coal is cheaper than gas. Burning coal to produce electricity currently works out at about 12 pounds a megawatt hour against about 12.5 pounds when burning gas. Coal plant is also a lot more flexible than gas-fired generation, an attribute that has become more prized following the introduction in March of a new wholesale trading market (NETA) which rewards predicable output[5.9].

Coal mines are located primarily in central and northern England and southern Wales, with some coal mines also found in southern Scotland. The UK produced 40.5 million tons of bituminous coal and 409 thousand tons of anthracite coal in 1999. The UK also produces coke-oven coke in quantities such that it is self-sufficient. Nevertheless, net imports of coal in 1999 were 23.9 million tons, and this figure is expected to increase.

Between 1984 and 1985, the British coal miners' union staged a yearlong strike. The strike dramatically altered energy production and consumption patterns in the United Kingdom for that year and precipitated the longer-term decline of the industry.

5.3 Generating Electricity Using Coal

Figure 5-2 Schematic of a Coal-Fired Power Station[5.10]



Coal-fired stations produce steam to drive electricity generators. Several of the largest can generate about two gigawatts, and Drax (in Yorkshire) can supply nearly twice that, which is enough for a large city.

The coal is typically shipped to a power plant by rail car or barge. In addition to the carbon content, coal contains ash (alumino-silicates) and trace metals.

A single coal-fired boiler in a modern power station can burn over 260 tonnes of coal an hour. The coal is used to boil water and produce steam. Because the steam is contained in a closed system of pipes, it reaches a very high pressure, and can be directed through the vanes of a turbine to keep them spinning. The spinning shaft of the turbine drives an electricity generator. Once it has passed through the turbine, the hot steam is cooled in a condenser and returned to the boiler to repeat its cycle.

In practice, the process is a little more complicated than this. To increase the rate at which the coal burns; it is ground to a very fine powder and mixed with pre-heated air before being blown into the furnace, where it burns like a gas. The steam emerging from the boiler is passed in pipes through the furnace to be 'superheated', which greatly increases its pressure and therefore the energy it can transfer to the turbine. This superheated steam may reach temperatures as high as 560°C - enough to make the pipes glow red. The hot flue gases emitted by the burning coal are used to pre-heat both the air needed for combustion and the condensed water returning to the boiler.

The condenser dissipates its heat through direct cooling by river or seawater, or by evaporating water in a cooling tower. Various chemicals are used to treat the cooling water to minimise corrosion, fouling and scaling. This treatment process can result in certain waste waters and waste solids. Releases to water may include chemicals from the water treatment, as well as from the coal itself, where chemicals can be 'leached' from the coal, if the coal is allowed to become wet.

In addition to the burnable carbon, the coal contains ash, which is removed from the bottom of the furnace (called appropriately 'bottom ash'). There is also dust in the flue gases emerging from the boiler and if untreated, these can cause large pollution problems. This dust is filtered out in all industrial countries before the gases are released, but many power stations in less developed countries emit this dust to the air.

Coal also contains many heavy metals, which are mostly bound in the ash and the dust. Ash from the burning process is typically sent to an ash pond, landfills or is used commercially. Other waste solids may also be sent to the land.

In addition to fly ash, the flue gases contain other contaminants, including carbon dioxide, sulphur dioxide, and nitrogen oxides. In general the carbon dioxide emissions are not directly measured because they are relatively easy to calculate using a model of combustion based on fuel carbon content, calorific value and fuel efficiency. That is the approach taken in this report, where it was also assumed that in most of the relevant processes combustion efficiency exceeds 99% and therefore the emission factor is largely a function of the fuel used[5.11].

There is also dust in the flue gases emerging from the boiler and if untreated, these can cause large pollution problems. This dust is filtered out in all industrial countries before the gases are released, but many power stations in less developed countries emit this dust to the air.

Coal also contains many heavy metals, which are mostly bound in the ash and the dust. Ash from the burning process is typically sent to an ash pond, landfills or is used commercially. Other waste solids may also be sent to the land.

In addition to fly ash, the flue gases contain other contaminants, including carbon dioxide, sulphur dioxide, and nitrogen oxides. In general the carbon dioxide emissions are not directly measured because they are relatively easy to calculate using a model of combustion based on fuel carbon content, calorific value and fuel efficiency. That is the approach taken in this report, where it was also assumed that in most of the relevant processes combustion efficiency exceeds 99% and therefore the emission factor is largely a function of the fuel used[5.11].

Emissions of sulphur dioxide depend again critically on the sulphur content of the fuel and any 'clean up' technology used. The sulphur content of indigenous bituminous coals used in the UK for power generation is in the range 0.5% to 4.0%[5.12]. A typical analysis for coals extracted in the UK is 1.6%5.13. Due to the increasing usage of imported coal for steam generation, this figure will decrease, as the average sulphur content in imported coal is lower.

Nitrogen oxides (NOx) are formed by the oxidation of a portion of the nitrogen component of the fuel and by the reaction of atmospheric nitrogen and oxygen at high temperatures. Models have been NOx formation have been derived, and show that the most important factors are the flame temperature and the oxygen concentration in the flame. This knowledge has been used in the design of combustion techniques to abate NOx formation.

In terms of the nitrous oxide emissions, which are the least well know of all the direct greenhouse gases, .the only significant emissions concerned with the life cycle analysis of the coal combustion industry are those associated with the combustion process itself. This is the subject of some controversy in the literature and will be covered in more depth in chapter 10 of this report. In this report the thermal efficiency of a conventional coal powered station has been assumed to be 35%[5.14] which is in line with other energy balances. Official UK figures for 2000[5.15] give the thermal efficiency of conventional thermal stations as 36%, up from 33.9% in 1990. However, these do vary from year to year, and also depend on whether the power station concerned uses a flue gas desulphurisation (FGD) system for the removal of sulphur dioxide from the gas stream, or NOx abatement techniques. If it does the abatement technologies impact on the thermal energy efficiency (reducing it by up to 2%[5.16]) and increases the carbon dioxide emissions, in the case of desulphurisation. Firstly, the decrease in thermal efficiency automatically increases the carbon dioxide emitted per kWh of electricity generated, and secondly, for each sulphur dioxide molecule removed, one carbon dioxide molecule is emitted, increasing on average the carbon dioxide emitted by 7g/kWh[5.17]. While FGD systems and low NOx burners are required for all new power stations, and have been retrofitted to some older units, this report has assumed that these systems are not used, due to difficulties in calculating the contribution to the thermal efficiency and carbon dioxide emissions.

Table 5-2 Statistics for coal-fired power stations in the UK, 2000

Number of power stations 16 with 4 mixed fuel		
Output range 393 – 3870 MW installed capacity		
Efficiency range (efficiency of converting chemical energy in coal to electrical energy) 21%-39% (average 31%)		
Output from typical 800MW station at 35% efficiency using coal of calorific value 27.9MJ/kg:		
	per kWh	per day (tonnes)
Coal consumed	396 grams	7673
SO2 produced	12 grams	233
SO2 produced (with FGD)	1.2 grams	23
Nox produced	4 grams	78
NOx produced (with LNBs)	2.6 grams	50
CO2 produced	970 grams	18,794
CO2 produced (with FGD)	979 grams	18,968
Ash produced	48 grams	930
Gypsum produced	32 grams	620



6 The use of Oil to Generate Electricity

6.1 What is Oil?

Together with natural gas oil makes up petroleum, which is Latin for 'rock oil', and was known as bitumen in ancient times. Most geologists today agree that crude oil forms over millions of years from the remains of tiny aquatic plants and animals that are exposed to the combined effects of time and temperature. In other words, oil forms from organic matter that is either 'cooked' deep within the earth for long periods of time at low temperatures, or 'cooked' for short periods of time at high temperatures[6.1].

Fossil organic matter is called kerogen and sulphur rich kerogens form oil sooner, and at lower temperatures, than other types of organic matter. This is because the atomic bonds between carbon and sulphur break much faster than carbon-oxygen bonds. Then a period of time in anaerobic, that is oxygen-deficient mud, was required after the animals had died when the organic material was converted into kerogen. Finally if sufficient kerogen remained, it was later converted into oil. In summary most crude oil formed from microscopic plants and animals that died millions of years ago and were rapidly buried under conditions, which favoured their preservation. Given deeper burial with sufficient time and temperature, the soft parts of these organisms, over probably millions of years were slowly converted to oil.

Petroleum is therefore essentially a mixture of naturally occurring organic compounds from within the earth, consisting primarily of hydrogen, carbon and oxygen. When petroleum comes straight out of the ground as a liquid it is called crude oil; if dark and viscous, and condensate if clear and volatile. When solid, it is asphalt, and when semi-solid, tar. There is also natural gas which van be associated with oil or found alone[6.2].

Crude oil comes in many forms, and indeed colours, usually being black, but green, red and brown oils are not uncommon.

Condensate density tends to be lower than water, so it floats easily, where in contrast some of the heavy oils can sink rather than float. Most oils are mixtures of many different compounds, most of which are hydrocarbons. Saturates are hydrocarbons consisting of straight chains of carbon atoms, while aromatics are hydrocarbons consisting of rings of carbon. Asphlatenes are complex polycyclic hydrocarbons that contain many complication carbon rings. In addition to hydrogen, carbon and oxygen being present, it is also common to find sulphur.

Table 6-1

Typical North Sea Heavy Fuel Oil Composition[6.3]	
Average Crude Oil Composition	**Percentage (%)**
Carbon	86.3
Hydrogen	11
Sulphur	1.5-3.5
Nitrogen	0.2-0.3
Ash	0.04-0.1
Moisture	0.1-1
GCV	41.6-42.7
NCV	39.3-40.3



Table 6.1 is a typical North Sea oil analysis from the ExternE project, which was taken as the typical gas analysis for this reports mass balance. The location for the oil extraction was taken to be the Alba field, UKCS, in the North Sea.

6.2 The Use of Oil for Generating Electricity

Petroleum oil is a vitally important element of the world's economy. It provides fuel for transport, heating and power generation, and is used to make a huge range of petrochemicals from plastics to paints. It is estimated that oil accounts for 8.5% of the world's electricity generation (1999)[6.4].

The use of oil in power generation has declined in recent years because of rising prices and direct competition from natural gas. As well as being cheaper, gas combustion is much cleaner, making it easier for the generating companies to meet increasingly stringent pollution limits. Many people would argue that it makes more sense to reserve a valuable resource like oil for transport and petrochemicals rather than burning it to generate power. However, as always, there are many factors to consider - economic, environmental, social and political.

As oil-fired burners are relatively easy to quickly start up and shut down, they are increasingly used to meet the variable peaks in demand which are encountered very day in a typical electricity network, thereby maximising oil's potential for flexibility, whilst minimising the cost associated with the fuel.



Global consumption of petroleum (which includes both crude oil and natural gas plant liquids) increased by 9.3 million barrels per day between 1991 and 2000, an average annual rate of growth of 1.5 percent. Saudi Arabia, the United States and Russia were the three largest producers of petroleum in 2000. Together they accounted for 31.7% of the world's petroleum[6.5].

In 2000 the world consumption of oil rose by 1%, effectively in line with it 1990-2000 average. However, this total disguised marked regional variations. The growth in consumption[6.6] in almost every region was below its 10 year average, but this was offset by a relative improvement in the countries that comprise the former Soviet Union (FSU). Oil consumption also fell there, but by significantly less than the average rate of decline for 1990-2000.

In the year 2000 proven oil reserves were an estimated 40 years [6.4], expressed as a multiple of annual production. The following table gives the worlds crude oil reserves as of January 1st 2002. (Table 6.2)

North Sea oil and gas reserves were first discovered in the 1960's, but did not immediately emerge as a key non-OPEC oil producing area until later. Although the region is a relatively high cost producer, its high quality crude oil, political stability and proximity to major European consumer markets have allowed it to play a major role in the world oil and gas markets. Many of the worlds major crude oil prices are linked to the price of the North Seas Brent crude oil, which is a mixture of North Sea crude oils.

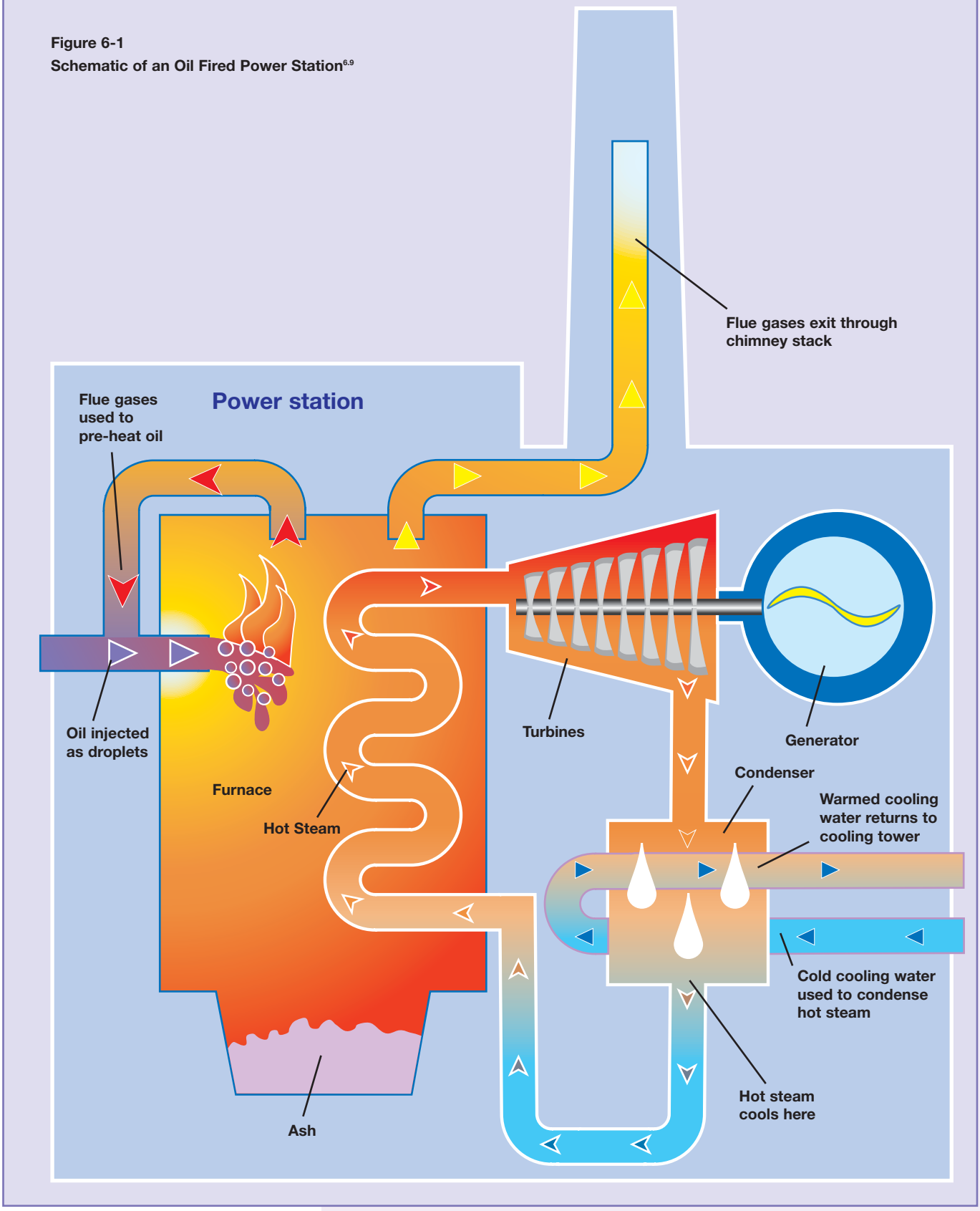
The North Sea is considered a 'mature' area with few large discoveries likely to be made. Only a few frontier areas hold the possibility of further discoveries of large oil and gas fields. The UK holds about 5 billion barrels of proven oil reserves, mostly in the North Sea. There are over 100 oil and gas fields currently on stream, and several hundred companies are active in the area. The production has been declining since 1999, with 2.75 million barrels per day being produced in 2000. Most of the high quality crude oil is exported, while cheaper, lower quality crude oils are imported for refining, mostly from the Middle East.

Table 6-2

World Crude Oil Reserves[6.7]

Region Country	Crude Oil (Billion Barrels) Oil and Gas Journal	World Oil
North America		
Canada	4.9	5.4
Mexico	26.9	23.1
United States	22.4	22.4
Total	**54.2**	**50.9**
Central & South America		
Argentina	3.0	2.9
Brazil	8.5	8.6
Venezuela	77.7	50.2
Total	**96.0**	**69.1**
Western Europe		
Norway	9.4	10.3
United Kingdom	4.9	4.6
Yugoslavia	0.1	NA
Total	**17.3**	**17.7**
Eastern Europe & Former USSR		
Kazakhstan	5.4	NA
Russia	48.6	53.9
Total	**58.4**	**67.1**
Middle East		
Iran	89.7	99.1
Iraq	112.5	115.0
Kuwait	96.5	98.8
Oman	5.5	5.9
Qatar	15.2	13.8
Saudi Arabia	261.8	261.7
United Arab Emirates	97.8	62.8
Other	0	0.7
Total	**685.6**	**662.5**
Africa		
Algeria	9.2	17.0
Angola	5.4	6.0
Libya	29.5	30.0
Nigeria	24.0	30.0
Total	**76.7**	**94.9**
Asia & Oceania		
China	24.0	29.5
India	4.8	3.8
Indonesia	5.0	9.2
Malaysia	3.0	4.5
Total	**43.8**	**56.5**
World Total	**1,032.0**	**1,018.7**

Figure 6-1
Schematic of an Oil Fired Power Station[6.9]



At present average production costs are $15 per barrel[6.8].

The UK's crude oil refining capacity is approximately 1.77 million barrels of oil per day, just slightly above the country consumption of 1.7 million barrels per day, for which demand varies seasonally. Petroleum products represented 45% of final energy consumption in 2000, with the transport sector consuming 74% of the petroleum products in the same year. Nationally, the energy sector consumed just 7%, 1.55 below the world average of 8.5%. This was equivalent to 1.34 million tonnes of oil.

6.3 Generating Electricity Using Oil

Even a relatively small 500-megawatt power station may burn nearly 3,000 tonnes of heavy fuel oil in a single day. They are therefore normally situated either close to an oil refinery so that oil can be piped directly, or on the coast or an estuary for deliveries by sea. They also need large storage tanks on site to ensure a constant supply.

Oil is sprayed into the boiler furnace as a cloud of fine droplets, along with a supply of air, to help the oil burn as completely as possible. Water passing through the boiler in tubes turns to steam, which reaches very high pressures because it is contained in a closed system. The steam is directed through the vanes of a turbine to keep them spinning, and the spinning shaft of the turbine drives an electricity generator.

Once it has passed through the turbine, the hot steam is cooled in a condenser and returned to the boiler to repeat its cycle. In practice, a number of refinements improve overall efficiency with which the fuel's chemical energy is converted into electrical energy. The steam tubes from the boiler are routed back through the hottest part of the furnace to superheat the steam and increase its energy before it enters the turbine. The hot flue gases, on their way to the chimney, are used to pre-heat the combustion air before it enters the furnace, and also to pre-heat the water before it enters the boiler. Flue gases are drawn out of the furnace to the chimney by a fan, to ensure they do not linger to inhibit combustion.

Large oil-fired power stations were built in the UK from the late 1960s to the early 1980s. The discovery of North Sea oil from 1970 onwards was an incentive to install oil-burning plant as an alternative to coal. However, rising prices worldwide reduced oil's competitiveness. New fossil-fuel stations being built in the UK use natural gas, which is also easier to burn cleanly to meet increasingly stringent limits on pollution.

Power stations using oil, sometimes with coal or gas-fired boilers on the same site, currently make up about 2% of the UK's total electricity generating capacity, down from 14% in 1994. There were also many small oil-fired boilers supplying private users such as factories, but these too tended to be replaced by gas-fired plants.

In terms of emissions, the same comments hold for oil as those found in Chapter 5.3 for coal, and Chapter 10 on emissions. However, the main difference between coal and gas, is that the amount of solid residue produced by burning oil is insignificant when compared to that produced burning coal, albeit that oil is more polluting in terms of gaseous emissions than natural gas.

In conclusion, oil is easy to transport directly through pipes without using road vehicles. It provides flexible power generation on demand, and can meet pollution limits with modern techniques. However, it burns less cleanly and efficiently than natural gas. Also, it is a limited resource, which provides our transport fuels and a huge range of petrochemical products.

Table 6-3 Statistics for oil-fired power stations in the UK, 2000

	per kWh	per day (tonnes)
Oil consumed	396 grams	7673
SO_2 produced	13.9 grams	269
SO_2 produced (with FGD)	1.4 grams	27
NOx produced	3.72 grams	72
NOx produced (with LNBs)	2.42 grams	47
CO_2 produced	755 grams	14,628
CO_2 produced (with FGD)	766 grams	14,841

Output from typical 800MW station at 35% efficiency using fuel oil of calorific value 42.3MJ/kg





7 The use of Gas to Generate Electricity

7.1 What is Gas?

Natural gas is in many ways the ideal fossil fuel. It is clean, easy to transport and convenient to use. Currently about half the gas produced is used in industry, while a large portion is also utilised in the home for heating, lighting and cooking. However, like with everything there are limits on how much gas is available and obtainable using today's technologies.

Research is continuing on how natural gas was formed, and where it has collected within the earth's crust. It has been found that gas is not only found in pockets by itself, but in many cases it is found alongside oil, and both flow together to the surface from the same underground formation.

Like oil production, some natural gas flows freely to the surface, due to the natural pressure of the underground reservoir being high enough to force the gas through the reservoir rocks. Only a small number of these free-flowing gas formations still exist. Almost always some type of pumping system will be required to extract the gas present in the underground formation.

Often the flow of gas through as reservoir can be improved by creating tiny cracks in the rock called 'fractures'. These serve as open pathways for the gas to flow. In a technique known as 'hydraulic fracturing' drillers force high pressure fluids like water into the formation to crack the rock. A 'propping agent' like sand or tiny glass beads, is added to the fluid to prop open the fractures when the pressure is decreased.

Natural gas can be found in a number of different underground formations, including[7-1]:

1. Shale formations
2. Sandstone beds
3. Coal seams, and
4. Deep salt water aquifers (which are underground pools of water).

Some of these formations are more difficult and expensive to produce than others, but ultimately all are accessible.

Other more speculative sources of methane exist, which include:

1. Light sand lenses where the gas is held in sandstone deposits where the holes are very small, and therefore it is very difficult for the gas to flow through these structures.
2. Coal bed methane gas which is found in all coal deposits was once viewed solely as a safety hazard, but now due to ongoing research is regarded as a potential gas source.
3. Another gas deposit is that found in deep ocean beds or in cold areas, called methane hydrate. A methane hydrate is a tiny cage of ice inside of which are trapped molecules of natural gas.

Once natural gas is produced from the underground rock formation, it is sent by pipeline to storage facilities and from there on to combustion plants, homes and factories by smaller pipes, through a well organised distribution system.

Table 7-1

Typical North Sea Heavy Fuel Oil Composition[7-2]	
Composition of Gas	**Value (%)**
Methane	93
Ethane	3
Heavier Alkanes	1
Nitrogen	3
Carbon Dioxide	0.3
Hydrogen Sulphide	Not quoted
Heating Value	Not quoted

7.2 The Use of Gas for Generating Electricity

The use of gas for power generation has increased rapidly in the European Union since the early 1990's after the European Union removed a ban on using it for this purpose. The natural gas share of utility fuels was 1% in 1988. In 1994 it had already overtaken oil to account for 10% of the power generated, however, by 2000, it had also overtaken the use of coal, and stood at around 41%. Forecasts predict that it will increase to 50% by 2010 (see reference 7.7). Worldwide, the use of gas for electricity generation is 17.1%[7.3] of the total world electricity generation.

There are a number of reasons for this rapid acceleration in the use of natural gas to generate electricity and these include:

1. Gas was very attractive from an economic viewpoint in the middle 1990's.
2. A new gas-fired power station can be built more quickly and cheaper than the equivalent coal or oil plant.
3. The government was encouraging the use of gas, which burns comparatively cleanly to help achieve the national targets for reduced total emissions of pollutants.

As was discussed in Chapter 5, on the use of coal to generate electricity, more recently government figures have shown that in the first quarter of 2001 coal consumption rose 17.4 percent against 3.6 percent for gas. In 2000 the amount of coal burned in power stations rose 15 percent compared with 1999 levels. In contrast gas use rose only 0.7 percent over the same period. But the "dash for gas" - a defining characteristic of the last decade's electricity generation trends which saw gas-use shoot up, - has stalled in the face of soaring wholesale gas prices. Therefore, analysts say the reason is simple - coal is cheaper than gas. Burning coal to produce electricity currently works out at about 12 pounds a megawatt hour against about 12.5 pounds when burning gas. Coal plant is also a lot more flexible than gas-fired generation, an attribute that has become more prized following the introduction in March of a new wholesale trading market (NETA) which rewards predictable output[7.4].

World wide the production of dry natural gas between 1991 to 2000, increased by an average annual rate of 1.8%, or by 13.3 trillion cubic feet in 2000 alone. Russia was the leading producer in 2001 at 20.6 trillion cubic feet with the United States following at 19 trillion cubic feet. Together these countries produced 45% of the world's total. Canada is ranked third with 6.5 trillion cubic feet while the United Kingdom is fourth with 3.4, and Algeria fifth with 2.9 trillion cubic feet. These last three countries account for 15 percent of the world's production[7.5].

It should be noted that the production of natural gas appears to be quite volatile with the figures for 2000 for the United Kingdom placing it in third place, followed in this case by Canada and Germany. In 2001, Canada effectively doubled its production of natural gas, due to an increase in demand for natural gas (see below).

BP, in its annual review in 2000 noted that natural gas was the fastest growing fuel in 2000, with global consumption rising by 4.8%, the highest rate since 1996. This was driven in particular by a 5.1% rise in demand in Canada and the US. Chinese consumption increased by 16% although in absolute terms China only represents 1% of the world's natural gas consumption. In contrast the US and Canada consumes 30%. Gas output responded to this increase and the highest rise in some time, more than doubling the average of the past decade[7.6].

Proven reserves of gas in 2000[7.6], were an estimated 61 years, expressed as a multiple of annual production. The following table gives the worlds natural gas reserves as of January 1st 2002[7.7]. It is interesting to compare the natural gas distribution with that of oil; natural gas appears to be more widely found, albeit, not all the reserves are economically viable whether from geographical or market access perspectives. This is perhaps why there is so much technical focus on effective liquefaction over considerable distances.

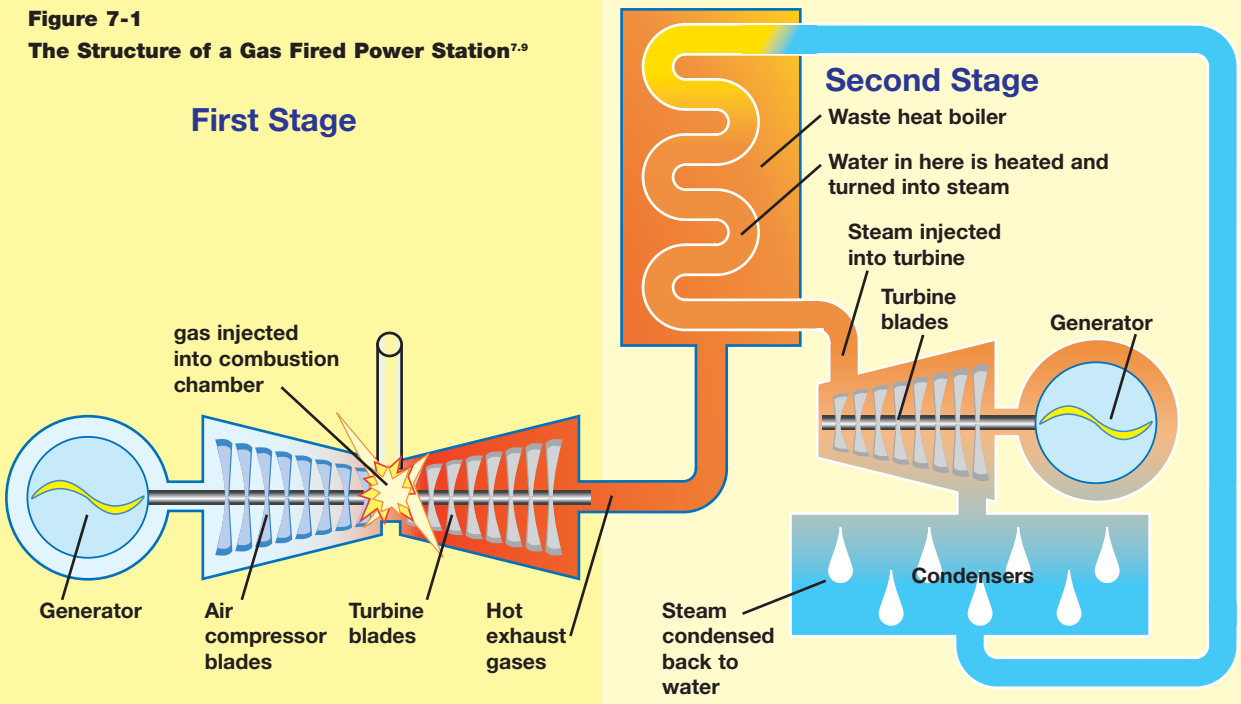
The UK contains approximately 26 trillion cubic feet (Tcf) of natural gas reserves, most of which are in non-associated gas fields located off the English coast in the Southern Gas Basin, adjacent to the Dutch North Sea sector[7.7].

Table 7-2

World Natural Gas Reserves

Region Country	Batural Gas (Trillion Cubic Feet) Oil and Gas Journal	World Oil
North America		
Canada	59.7	59.7
Mexico	29.5	39.0
United States	183.5	183.5
Total	**272.7**	**282.1**
Central & South America		
Argentina	27.5	26.8
Bolivia	24.0	27.4
Trinidad and Tobago	23.5	19.7
Venezuela	147.6	149.2
Total	**253**	**250.2**
Western Europe		
Netherlands	62.5	57
Norway	44.0	77.2
United Kingdom	26.0.	24.5
Total	**160.7**	**182.4**
Eastern Europe & Former USSR		
Kazakhstan	65.0	NA
Russia.	1,680.00	1,700.00
Turkmenistan	101.0	NA
Ukraine	39.6	NA
Uzbekistan	66.2	NA
Total	**1,967.90**	**1,950.50**
Middle East		
Iran	812.3	939.4
Iraq	109.8	112.6
Kuwait	52.7	56.6
Oman	29.3	30.5
Qatar	508.5	757.7
Saudi Arabia	219.5	228.2
United Arab Emirates	212.1	204.1
Total	**1,974.60**	**2,367.90**
Africa		
Algeria	159.7	175.0
Egypt	35.2	54.1
Libya	46.4	46.9
Nigeria	124.0	159.0
Total	**394.8**	**477.1**
Asia & Oceania		
Australia	90.0	80.0
China	48.3	42.8
India	22.9	15.4
Indonesia	92.5	87.5
Malaysia	75.0	82.5
Pakistan	25.1	24.1
Total	**433.3**	**419.9**
World Total	**5,457.10**	**5,930.20**

Figure 7-1
The Structure of a Gas Fired Power Station[7.9]



The Irish Sea has the large Morecambe and Hamilton fields, with Morecambe alone accounting for up to 20% of the British natural gas production. The last project to come on-line in 2001 is the TotalFinaElf operated Elgin/Franklin platform, which may be the last big North Sea production platform. It is also the world's largest high pressure, high temperature development, and has, unlike the others, extensive processing facilities. Most of the other gas is processed on-shore.

British Gas was the monopoly supplier to the interruptible market until the passage of the 1995 Gas Act. The consumer gas market was deregulated by 1998 with the effect that all residential and commercial customers could choose their own supplier. By the end of 2000 suppliers other than British Gas Trading had captured between 20 to 30% of the market in many regions of the UK.
The UK's gas and regulatory body is the Office of Gas and Electricity Markets (OFGEM). OFGEM has proposed reforming price controls on pipeline usage fees.
The privatisation of the UK's gas industry leading to an increased gas supply and reduced prices, has, as indicated above, helped gas to replace much of the UK's reliance on coal as a source for electricity generation. It should also be noted that privatisation in the UK has progressed well in advance of EU requirements.

The first natural gas pipeline to link the UK to the European continent was opened in 1998, is known as the UK-Continent Interconnector and has terminals at Bacton, England and Zeebrugge, Belgium.
There is at present one pipeline linking Ireland to Britain to access the Scottish gas sources, however there are more being planned after permission was granted in 2000. Despite these projects the UK remains a much smaller natural gas exporter than Norway, and has become a net importer again as the new Norwegian field, Vesterled, came on line. However, the return to importing natural gas, has tended to increase the gas price, and raise it's volatility, due to the UK's system of auctioning entry capacity or access rights to the national pipeline.

7.3 Generating Electricity Using Gas

Conventional gas-fired power stations use an open-cycle gas turbine (OCGT). Natural gas is burned in a combustion chamber where it heats a continuous supply of compressed air. The air and burned gas expand and escape under high pressure through the multiple blades of a turbine, causing it to spin. The spinning turbine shaft drives an electricity generator and also the air compressor, which feeds the combustion chamber.

In an OCGT power station, the hot exhaust gases are vented to the atmosphere, and most of the heat energy they contain is wasted. Today, power stations being built include a second stage which uses this heat to generate more electricity.

Instead of being vented, the exhaust gases from the first turbine pass through a boiler, heating water to produce steam which drives a second turbine and electricity generator. The steam is then condensed back to water in an air-cooled condenser before passing back into the boiler in a continuous cycle.

This type of plant is called a combined cycle gas turbine (CCGT). It can convert more than 50% of the chemical energy in the gas to electrical energy - a very efficient process compared with any other kind of fossil-fuel power station. The overall efficiency can be improved to 80% or more in a combined heat and power plant (see Chapter 12 for more details).

Combustion turbines were first developed in the late 18th century but were not economically practical until the 1930's. The first sizeable gas turbine power plant built expressly for power generation was completed in 1939 by Brown Boveri. This plant was used for standby power only.

Although gas turbines were first used in stationary applications, much of their development has occurred in the effort to develop better aircraft propulsion systems.

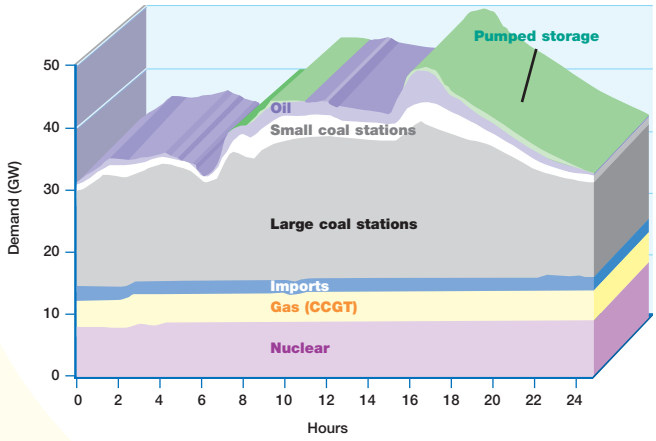
During the 1960's gas turbines first began to appear in quantity in the power generation market. The first applications were to provide peaking power, taking advantage of the turbine's ability to start-up quickly. General Electric (GE) and Westinghouse both formed power generation design groups that were independent of their aircraft engine groups[7.8].

Between 1960 and 1970 gas turbine efficiency was increased through higher pressure ratios and higher turbine inlet temperatures achieved through turbine cooling. GE began development of a water-cooled turbine in the early 1960's, but the first model was not tested successfully until 1973. By the early 1960's both GE and Westinghouse were offering gas turbine power systems sold as standard packages which allowed for multiple sales with little redesign and lowered system cost. In 1963, GE installed the first large (250MW) combined-cycle power plant at Horseshoe Lake Station in Oklahoma, United States. This combined cycle plant consists of a gas turbine the exhaust of which comprises the combustion air for a steam generator which supplies steam to a steam turbine cycle. However, until the early to mid-1970's, GE, Westinghouse and Brown Boveri were mostly selling "recuperative" combined-cycle plants which consisted of a gas turbine exhausting to a heat recovery steam generator (HRSG) which supplied steam to a steam turbine cycle with no supplementary heating of the exhaust. The recuperative plants of the time achieved thermal efficiency of approximately 41 percent.

However, it is true to say that the success of gas turbine power systems has resulted from the successful inter-reaction between military / technology R&D and a variety of regulatory and market factors worldwide, which has resulted in a major take up of this particular method of generating electricity.

In 1988 the European Council adopted the Large Combustion Plants Directive (LCPD) to reduce emissions of pollutants from power stations and other sources. This sets emissions limits for new plants and requires progressive reductions for existing large plants.

Figure 7-2
The 24 hour Electricity Demand Cycle in the UK



Natural gas is an important element in the UK Government's programme to meet its international commitments, since it burns much more cleanly than either coal or oil.

Gas contains very little material which cannot burn, so virtually no dust is emitted in the exhaust gases. Carbon dioxide (CO_2), a 'greenhouse gas' which contributes to global warming, is a by-product of burning fossil fuels because the carbon and hydrogen in the fuel react to produce carbon dioxide and water. however, the highly efficient CCGT power stations burn much less fuel per unit of electricity generated than any coal or oil-fired station, and therefore emit less carbon dioxide - only half that emitted by a coal-fired station. Also, natural gas contains only trace amounts of sulphur and therefore produces very little sulphur dioxide (SO2), a main constituent of 'acid rain'.

Nitrogen oxides (NOx) are the other main constituents of acid rain. They are produced when nitrogen in the fuel reacts with air used for combustion. Natural gas emits only about a quarter as much NOx as coal per unit of electricity generated.

Due to the particularly economic and clean method of producing electricity with CCGT, the CCGT power stations are normally kept in constant operation to provide what is known as the 'base load' demand for electricity. The less efficient generation methods, for example, OCGT and oil are only used to meet short term peaks in demand.

Table 7-3 Statistics for gas-fired power stations in the UK, 2000

	per kWh	per day (tonnes)
Gas consumed	237 grams	4592
Gas consumed (with CCGT)	158 grams	3061
SO_2 produced	0 grams	0
SO_2 produced (with CCGT)	0 grams	0
NOx produced	0.695 grams	13.47
NOx produced (with CCGT)	0.463 grams	8.98
CO_2 produced	651 grams	12,614
CO_2 produced (with CCGT)	434 grams	18,409

Output from typical 800MW station at 46% efficiency using CCGT of calorific value 42.3MJ/kg:



8 The use of Nuclear Power to Generate Electricity

8.1 What is Nuclear Power?

Nuclear and fossil-fuelled power stations both use heat to produce steam, which drives a turbine, coupled to a generator. The fossil fuels, namely oil, coal and gas, have been covered in the previous three chapters. In fossil-fuel fired stations, the heat is produced when coal, oil or gas is burnt, producing carbon dioxide, other gases and solid waste. In nuclear reactors however, the heat comes from energy released when the nuclei of uranium or plutonium atoms are split, this process is known as fission. The energy recoverable from each tonne of nuclear fuel depends on the type of reactor and fuel cycle, but is at least 10,000 times that released when one tonne of coal is burnt in a power station.

Or put another way[8.1], one pellet of a nuclear fuel called MOX (mixed oxide) weighing just 6 grams can yield the same amount of energy as a tonne of coal. Three pellets can provide a family with electricity for one year. All this and zero emissions of carbon dioxide.

All nuclear power stations use uranium as fuel; in Britain some power stations (using Magnox reactors) have uranium metal as their feed stock. Others, including the Advanced Gas Reactors (AGR's) in the UK used uranium dioxide as their principal fuel source, albeit now enriched with plutonium in the MOX fuel pellets. Uranium is one of the heaviest elements found in more than trace amounts in nature.

There used to be a general perception, which is sometimes still apparent today, that uranium is a scarce resource. However, it is a metal approximately as common as tin or zinc and it is a constituent of most rocks and even of the sea. Some typical concentrations are: (ppm = parts per million)[8.2].

An ore body is, by definition, an occurrence of mineralisation from which the metal is economically recoverable. It is therefore relative to both costs of extraction and market prices.

At present neither the oceans nor any granites are ore bodies, but conceivably either could become so if prices were to rise sufficiently.

Uranium is also radioactive, which the French scientist, Henri Becquerel, discovered when investigating radioactivity. That is under the correct circumstances the uranium nucleus can split, releasing energy and other particles. To trigger the fission of a uranium nucleus it must be struck by a particle known as a neutron. This particle is temporarily absorbed, making the uranium nucleus unstable. The nucleus then splits to form 2 smaller nuclei and releases a further two or three neutrons in the process, in addition to energy in the form of the kinetic energy of the particles and gamma radiation.

All the uranium on Earth, unlike the fossil fuels, was forged from lighter elements during supernova explosions billions of years ago.

Table 8-1

The Natural Occurrence of Uranium	
Deposit	**Concentration**
High-grade ore body	2% U, 20,000 ppm U
Low-grade ore body	0.1% U, 1,000 ppm U
Granite	4 ppm U
Sedimentary rock	2 ppm U
Average in earth's continental crust	2.8 ppm U
Seawater	0.003 ppm U

Material from these explosions eventually became incorporated into stars, like our Sun and planets, like Earth. Therefore nuclear power here on Earth harnesses energy that has been stored in uranium for over 4.5 billion years.

Interestingly, in 1972, French scientists testing nuclear fuel samples found that one was deficient in the uranium isotope U-235 which is the one which undergoes fission (U-238 is stable, 235 and 238 refer to the number of protons and neutrons in an atoms nucleus). So where had the missing uranium gone?

The uranium sample had come from an area in Central Africa, called Gabon, where there is a mine at Oklo producing uranium ore. About 2 billion years ago, several, maybe as many as 20, natural fission reactors started up in the area, and are believed to have run (operated) for about one billion years, moderated (or controlled) by water seeping down. Therefore with time the amount of uranium 235 decreased and the daughter products of the reaction were in place instead. It would not have happened today, as the amount of U-235 has decreased with time, due to the natural radioactive decay processes which occur all the time.

Having established that the uranium is contained in the rocks, which make up our planet Earth, how is it extracted and developed for use in the nuclear reactor? Unlike oil, gas and even coal, where it is possible to extract the fossil fuel and with minimum of processing deliver it to the end customer at very high recoveries, the extraction of uranium from the ore is a more difficult and indeed costly process.

For example, since the fifteenth century many miners who had worked underground in the mountains near the present border between East Germany and the Czech Republic contracted a mysterious illness, and many died prematurely. In the late 1800s the illness was diagnosed as lung cancer, but it was not until 1921 that radon gas was suggested as the possible cause.
Although this was confirmed by 1939, between 1946 and 1959 much underground uranium mining took place in the USA without the precautions which might have become established as a result of the European experience. In the early 1960s a higher than expected incidence of lung cancer began to show up among miners who smoked.

The cause was then recognised as the emission of alpha particles from radon and, more importantly, its solid daughter products of radioactive decay. The miners concerned had been exposed to high levels of radon 10-15 years earlier, accumulating radiation doses well in excess of present recommended levels. Today all uranium mining takes place in well-ventilated underground mining or above the surface to prevent the re-occurrence of the overexposure to radon.

After mining is complete most of the ore body, with virtually all of the radioactive radium, thorium and actinium materials will end up in what is known as the tailings dam. Hence radiation levels and radon emissions from tailings will be significant. In the unlikely event of someone setting up camp on top of the material, they could eventually receive a radiation dose exceeding international standards, just as they could from out cropping ore bodies. Therefore, the tailings need to be covered over with enough rock, clay and soil to reduce both gamma radiation levels and radon emanation rates to levels near those naturally occurring in the region. A vegetation cover can then be established. Measures will be in place to prevent the tailings becoming dust and being exposed to winds for distribution.

As the uranium (U-235) is only present at typically 0.72% of the ore body this means for every 720 grams of U-235 produced it requires a minimum of 1,000, 000 grams of rock to be dug out. Most of this as described above ends up in the tailings dump.

Therefore, starting in uranium mines such as Olympic Dam or Ranger in Australia or the northern Saskatchewan mines of Canada, the uranium containing ore is mined and milled to produce uranium in the form of uranium oxide concentrate. It is a mixture of two oxides, commonly known as U_3O_8. This material, a khaki-coloured powder, is shipped to customers. It has the same isotopic ratio as the ore, where uranium-235 (U-235) is present to the extent of about 0.7 percent. The rest is a heavier isotope of uranium - U-238 (with traces of U-234). Most reactors, including the common light water type (LWR) cannot run on natural uranium, so the proportion of U-235 must be increased to about 3.5 percent. This is called enrichment. Canadian reactors use un-enriched uranium.

Enrichment is a fairly high-technology physical process, which requires the uranium to be in the form of a gas. The simplest way to achieve this is to convert the uranium oxide to uranium hexafluoride, which is a gas at little more than room temperature.
This form of uranium is commonly referred to as UF6 or “hex”. Hence the first destination of uranium oxide concentrate from a mine is a conversion plant where it is purified and converted to uranium hexafluoride.

The UF6 is then fed to an enrichment process which increases the proportion of the fissile U-235 isotope. In the process about 85% of the natural uranium feed is rejected as “depleted uranium” or “tails” (mainly U-238) which is stockpiled.
Thus, after enrichment, about 15% of the original quantity is available as enriched uranium containing about 3.5 percent U-235. The enrichment takes place in either the US or the UK.

The enrichment methods now in use are based on the slight difference in atomic mass of U-235 and U-238. Much of the installed capacity relies on the gaseous diffusion process, where the UF6 gas is passed through a long series of membrane barriers which allow the lighter molecules with U-235 through faster than the U-238 ones. More modern plants use high-speed centrifuges to separate the molecules of the two isotopes.

Enriched uranium then goes on to a fuel fabrication plant where the reactor fuel elements are made. The UF6 is converted to uranium dioxide, a ceramic material, and formed into small cylindrical pellets about 2 cm long and 1.5cm in diameter. The pellets are loaded into zirconium alloy or stainless steel tubes about 4 metres long to form fuel rods. These are assembled into bundles about 30-cm square to form reactor fuel assemblies. Fuel assemblies of this type are used to power the US-developed light water power reactor, currently the most popular design.
A 1000 MWe reactor has about 75 tonnes of fuel in it.

8.2 The Use of Uranium for Generating Electricity

The use of uranium as a fuel source for generating nuclear power began in earnest in 1945, following the end to the Second World War and the dropping of the nuclear bombs over Japan.

The use of nuclear power has grown steadily from that time. In 1973, it accounted for 0.9% of the worlds total primary energy production, while in 2000, that had increased to 6.8%.[8.3] Furthermore, that represented 17% of the worlds total electricity supply as shown in Table 8.5.

Table 8-2

Regional Shares of Nuclear Production (IEA Key Energy Statistics)		
Geographical Region	**1973**	**2000**
OECD	92.8%	86.6%
Non-OECD Europe	0.0%	1.1%
Former USSR	5.9%	8.4%
Asia*	1.3%	2.2%
Other**	0.0%	1.6%
Total (TWh)	**203.0**	**2592.0**

* Excludes China

** Includes Africa, Latin America and China

The following tables give some key information regarding the main producers installed capacity and percentage of the world's electricity generation coming from nuclear power.

Table 8-3

Producers of Electricity		
Producers	**TWh**	**% of World total**
United States	800	30.9
France	415	16.0
Japan	322	12.4
Germany	170	6.6
Russia	131	5.1
Korea	109	4.2
United Kingdom	85	3.3
Ukraine	77	3.0
Canada	73	2.8
Spain	62	2.4
Rest of the World	348	13.4
World	**2592**	**100.00**

Table 8-4

Installed Capacity	
Installed Capacity	**GW**
United States	98
France	63
Japan	44
Germany	21
Russia	20
Canada	15
Korea	13
United Kingdom	12
Ukraine	11
Sweden	9
Rest of the World	51
World	**357**

Table 8-5

Nuclear Domestic Electricity Generation By Country	
Country (Based on first 10 Producers)	**% of Nuclear Total** in Total Domestic Electricity Generation
France	77
Ukraine	45
Korea	37
Germany	30
Japan	30
Spain	28
United Kingdom	23
United States	20
Russia	15
Canada	12
Rest of the World	9
World	**17**

As mentioned previously there was a perception that uranium was a scarce resource. In the early 1970's there was perhaps some justification for this as anticipated rates of exploitation of known reserves where such that concerns about possible future shortages have some validity.

It is now however quite clear that there are very adequate reserves to fuel nuclear power for the foreseeable future. Consumption for the next 20 years is likely to be in the range of 60-80,000 tonnes per annum, which implies over 40 years supply if all cost categories in all classes are concerned. However, given the relatively low impact of the cost of uranium on the overall economics of nuclear power, it can be considered that the total potential supply base as indicated below could be in excess of 100 years.[8.4]

With major qualifications outlined in note [8a] Table 8.3 gives some idea of our present understanding of uranium resources.

It can be seen that Australia has a substantial part (about 28%) of the world's low-cost uranium, and Canada 15 percent[8.5].

However, there has been very little uranium exploration in recent years on account of the extensive reserves having been discovered and an expectation that there will be an entry into the commercial market of material recycled from nuclear weapons. Military material is highly enriched in U-235 and therefore has to be blended with depleted or reacted uranium in order to bring the U-235 levels to that required for use in a civilian nuclear power station. For the nuclear fuel market this is a big issue as it is estimated that 600,000 tonnes of uranium, or roughly one-third of all uranium cumulatively produced since 1945, may at some point arrive on the market, representing 10 years total production. However, like with gold being released from the Reserve Banks, it is anticipated that the uranium will be released slowly and that the market will absorb it.

Table 8-6

Current Uranium Reserves		
Australia	863,000	28%
Kazakhstan	472,000	15%
Canada	437,000	14%
South Africa	298,000	10%
Namibia	235,000	8%
Brazil	197,000	6%
Russian Fed.	131,000	4%
USA	104,000	3%
Uzbekistan	103,000	3%
Rest of World	267,000	8%
World Total	**3,107,000**	**100%**

Therefore the supply of nuclear fuel can be categorised into 3 stages:

- A military era from 1945 to the mid 1960's where the generation of electricity was incidental to the arms race.
- A period of rapidly expanding civil nuclear power lasting form the late 1960's through to the mid 1980's. Uranium demand picked up as reactor orders were expanded. Production peaked in 1980 and stayed above annual reactor demands until 1985.
- An age dominated by inventory overhang, which resulted from a cutback in the building of new capacity and long-term supply contracts with mines. Also material arrived on to the market from the old Eastern bloc countries.

Currently, primary uranium production is rising, supplemented by secondary sources. At present [8.6] there were 441 operational[b] reactors in December 2002, with a further 34 reactors under construction[c] and 29 reactors planned[d]. The uranium requirement world wide for 2002 was 65,434 tonnes.

[b] Operating, connected to the electricity grid.

[c] Construction, the first concrete poured for the reactor.

[d] Planned, approvals and funding in place.

China, Canada, Japan Korea and the former USSR countries are the leading nations with reactors under construction, while Japan and Korea are those with most planned (accounting for 21 out of the 29 planned). The others are in Argentina, Romania, Russia and the Ukraine.

The position in the United Kingdom is as follows. In 1995, the government announced that it would privatise its more modern nuclear stations while retaining ownership of older stations. In 1996, more modern stations were privatised and British Energy became the holding company of Nuclear Electric and Scottish Nuclear, which merged in 1998 to form British Energy Generation, the nation's largest private nuclear generator and the world's first wholly privatised nuclear utility. British Energy operates eight nuclear power stations in the UK. Each station consists of two advanced gas-cooled reactors, except Sizewell B, which is a modern pressurised-water reactor.

Nuclear power stations were not privatised simultaneously with non-nuclear stations. No new plants have been built since 1995. Of the UK's 33 reactors, 26 are of the old Magnox design. Six of the Magnox reactors are being decommissioned, as well as the Dounreay prototype fast reactor.
The state-owned British Nuclear Fuels run the remaining Magnox plants. British Nuclear Fuels operates the Sellafield reprocessing plant, and is one of only two companies in the world that provides reprocessing and recycling technologies. The Department of Trade and Industry's Nuclear Directorate regulates the British nuclear industry.

With respect to the position of the United Kingdom, in part because it is the most politicised of all electricity generation technologies, future nuclear power capacity is in particular difficult to forecast [8.7].
The difficulty arises form a number of issues such as safety, nuclear proliferation, waste disposal and plant decommissioning. However, as reported in [8.7], the United Kingdom is one country where new nuclear construction is thought to be a possibility. However this is only in the high growth scenario which predicts by 2020 that three new 1000 megawatt units will have been built and operating by the end of the forecast period. This is in contrast to all previous scenarios, which forecast zero building of new nuclear reactors.

One of the difficulties in forecasting the future role of nuclear power is that different parties often have opposing views on the subject. For example while the Conservative government was in power in the United Kingdom nuclear power was thought to be a viable future contributor to new electricity generation. When Labour assumed office it was assumed that Labours previous opposition to nuclear power would become the stated government policy, however, the option has been left open that nuclear power would continue to play a role in the nations electricity supply. Britain's support of the Kyoto Protocol (See Chapter 14) forced a re-evaluation of the nuclear option, as compliance would be very difficult without it.

In 2002 a UK government review of energy was released which called for a national debate on nuclear power and for an examination of 'low waste, modular designs' of nuclear reactors. There have been several calls from within the industry for the government to do more to promote the use of nuclear power for electricity generation. However, two reports completed by the government in 2001 pointed out that nuclear power was much more expensive than wind or biomass and that increased energy efficiency and combined heat and power were preferable options. Concerns over nuclear proliferation and terrorism post September 11th, 2001 may also have contributed to the decision making.

Since the reform of the UK electric power market, which commenced in 1989, our electricity market has developed into one of the most competitive in the world, which does not figure well for the future of the nuclear industry. For example in 1995 a UK government white paper concluded that in a competitive private market no-one could invest in new nuclear capacity and indicated that government subsidies were not appropriate for construction of new plants [8.8].

8.3 Generating Electricity Using Nuclear Power

In Section 8.1 the natural occurrence of uranium was discussed, and uranium, with exceptions like Oklo, releases its energy very slowly and does not generate much heat. However, the use of nuclear fission speeds up the release of energy.

In nuclear fission, the nuclei of a heavy element splits by being struck by a neutron and releases its energy. Some of the energy is released in the increased speed of the particles (their kinetic energy) and in gamma (very high-energy) radiation. In a nuclear reactor the reaction is controlled so that, on average, one neutron from each fission event leads to the release of another. Therefore the neutron flux within the reactor remains constant and the energy is released at more or less a steady rate. If you allow more than one neutron from each event to cause further fission then the neutron flux increases and the power output goes up [8.9].

This is not a desirable situation as it can lead to the nuclear chain reaction getting out of control. This is prevented by the use of 'control' rods, which are interspersed with the uranium rods. These regulate the rate of fission by soaking up the neutrons and can be raised or lowered to keep the release of energy steady. They are made from a neutron absorbing material such as boron or cadmium and when they are lowered into position soak up the neutrons.

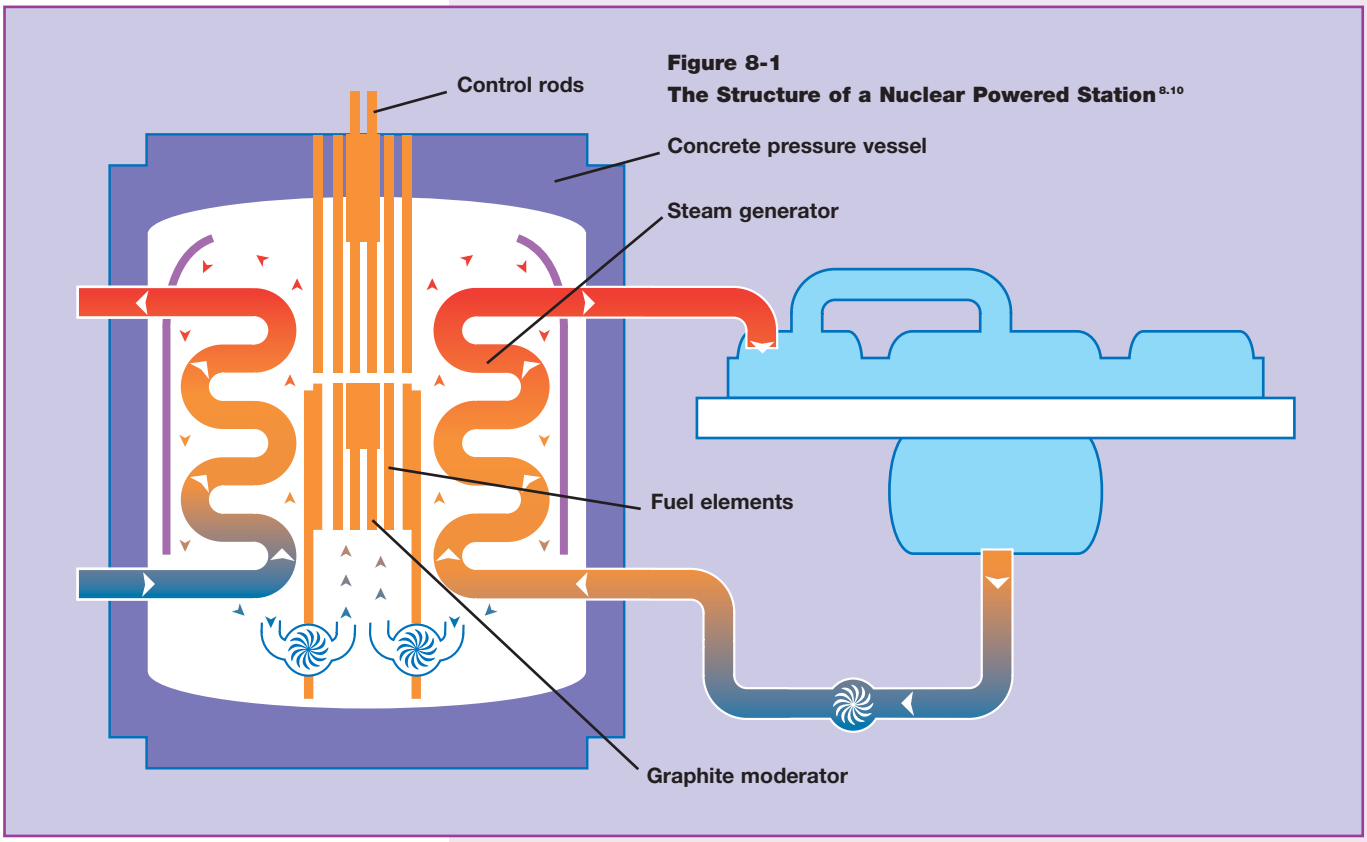


Figure 8-1
The Structure of a Nuclear Powered Station[8.10]

Raising them up speeds up the production of neutrons and hence the amount of energy produced. Reactors have what is known as a fail safe design in that the control rods automatically drop down into the reactor core in an emergency, shutting the reactor down as soon as possible.

The other material in the reactor is known as the moderating material, which slows the fast moving neutrons, which are released during fission, and enables them to react more efficiently with the uranium, making fission more probable. Moderating materials include water (including what is known as heavy water) or graphite blocks.

Surrounding and circulating through the core is a coolant, which carries away the heat. In the UK gas cooled reactors such as Magnox, and the advanced gas cooled reactors (AGR's) use carbon dioxide (CO_2) as a coolant. Pressurised water reactors, such as that at Sizewell B, use water. Sometimes the water is used as both a coolant and moderator. After it is heated in the core of the reactor the coolant is pumped through a heat exchanger where is transfers its energy to water, creating high-pressure steam. The steam is used to turn turbines, which drive a generator.

This part of a nuclear power station is like any other part of the conventional thermal electricity-generating stations. However, as most nuclear power stations have their core at temperatures around 300°C, and are cooled by water at around 20°C, the temperature difference between the two is smaller than the other thermal generating methods. Therefore the efficiency, or that percentage of energy, which can be diverted into a useful form such as electricity, is smaller.

Finally, as nuclear reactors can take days to start up and switch off they are used as base load applications and are kept running at steady state of months on end (see chapter 7 on the different generating methods used during a twenty four hour period).

As has been discussed, the amount of carbon dioxide emitted by the nuclear power generating stations is zero, along with most of the other potentially damaging gases. However, during fission, as has been mentioned, gamma radiation is emitted and the fission products are highly radioactive. As it is used up the uranium-235 becomes increasingly dilute, and eventually cannot sustain the chain reaction.

Therefore the nuclear fuel is termed as 'spent' and has to be removed from the core of the reactor. However, the spent flue rods are now surrounded by a number of highly radioactive elements whose disposal needs to be handled very carefully. Also other materials which have come into contact with the uranium need to be treated as well.

This radioactive waste is produced in solid, liquid and gaseous forms by a diverse range of activities within the generation of electricity. It arises from the routine operation of nuclear reactors; the reprocessing of spent nuclear fuel and the decommissioning of reactors. Significant quantities are also produced in defence and research establishments, by some engineering industries and in medical diagnosis and treatment. Some 7,000 sites in Great Britain produce radioactive waste in the course of providing products and services[8.11].

In the UK, radioactive wastes are classified into three main categories: high, intermediate and low level waste (HLW, ILW, LLW respectively), according to their levels of radioactivity and heat-generating capacity. LLW is defined as waste material that has a radioactive content above 400 becquerels[8.12] per kilogram (Bq/kg), but not exceeding

4 million Bq/kg of alpha activity or 12 million Bq/kg of beta/gamma activity.
The radioactive content of ILW is above the threshold for LLW, but not sufficiently great to result in significant heat output from the waste. HLW is highly radioactive and consequently generates significant heat such that this has to be taken into account in managing the waste.

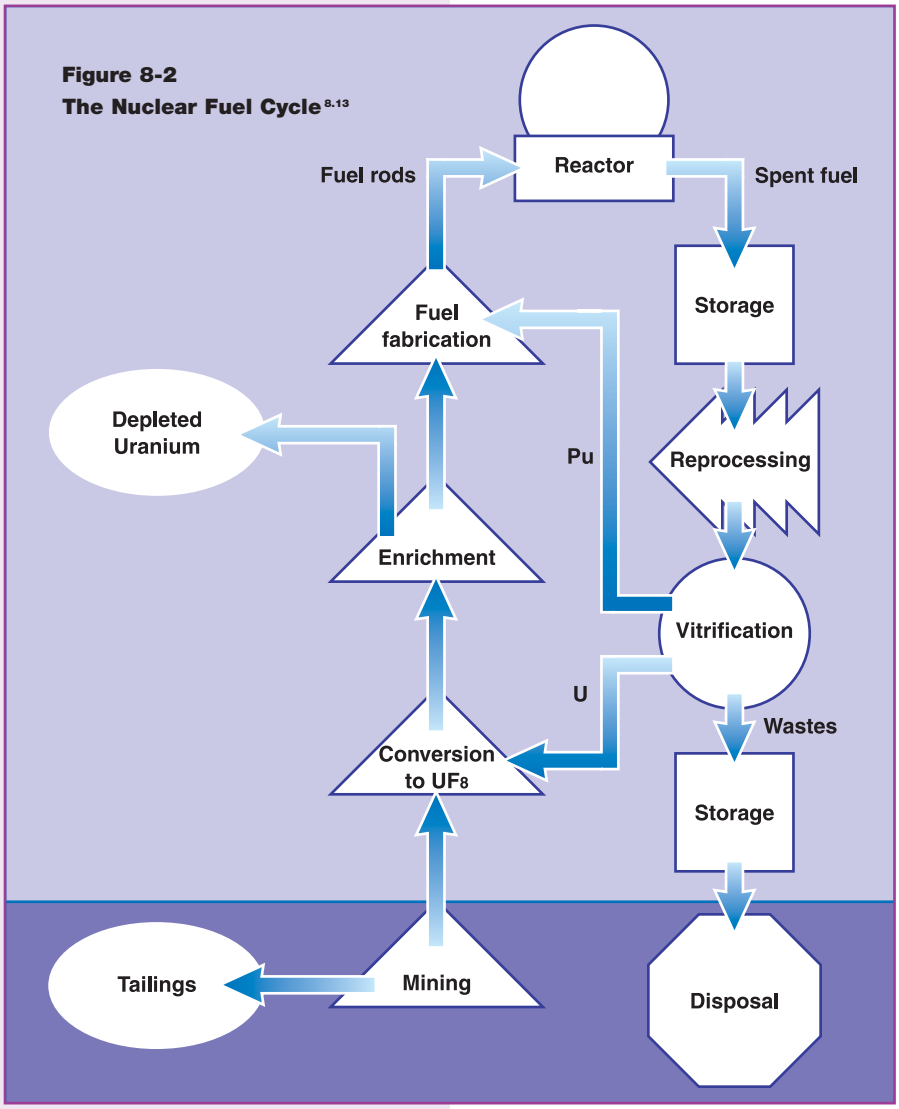
LLW accounts for about 70% of the volume of radioactive waste produced in the UK, but only a small fraction of the total radioactivity. LLW has a wide range of origins. It consists of materials such as protective clothing, packaging, scrap metal, worn out or damaged equipment, and concrete, rubble and soil from building demolition. Although the use of nuclear fuel for electricity generation has increased the level of LLW is reported to have decreased.

In the UK some industrial low level waste is incinerated, but most solid LLW, including the incinerator ash, is disposed of at the Drigg repository in Cumbria, which is owned and operated by BNFL. Since 1988 Government policy has required that, where appropriate, LLW undergoes supercompaction to minimise volumes. It is then grouted into standard steel containers, which are stacked into purpose built, open air concrete structures at Drigg known as 'vaults'. As each of these is filled dome-shaped water resistant cap is placed over it to stop rainwater entering. This minimises the build up of leachates, which could contaminate groundwater. After capping the vault is covered with topsoil and landscaped. It is predicted that Drigg has sufficient capacity for LLW until the middle of the 21st century.

The discharge of low level radioactive liquid and gaseous wastes to the environment is regulated by strict authorisation conditions designed to limit public exposure to safe levels. Liquid LLW is filtered and, where necessary, passed through an ion exchange process before dilution and eventual discharge to sea. Gaseous wastes, which have a low radioactive content, are filtered to remove radioactive particles before discharge to the atmosphere.

ILW accounts for around 30% of all radioactive waste arising by volume. For radiological protection purposes it usually requires some shielding and containment. ILW mainly consists of solids and liquids from nuclear fuel fabrication and reprocessing facilities and nuclear power stations. Before ILW is transported or disposed of, it usually undergoes a process of solidification which is known as 'conditioning' or 'encapsulation'.

Figure 8-2
The Nuclear Fuel Cycle[8.13]



Conditioned ILW is held in shielded stores on licensed sites at nuclear power stations or at the BNFL Sellafield site. This interim storage is in anticipation of the eventual construction of a deep underground repository in the UK for the disposal of ILW and some LLW. Such a repository would be based on the multi-barrier concept where waste is contained in stainless steel drums or concrete containers and a cement grout or back fill packed around the containers. This level of shielding and containment is designed to isolate the radioactivity from the environment for several thousand years, by which time most of the radioactivity would have decayed.

HLW contains around 95% of the radioactivity in wastes from the nuclear cycle, but it accounts for less than 1% of all UK radioactive waste by volume. It arises from the reprocessing of spent nuclear fuel. About 96% of the spent fuel is uranium and a further 1% is plutonium, and both these components are separated out for recycling as new fuel. The remaining 3%, consisting of fission products and some other heavy metals such as americium and neptunium from the nuclear reactions, become high level liquid waste. At all stages of the transportation and handling of HLW, special precautions are employed to minimise the risk of escape of radioactivity. HLW is heavily shielded within secure containers, which meet international standards of design and construction. The management of HLW is primarily the responsibility of BNFL.



9 The use of Air and Water in Electricity Generation

The other two main 'raw materials' used in electricity generation are air (with the exception of the nuclear industry) and water, both of which are passed through in huge volumes, and returned to the environment, in an altered condition. The issue of both gaseous and aqueous emissions will be dealt with in the following Chapter.

9.1 The Use of Air in the Combustion Process

Combustion is a chemical process in which a substance reacts rapidly with oxygen and gives off heat. The reacting substance is called the fuel and the source of oxygen the oxidiser. The fuel, as we have seen, can be a solid for example coal, liquid, for example oil, or a gas. The oxidiser likewise can be a solid, liquid or gas.

During the combustion new chemical substances are created from the fuel and the oxidiser. These substances are called the exhaust. Most of the exhaust comes from the chemical combinations of the fuel and oxygen. When a hydrocarbon-based fuel, like coal, oil or natural gas burns the exhaust includes water and carbon dioxide.
But the exhaust can also contain chemical combinations of other elements present during combustion. If, for example, as in the power generation process, the fuel is burnt in air, air contains approximately 21% oxygen and 78% nitrogen. Therefore the exhaust can contain nitrous oxides (NO_x). If the fuel contains sulphur, like in coal and oil, then the sulphur will be converted to sulphur dioxide.

If there is insufficient oxygen present to completely combust the fuel, carbon, hydrogen and carbon monoxide may be present in the exhaust, along with possibly some liquid components and even some solids, for example, carbon in the form of soot.

During the combustion process as the fuel and oxidiser are turned into exhaust products, heat is generated. Heat is also required to start the combustion process. As heat is required to start the combustion process, and the combustion process itself produces heat, once the process is started, the heat from the combustion will keep things going.

Therefore for combustion to occur you require three things, a fuel to be burned, a source of oxygen, in this case air, and a source of heat. As a result of combustion, exhausts are created and heat is released. Adjusting the amount of fuel or oxygen available or the source of heat controls the combustion process.

In order to maximise the efficiency of the combustion process, and to minimise the amount of reduced gases formed (for example, carbon monoxide) the amount of oxygen (air) required for the theoretical complete combustion, is known as the stoichiometric amount. Typically more air is supplied than the stoichiometric amount, the exact amount being dependent on the local conditions, for example, amount of ash present. In the mass balance, the stoichiometric amount is used, based on the carbon content of the fuel.

In the UK the average amount of air used for the oxygen content is 8084 litres/kWh, with approximately 1x1015 litres of air, 0.21x1015 litres of oxygen, being used in 2000.

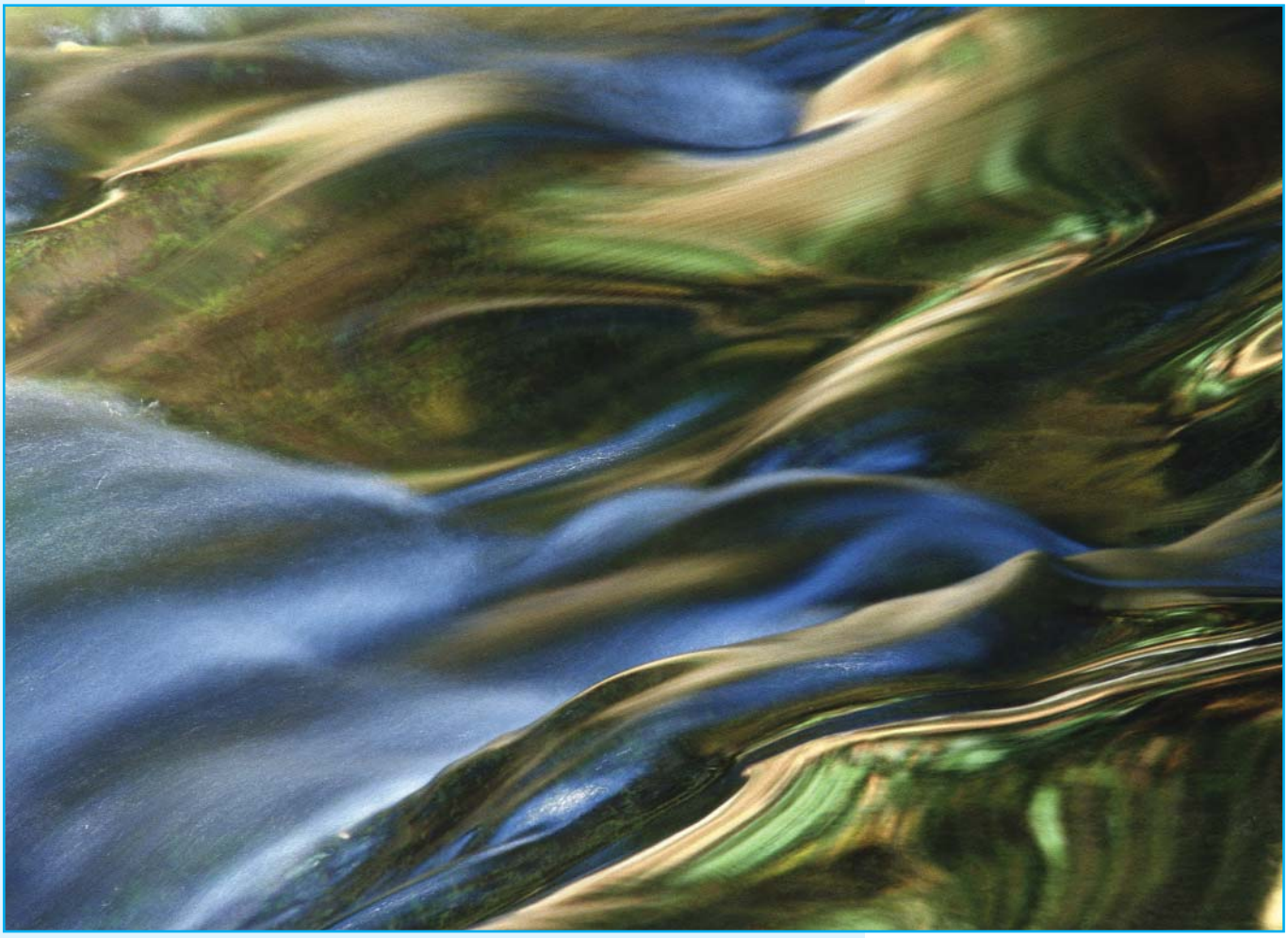
9.2 The Use of Water in Combustion Processes

Water is also used in the combustion process. Thermal electric power generation uses the heat released from fossil fuels (coal, oil or natural gas) or uranium (oxide) to produce steam from water to drive a turbine coupled to a generator. The power plants are all types of heat engines in that energy flows from a high-temperature source, such as a reactor core in a nuclear power station, to a cooler 'sink' usually a reservoir of cooling water. The greater the temperature difference between the two, the greater the percentage of energy that can be diverted into a useful form such as electricity. This is also known as the operating efficiency. Coal fired power stations have their heat source around 550°C, while nuclear power stations have their reactor core around 300°C. Therefore the efficiency of the coal-powered stations is higher than the nuclear powered stations where about one-third of the energy released by the fission process ends up as electricity.

The rest is wasted as heat. Thermal electric plants also require a supply of water to cool and condense the exhaust steam from the turbine.

In the UK around 10,000 million m^3 of water is passed through the power generating stations each year, after being abstracted from both fresh and tidal waters. 99.13% is returned to the original source with some minor modifications, generally being slightly warmer and having some chemicals from such activities as preventing fouling in the heat exchangers. These modifications will be covered in the following chapter. Therefore on average all but 0.87% returns to the extraction source; the 0.87% is generally released as steam. The appearance of steam around power stations can be deceptive with respect to the amount being released. 46.50% of the water used in the power generation applications is from freshwater, while the balance, 53.50%, is from seawater sources.







10

This Chapter examines the issue of solid, liquid and gaseous emissions arising from the generation of electricity.

Emissions

10.1 Solid Emissions

In terms of solid emissions the key issues for the electricity generation industry are the responsible management of the residual ash for the coal burning and the radioactive waste from nuclear generation.

At present around 200 million tonnes of household and business waste are generated in the UK each year, of which around 60% goes to landfill. Sustainable waste management seeks to minimise the waste generation and maximise re-use, recycling and energy recovery. Some special wastes, and this would include radioactive waste, have special handling and disposal requirements.

The 1996 landfill tax was introduced to encourage recycling and other non-disposal options. At 1999 inert waste was taxed at £2 per tonne and 'active' waste, that is waste with pollution potential at £10 per tonne rising to £14 by 2004. A tax credit scheme encouraged operators to redirect some of the tax revenue into environmental programmes and projects.

10.1.1 Ash from Coal-based Generation

Pulverised fuel ash (PFA) and furnace bottom ash (FBA) are inevitable by-products of coal-fired generation due to the incombustible, inorganic material present in coal. The release of trace elements to the environment as a result of the coal-fired generation is an area of increasing concern. Knowledge of how the trace elements are distributed amongst the flue gas, fly ash and bottom ash would be vital for developing future control practices.

Most of the trace elements of interest are associated with the coal mineral matter, but some are also associated with the coal organic matter. There are four main groups of mineral phases:

1 Oxides, carbonates and monosulphide (MS)

2 Pyrite

3 Silicates

4 Organic matter

For example, arsenic is associated mainly with oxides and organic matter, while selenium is associated with the pyritic material. Mercury, arsenic, selenium, nickel, lead, copper and zinc all tend to be associated with the sulphide minerals and organic matter in coal. Elements associated with either the pyrite or the organic matter in the coal tend to volatilise and exit with the flue gas, often as a condensate on the surface of the fine ash particles. This is very important from the viewpoint of both controls of the trace elements and subsequent issues in landfill, for example leaching of metals into the soils.

However, ash produced from the same source of coal and with a very similar chemical composition can have significantly different ash mineralogies depending on the coal combustion technology used. Therefore the leaching behaviour, that is the behaviour in contact with water, can vary significantly.

The amount of crystalline material versus the glassy phase material depends largely on the combustion and glassification process used at a particular power plant. When the maximum temperature of combustion is above approximately 1200°C and the cooling time is short, the ash produced is mostly glassy phase material. Where boiler design or operation allows a more gradual cooling of the ash particles, then crystalline phase calcium compounds are formed.

The factors which affect the hydration, and leaching properties of fly ash are:

- Relative proportion of the spherical gassy phase and crystalline materials,
- The size distribution of the ash,
- The chemical nature of the glass phase,
- The type of crystalline material and the nature and
- The percentage of unburned carbon

The primary factors, which influence the mineralogy of the coal fly ash, are:

- Chemical composition of the coal
- The coal combustion process including coal pulverisation, combustion, flue gas clean up and fly ash collection operations
- The additives used, including oil additives for flame stabilisation and corrosion control additives.

To summarise, the minerals present in the coal dictate the elemental composition of the ash produced, but it is the boiler design and operation which dictate the mineralogy and crystallinity of the ash itself. Furthermore, the ultimate leaching characteristics of the ash will also be dictated by the soil in which it is in contact with. Some of the metals leached from the ash will find their way into the water network, which others will be absorbed on the clay minerals of the soil.

PFA and FBA are both classified as inert and can be recycled as secondary raw materials for building and construction work. This in turn reduces the need for quarrying of building materials with its associated environmental impacts. Some ash is also used to reclaim derelict land. Unused ash is disposed of as inert waste to landfill sites.

The following table shows the estimated amount of fly ash produced within the United Kingdom between 1995 and 1999. Due to the change in the generating mix away from coal and towards the use of gas, the amount of flyash fell by 34% over the four-year period. During the same period the percentage recycled rose from 47% to 54%, but as the overall amount produced declined, this would suggest that the demand for flyash has also fallen.

10.1.2 Radioactive Waste

Radioactive waste is registered under the Radioactive Substances Act1993, and by conditions imposed in nuclear site license under the Nuclear Installations Act 1965. It is classified as low, intermediate or high level depending on its concentration of radioactivity, and can be solid, liquid or gaseous. The bulk of the solid waste is low level, items such as protective clothing, paper towels, packaging materials and worn-out equipment. Where possible the amount is reduced by compaction or incineration before it is sent to the UK's designated repository at Drigg in Cumbria. While the amount of low level waste created by the generating process is falling in line with improved practise, the overall amount being stored each year has started to increase due to increased amounts of decommissioning waste being generated.

Intermediate waste includes irradiated equipment removed from reactors during maintenance and chemical sludges for treatment of radioactive effluent. As the amount produced is relatively small, it is currently stored on station sites in specially shielded stores pending final disposal in a purpose built repository.

High level waste arises from the reprocessing of spent fuel at BNFL Sellafield where it is stored under authorisation from the regulatory bodies, but the nuclear generators remain responsible for the waste pending final disposal.

10.1.3 Other Solid Wastes

A by-product of the flue gas desulphurisation plant is gypsum (calcium sulphate). In 1999 over 500,000 tonnes of gypsum were produced and almost all of this was sold for plasterboard manufacture.

It is furthermore estimated at 98% of metal waste / scrap was recycled.

Table 10-1

Ash from Fossil Fuel Generation				
FBA	**1995/96**	**1996/97**	**1997/98**	**1998/1999**
Produced	2.2	1.7	1.4	0.8
Sold for Use	2.1	1.6	1.4	0.8
Landfilled	0.1	0.1	<0.1	<0.1
PFA				
Produced	6.2	5.8	5.7	4.7
Sold for Use	1.8	2.2	2.2	2.2
Landfilled	4.4	3.6	3.5	2.5

And finally, due to the Codes of Practise for implementing the New Roads and Street Works Acts 1991, which effectively prevents spoil from roadwork's being used to backfill a hole or trench, electricity companies have to dispose of an estimated 500,000 tonnes of road spoil per year to landfill. This is the classified as inert waste.

The Table 10-2 gives the amount of solid waste generated by each of the four main electricity generation methods, by kWh/kg and in tonnes per annum.

10.2 Liquid Emissions

10.2.1 Water Abstracted for Cooling

As stated in Chapter 9, thermal electric generating facilities make electricity by converting water into high-pressure steam that drives turbines. Once water has gone through this cycle, it is cooled and condensed back to water and then reheated to drive the turbines again. The process of condensation requires a separate cooling water body to absorb the heat of the steam. These condenser systems typically consist of banks of thousands of one-inch diameter tubes, through which cooling water is run, and over which the hot steam and water is circulated.

Two cooling technologies are in use today:

- **Closed-cycle** systems discharge heat through evaporation in cooling towers and recycle water within the power plant. The water required to do this is comparatively small since it is limited to the amount lost through the evaporative process. Because of the expense associated with closed-cycle cooling, once-through systems are far more common.
- **Once-through** systems require the intake of a continual flow of cooling water. The water demand for the once-through system is 30 to 50 times that of a closed cycle system.

The amount of water used for power plant cooling also varies by each specific power plant's electricity generating technology and size. For example, nuclear reactors require the most water for cooling, and base load fossil fuel power plants come in second. Most renewable energy technologies require little or no water for cooling.

Table 10-2

Solid Waste Produced by the Different Electricity Generation Methods [10.1]						
Units	**Solid Waste Type**	**Coal-based Generation**	**Oil-based Generation**	**Gas-based Generation**	**Uranium-based Generation**	**Total**
kg/kWhe	Other waste	0.04154	0.00056	0.00047	0.00090	0.04346
kg/kWhe	Radio active waste	0.00015	0.00169	0.00001	0.00001	0.00185
kg/kWhe	Waste to incinerator	0.00002	0.00265	0.00000	0.00000	0.00268
kg/kWhe	Other waste	0.00019	0.00368	0.00000	0.00001	0.00389
kg/kWhe	Ash	0.01662	0.00000	0.00000	0.00000	0.01662
Tonnes	Inert waste	56,027,899	271,473	789,369	434,842	57,523,583
Tonnes	Other waste	4,861,723	1,346	60,320	76,250	4,999,639
Tonnes	Radio active waste	17,590	4,072	1,072	551	23,286
Tonnes	Waste to incinerator	2,590	6,409	148	407	9,554
Tonnes	Other waste	22,721	8,888	378	992	32,979
Tonnes	Ash	5,694,804	0	0	0	5,694,804

As stated most electric power stations require water to operate. Since greater than 98% of the water used in power plants is returned to its source, distinctions are made between water use and water consumption.

Water use is a measure of the amount of water that is withdrawn from an adjacent water body (lakes, streams, rivers, estuaries, etc.), passes through various components of a power plant, and is then ultimately discharged back into the original water body. Environmental concerns surrounding water use centre around any chemical or physical alteration of the water body and any impacts these changes may have on the plants, fish and animals who reside in the ecosystem.

Water consumption refers to water sucked up in power plant operations that is lost, typically through evaporation. The primary concerns surrounding water consumption is how best to utilise this essential resource, especially in areas where water is in short supply.

The thermoelectric power generation category includes water-use activities, such as: withdrawals from ground and surface water; deliveries from water suppliers; consumptive use from **cooling towers**, **cooling ponds**, and **steam venting**; water and wastewater treatment; and return flow (figure 11). The water in the steam cycle usually is treated at the power plant before use to reduce impurities that would cause build-up of mineral residue inside the boiler.

The cooling water, which comes from lakes, rivers, or oceans, always is separate from the boiling water/steam (non-contact cooling water) and can be:

(1) Discharged directly to the ocean, lake, or major river (once-through cooling),

(2) Discharged to a canal, cooling pond, or cooling tower before returning to the river, or

(3) Sent to a cooling pond or cooling tower before being recycled.

Although most of the water used in thermoelectric plants is cooling water for condensing the steam, water is required for

(1) **makeup water** to replace the water lost as steam,

(2) **blow down** (purging) of boilers, washing of stacks, plant and employee sanitation, water and wastewater treatment,

(3) And in nuclear plants, to keep the nuclear fuel from overheating and melting.

Water from non-cooling uses goes to either a public wastewater treatment facility or the plant's onsite wastewater treatment facility.

Storm water from roof drains and area storm sewers also may be treated at the wastewater facility and may cause discharge values to be higher than expected.

The volume of water that is required in the thermoelectric power generation and the rate of consumptive use are dependent on whether cooling towers are used. Some plants built on an ocean or large river simply pump in large amounts of water to cool the steam. This cooling water then is returned back to the ocean or river. The water is somewhat warmer than when it entered the plant. If the cooling water is discharged to a significant water body, such as an ocean, lake, or major river, the water can be discharged directly. However, if the water is discharged to a river, its return to the river may be delayed by routing it through a canal or cooling pond first. Some plants recycle cooling water. Cooling ponds and towers are used to transfer the heat in the cooling water to the air.

A cooling pond is a shallow reservoir having a large surface area for removing heat from water. The surface area exposed to the air may be increased through the use of spray



nozzles. Cooling ponds are used where land is relatively inexpensive, cooling water is scarce or expensive, or where there are strict thermal loading restrictions in place. If cooling ponds are used, water in the pond can be reused, thus reducing the overall water-withdrawal requirement.

A cooling tower is designed to remove heat by pumping water up into the tower and allowing it to fall down inside the tower. Air comes in from the sides of the tower and passes by the falling water. As the air passes the water, it exchanges some of the heat and evaporates some of the water. This heat and evaporated water flow out the top of the tower is in the form of a fine cloud-like mist. The cooled water is collected at the bottom of the tower and pumped back into the plant for reuse. Cooling towers are used where land and (or) water are expensive, or regulations prohibit the return of once-through cooling waters.

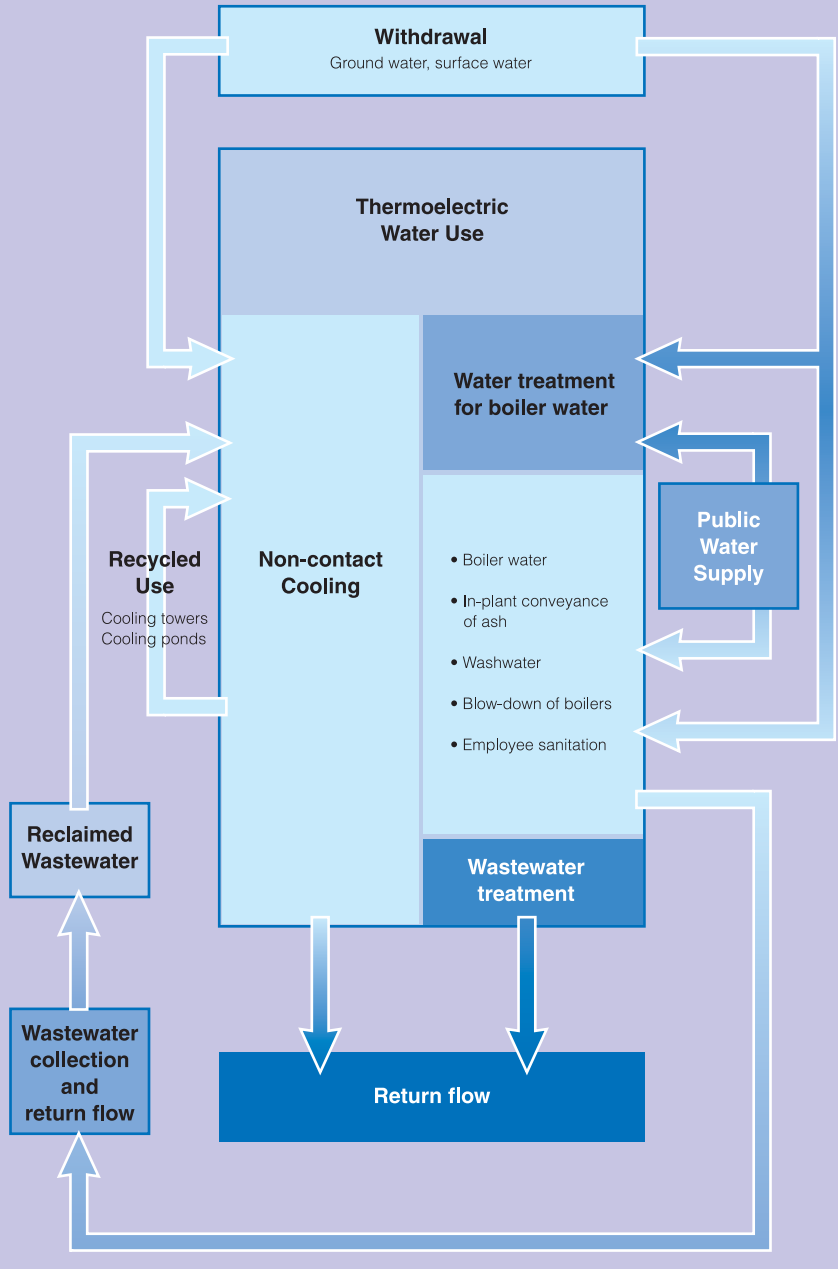
There are two primary types of thermoelectric plants-fossil fuel plants and nuclear plants. Although there are many similarities between them, there are some important differences that affect how each plant uses water. In fossil fuel plants, coal, natural gas, or oil are burned to provide the heat necessary to turn the water into steam. Biomass or solid waste fuel types are included with fossil fuels. Water is required to take care of the ash waste created during combustion. This includes both maintaining the stacks and carrying the waste ash away from the plant. In nuclear plants, water is not required for ash disposal but is needed to keep the nuclear material from overheating and melting.

The thermoelectric power generation water-use data are the rate of (1) withdrawal by source; (2) deliveries from public water supply, (3) evaporation, (4) return flow, and (5) recycled water. The power-generation values also are collected for quality assurance.

To recap, in the UK around 11503705 million litres of water is passed through the power generating stations each year, after being abstracted from both fresh and tidal waters. 99.13% is returned to the original source with some minor modifications, generally being slightly warmer and having some chemicals from such activities as preventing fouling in the heat exchangers. Therefore on average all but 0.87% returns to the extraction source; the 0.87% is generally released as steam. The appearance of steam around power stations can be deceptive with respect to the amount being released. 46.50% of the water used in the power generation applications is from freshwater, while the balance, 53.50%, is from seawater sources.

In 2000[10.2] the public water supply and electricity supply industry accounted for 77% of all inland water abstracted, and was just about evenly split between the two sectors. However, the electricity supply industry accounted for 94% of all abstractions from tidal waters, and when both tidal and non-tidal are accounted for, the UK electricity industry was responsible for 53%, with the public water supply the second largest abstractor at 28%.

Figure 10-1
Water Use and consumption in a Typical Thermoelectric Power Generating Plant



10.2.2 The Role of the Condenser (in Energy Efficiency)

The thermodynamic cycle of conventional thermal power plants obeys Carnot's principle.

Efficiency levels reach about 40% for conventional new design but can achieve 47% in advanced design and under very favourable climatic conditions in particular when cooling water conditions are suitable (once-through cooling system), even with hard coal firing. The result is that nearly 45% of the amount of energy provided by combustion must be dissipated at the condenser level. The condenser is the key point of the facility. Regardless of the mode of cooling adopted, it is in fact one of the main interfaces between the power plant and the surrounding environment.

The efficiency and availability of a power plant depends to a great extent on the integrity and cleanness of the condenser. These are reasons why specific solutions have been adopted for a long time now: continuous mechanical cleaning by foam balls, corrosion-resistant alloys, such as titanium and stainless steel, etc. Also cooling water treatment systems have been developed and are in operation, in particular for circulating cooling systems.

The operation of power plants is governed by Carnot's principle. The heat source, the boiler, provides the energy required for water vapourisation. The cold source, the condenser, condenses the steam coming out of the low-pressure turbine. One of the main characteristics of a power plant, from the technical and economic standpoints, is its **specific consumption**; in other words, the amount of heat needed to produce one kWh of electrical energy. This specific consumption results from the thermal cycle balance as shown in Table 10-3.

A look at the thermal cycle balance shows that a significant percentage of the heat generated is 'lost' in the condenser. In addition, this energy cannot be recovered because its energy is low. New generation systems, especially combined cycles (or gas-steam turbines), make it possible to obtain higher efficiencies, sometimes even more than 55%. The heating and flow rate of the water in the condenser depend on the installed capacity; typically a 250MW station requires 6 to 10 cubic metres per second with an accompanying temperature rise in the condenser of between 7 to 12°C.

Table 10-3

Simplified Balance of a Thermal Cycle			
Energy transformation	**Energy (kj)**	**%**	**Efficiency (%)**
Energy from combustion	9000	100	100
Steam generator loss	1050	-11.7	88.3
Condenser 'loss'	4200	-46.5	41.8
Feed water heating	-2000	-22.2	(Looping)
Turbogenerator losses	65	-0.75	41.05
Power supply of auxiliaries	65	-0.75	40.3
Loss in main transformer	25	-0.2	40.1
Overall efficiency of the facility	-	-	40.1

10.2.3 The potential environmental impacts of cooling systems.

The heat releases at the cold source mainly concern 2 receiving environments, namely air and water. It can be argued that via various natural processes for example, evaporation, conduction or radiation, the ultimate heat sink is the atmosphere. The trend in the UK over the past 5 years has been a decrease in the net amount of water lost through evaporation, as the trend towards the use of gas rather than coal to generate electricity continued. Some of the new gas-fired stations use air-cooled condensers, rather than water-cooling.

The main atmospheric modification is the formation of evaporation fog, in the form of artificial clouds, in the area close to the release. It should be noted that the temperature of formation or disappearance of evaporation fog is higher above salt water than soft water. This can result in a reduction of sunshine and light in the vicinity of the power plant itself.

The following procedures all can occur during routine operations and maintenance of power plants and impact on the water quality returning to the abstract sources.

Boiler blow down: This waste stream results from periodic purging of the impurities that become concentrated in steam boiler systems. These pollutants include metals such as copper, iron and nickel, as well as chemicals added to prevent scaling and corrosion of steam generator components.

Coal pile run-off: This waste stream is created when water comes in contact with coal storage piles maintained on the power plant site. While most piles are kept covered, active piles used to meet the power plants immediate needs are often open to the elements. Metals and other naturally occurring contaminants contained in coal leach out with the rainfall and are deposited in nearby water bodies.

Cooling process wastes: Water used for power plant cooling is chemically altered for purposes of extending the useful life of equipment and to ensure efficient operation. Demineralised regenerants and rinses are chemicals employed to purify waters used as makeup water for the plant's cooling system. Cooling tower blow down contains chemicals added to prevent biological growth in the towers and to prevent corrosion in condensers.

Boiler cleaning wastes: These wastes derive from the chemical additives intended to remove scale and other by-products of combustion.

Thermal pollution: Thermal plants create or use steam in the process of creating electricity requires water for cooling. This water typically comes from adjacent water bodies or groundwater sources and is discharged back into the water body at significantly higher temperatures, on average around 7°C higher. By altering the temperature in the "mixing zone," the discharge of thermal wastewater can have both negative and positive effects on aquatic life.

On the plus side, the warmer temperature water may create more favourable feeding and breeding conditions for certain species located near the power plant's water source. However, when the power plant is suddenly shut down for routine maintenance or unplanned outage, the resulting wide swing to colder temperatures can be lethal to sensitive fish populations. Indeed the higher temperatures can also have a negative effect by encouraging higher than normal growth rates at unseasonable times of year.

10.3 Gaseous Emissions

Electricity is essential for economic and social development and simultaneously provides the most efficient means of utilising many sustainable forms of energy. It is therefore the key to "sustainable development" which aims to maintain economic growth and social progress whilst protecting the environment and conserving natural resources. The provision of electricity in poorer nations was a key issue at the UN World Summit on Sustainable Development, which was held in Johannesburg in 2002.

Indeed the main focus of the 'NEPAD' which is the New Partnership for African Development places the electrification of Africa at the heart of its agenda.

However, on the other hand, the combustion of fossil fuels gives rise to emissions of a number of gases, but primarily carbon dioxide, CO_2, which, due to their increasing concentration in the atmosphere, have been implicated in the enhanced warming of the atmosphere and in the global climate change. The electricity supply industry is the major consumer of fossil fuels (followed by the transport industries) and as a result is the major producer of the greenhouse gas emissions.

Increasing atmospheric concentrations of greenhouse gases originating from mans activities are leading to an enhanced warming of the atmosphere and ultimately to climate change. The major greenhouse gases are carbon dioxide, methane and nitrous oxide all of which have both natural and anthropogenic (that is man-made) sources.

Table 10-4

Liquid Waste Produced by the Different Electricity Generation Methods [10.3]

Units	Liquid Waste Type	Coal-based Generation	Oil-based Generation	Gas-based Generation	Uranium-based Generation	Total
kg/kWhe	Chloride	0.01475	0.01125	0.00023	0.00027	0.02650
kg/kWhe	Sulphate	0.01023	0.00056	0.00015	0.00201	0.01294
kg/kWhe	Phosphate	0.00009	0.00022	0.00006	0.00017	0.00054
kg/kWhe	Ammonia	0.00000	0.00002	0.00000	0.00001	0.00003
kg/kWhe	Oils-freshwater	0.00000	0.00000	0.00000	0.00000	0.00000
kg/kWhe	Oils-seawater	0.00002	0.00037	0.00000	0.00000	0.00039
kg/kWhe	Zinc	0.00002	0.00000	0.00000	0.00000	0.00002
kBq/kWhe	Ra	0.02011	0.01379	0.00047	0.60120	0.63557
kBq/kWhe	H3	0.00000	0.00000	0.00000	0.00005	0.00005
kBq/kWhe	Radionucleides	0.00267	0.00000	0.00000	0.04284	0.04551
kBq/kWhe	Actinium	0.00170	0.00000	0.00000	0.03708	0.03878
Tonnes	Chloride	1,726,441	27,147	30,234	22,569	1,806,392
Tonnes	Sulphate	1,197,108	1,346	18,915	170,875	1,388,243
Tonnes	Phosphate	10,812	539	7,849	14,189	33,388
Tonnes	Ammonia	328	41	30	511	911
Tonnes	Oils- freshwater	34	6	59	3	101
Tonnes	Oils - seawater	2,174	889	433	81	3,578
Tonnes	Zinc	2,744	2	37	15	2,798
kBq	Ra	2,353,497,501	33,284,915	60,468,671	51,139,875,600	53,587,126,686
kBq	H3	187,303	0	0	4,195,307	4,382,610
kBq	Radionucleides	312,713,855	0	0	3,644,098,920	3,956,812,775
kBq	Actinium	198,703,595	0	0	3,154,136,040	3,352,839,635



In contrast the three industrial gases, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, are potent greenhouse gases but are only emitted from man made sources. These six greenhouse gases comprise the 'basket of emissions' against which reduction targets were agreed at the Third Conference of the Parties of the United Nations Framework Convention on Climate Change in Kyoto, Japan in December 1997. Carbon dioxide is the major contributor to the UK's greenhouse gas emission and arises predominately from the combustion of fossil fuels. Non-fossil fuel sources are more difficult to assess due to the importance of carbon dioxide in respiratory processes and its role within the global carbon cycle. Emissions of carbon dioxide from recently photosynthesised carbon sources are therefore excluded. These include emissions from biomass combustion, the organic component of waste incineration, landfill and sewage treatment are not included.

Methane, like carbon dioxide, is naturally occurring and is part of the global carbon cycle. However the magnitudes of sinks and sources is not well known. Methane in the atmosphere is eventually oxidised to carbon dioxide with an estimated lifetime of 12 years. The major methane sources are not from electricity generation, but rather waste disposal, agriculture, coal mining and leaks from the gas distribution system.

Nitrous oxide, the third greenhouse gas is emitted from both natural and anthropogenic sources, namely agriculture, biomass burning, coal combustion and some industrial processes.

Although emission totals are low, it is a very powerful greenhouse gas and therefore these emissions have a considerable impact. The last three gases namely hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, have very high greenhouse warming potential, however efforts are being made to phase them out of usage under the Montreal Protocol.

The level of carbon dioxide emissions associated with electricity generation is determined both by the fuel mix and the generating technology used. As natural gas has replaced coal and oil generation technologies this has had a major impact on the amount of carbon dioxide emitted. This is mostly due to the greater efficiency of the combined cycle gas turbine stations (around 50% instead of 34%) and the higher calorific (heating) value of natural gas per unit mass of carbon when compared with coal or oil. An increase in the proportion of nuclear power generated electricity over the past decade has also contributed.

Other gases, which are emitted during the combustion process and have potentially adverse effects on the environment, are acidifying gases and these include the sulphur and nitrogen oxides. The deposition of these gases can have adverse effects on buildings and vegetation, as well as acidifying streams and lakes and damaging the water inhabitants. Sulphur dioxide emissions can be calculated from the sulphur content of the fuel and from that remaining within the ash itself.

Flue gas desulphurisation techniques can also be employed, and are indeed being employed in order to reduce the amount of sulphur dioxide in the gaseous emissions. For more information please see Chapter 5. The UK National Atmospheric Emissions Inventory (NAEI) estimated in 2001 that sulphur dioxide emissions had fallen 68% from their 1990 levels, mainly accounted for in power generation by a switch from coal and oil to natural gas, and employment of clean up technologies.

The main source of the nitrogen oxides is also the combustion processes. However such emissions are much more complex since the nitrogen can be derived from both the fuel and atmospheric nitrogen. The emission is dependent on the conditions of combustion, in particularly temperature and excess air ratio, which can vary considerably.

Thus combustion conditions, load and even the state of the maintenance programme. Higher levels of NOx arise from intense combustion and high oxygen availability. These two factors tend to minimise the differences that exist between coals[10.4]. The NAEI records that total nitrous oxide emissions have decreased by 36% in the period from 1990 to 2001.

The other group of gases relates to the amount of ozone present in the troposphere or at ground level. While ozone naturally occurs in the atmosphere concentrations can be increased in-situ by the photochemical reaction of pollution precursors such as carbon monoxide, nitrogen oxides, and volatile organic compounds (NMVOC - non-methyl volatile organic compounds or NMHC, non-methyl hydrocarbons), together with hydrogen chloride and ammonia.

Ozone concentrations can rise significantly above background levels particularly in the summer months when the temperature rises above 20° carbon dioxide, there is sunshine, and light winds. The ozone produce can affect human health and damage crops and plants.

The other main gaseous emission is not really a gas as such but is emitted in the gaseous stream, so it tends to be included with it. This is particulate matter. Historically interest in particulate matter focused mainly on smoke, which can cause health problems particularly when in combination with other pollutants.

The classic example was the London smog's in the 1950's and early 1960's where smoke and sulphur dioxide combinations lead to several thousands of deaths being recorded.

As the colour of smoke is not a good indicator of the mass of particles interest has focused on the amount of different sized particles in the exhaust gases. Focus is on particles of less than 10µm in size, as these particles are the ones most likely to be inhaled into the thoracic region of the respiratory tract. The epidemiological evidence on the effects of these particles shows a good correlation between PM10 concentrations and mortality or morbidity. The NAEI records that particulate emissions have decreased by 39% in the period from 1990 to 2001.

Finally the figures presented below and in the mass balance section for the level of gaseous pollutants are from one particular set of data compiled by ETSU in 1995. They have been calculated from the amount of fuel, whether oil, coal, gas or uranium which was combusted for electricity generation in the UK in 2000.

In table 10.6, comparison is made for carbon dioxide emissions with:

1. Those calculated from ETSU data,
2. Those measured by the UK government, and published by DEFRA,
3. And with the ETSU data corrected by the NAEI official emission factors (i.e. kgC/tonne fuel) for power stations.

In Chapter 11 comparison is made for all the major gaseous emissions.

Table 10-5

Gaseous Emissions Produced by the Different Electricity Generation Methods[5]

Units	Gaseous Emission	Coal-based Generation	Oil-based Generation	Gas-based Generation	Uranium-based Generation	Total
Litres water (steam)/kWhe	Water (Steam)	0.27020	0.28846	0.16027	0.50007	1.21901
kg/kWhe	CO_2	0.93600	0.75510	0.43430	0.00000	2.12540
kg/kWhe	CO	0.00013	0.00015	0.00007	0.00000	0.00034
kg/kWhe	CH_4	0.00001	0.00001	0.00005	0.00000	0.00007
kg/kWhe	NMHC	0.00003	0.00003	0.00003	0.00000	0.00009
kg/kWhe	NO_x	0.00423	0.00372	0.00046	0.00000	0.00841
kg/kWhe	SO_x	0.01163	0.01390	0.00000	0.00000	0.02553
kg/kWhe	PM_{10}	0.00055	0.00040	0.00000	0.00000	0.00095
kg/kWhe	Benzopyrene	0.00000	0.00000	0.00000	0.00000	0.00000
kg/kWhe	HCl	474.59332	16.23301	0.28855	1.75320	492.86808
kg/kWhe	Hg	0.00026	0.00001	0.00000	0.00000	0.00027
kBq/kWhe	Rn & Ra	57.89760	25.71857	0.00000	1774.80000	1858.41617
Litres water	Water lost to steam	32,413,718,700	1,614,531,890	23,529,448,227	42,537,565,183	100,095,264,000
Tonnes	CO_2	112,282,560	4,226,295	65,431,935	0	181,940,790
Tonnes	CO	15,475	817	10,396	0	26,688
Tonnes	CH_4	720	50	7,684	0	8,454
Tonnes	NMHC	3,119	190	4,821	0	8,130
Tonnes	NO_x	507,431	20,815	69,756	0	598,002
Tonnes	SO_x	1,395,135	77,809	0	0	1,472,944
Tonnes	PM_{10}	66,218	2,239	0	0	68,457
Tonnes	Benzopyrene	0	0	42,360	0	42,361
Tonnes	HCl	56,932,215	90,856	0	149,132	57,172,204
Tonnes	Hg	31	0	0	0	31

Table 10-6

Comparative CO2 Data (Emissions (Tonnes)

	Coal	Oil	Gas	Nuclear	Total
ETSU[a]	112,282,560	4,226,295	65,431,935	0	181,940,790
DEFRA[b]	95,121,993	3,580,374	55,431,726	0	154,134,093
ETSU / NAEI[c]	98,540,515	4,162,631	59,483,577	0	162,186,724

The main observation that can be made from table 10.6 is that the carbon content assumed for each fuel can have a major impact on the amount of CO_2 estimated to be emitted.

a. CA Lewis MEET Project: Methodologies for Estimating Air Pollutant Emissions from Transport (ETSU 1995)

b. UK Defra, Environmental Protection Statistics

c. National Atmospherics Emissions Inventory available at http://www.aeat.com/netcen/airqual/naei/annreport/ as of 7th January, 2003

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The core of this report is this chapter's study on the inputs - outputs and waste streams associated with the various types of electricity generation.

The Electricity Generation Mass Balance

This chapter presents the data and the assumptions behind the data, for the mass balance on the electricity industry. Some of the information in this chapter can be found in the preceding ones, however, it is presented here in full for clarity.

All the mass balances are presented in 2 ways; firstly, in mass (kg) per kWhe generated or volume (l) per KWhe generated and secondly, in absolute mass (tonnes) or volume (litres) per annum.

The first mass balance is a composite for the United Kingdom, and also presents the data in percentage terms for the four main electricity generating methods, namely coal, oil, gas and nuclear. The following mass balances break the information down into each of the four generating methods.

Finally, suggestion on how the information could be used in the other Biffaward mass balances is given.

11.1 Introduction

The first table looks at the typical efficiency of a thermal cycle and highlights the main reasons for the relatively low efficiencies achieved in the generation of electricity.

Table 11-1

Example of simplified balance of a thermal cycle for conventional new design

Energy transformation	Energy (kJ)	Efficiency (%)	(%)
Energy from combustion	9000	100.0	100.0
Steam generator loss	1050	-11.7	88.3
Condenser 'loss'	4200	-46.5	41.8
Feed water heating	-2000	-22.2	(Looping)
Turbogenerator losses	65	-0.75	41.05
Power supply of auxiliaries	65	-0.75	40.3
Loss in main transformer	25	-0.2	40.1
Overall efficiency of the facility			40.1

The operation of power plants is governed by Carnot's principle. The heat source, the boiler, provides the energy required for water vapourisation. The cold source, the condenser, condenses the steam coming out of the low-pressure turbine.

One of the main characteristics of a power plant, from the technical and economic standpoints, is its specific consumption, in other words, the amount of heat needed to produce one kWh of electrical energy (KWHe). This specific consumption results from the thermal cycle balance (table 1). A look at the thermal cycle balance shows that 4200 kJ must be yielded for each kWh generated. In addition, this energy cannot be recovered because its energy is low. New generation systems, especially combined cycles (or gas-steam turbines), make it possible to obtain higher efficiencies of even more than 55%.

11.2 Key Assumptions and Reference Data

11.2.1 Key Assumptions

The following are the key assumptions made for each of the four main generating methods, namely coal, oil, gas and nuclear.

11.2.1a Coal

Power station coal - home produced plus imports	26 GJ per tonne
Coal produced	119960 GWhe
Efficiency	35% efficiency
Million tonnes of coal	47.45

Composition

Carbon content	67 weight %
Hydrogen content	3 weight %
Sulphur content	1.4 weight %
Oxygen content	8 weight %
Nitrogen content	1.4 weight %
Chlorine content	0.1 weight %
Fluorine content	0.01 weight %
Water content	7 weight %

11.2.1b Nuclear

Uranium produced	82300 GWhe
Requiring	2595 tonnes U
Magnox	566.8 tonnes U
AGR	2391.2 tonnes U_3O_8

11.2.1c Oil

Power Station Oil	43.1 GJ per tonne
Oil produced	5597 GWhe
Efficiency	35% efficiency
Million tonnes of oil	1.34

Composition

Carbon	86.30%
Hydrogen	11%
Sulphur	1.5-3.5%
Nitrogen	0.2-0.3%
Ash	0.04-0.1%
Moisture	0.1-1% vol.

11.2.1d Gas

Power Station Gas	49.4 GJ per tonne
Gas Produced	146807 GWhe
Average efficiency	46%
Million tonnes of gas	23.26
Trillion cubic metres of gas	28.87

Assume 100% methane (CH_4) as the gas is pre-treated to strip out the other higher order alkanes.

11.2.2 Reference Data

The following sources are the main references used in the construction of the mass balance. Additional resources are referenced in the body of the report.

The data upon which the following tables were constructed came from the following sources.

- CA Lewis MEET Project: Methodologies for Estimating Air Pollutant Emissions from Transport (ETSU 1995)
- J Bates Full Fuel Cycle Atmospheric Emissions and Global Warming Impacts from UK Electricity Generation (ETSU 1995)
- Michealis P, Royal Society, Energy Mass Balance, 1991 - used for liquid and solid emissions only - except for phosphate emission (Private communication from C-Tech Innovation)
- EU Energy Project principally the ExternE Project available at http://externe.jrc.es
- EIA (US Energy Information Agency) - for gas, coal and oil usage available at http://www.eia.doe.gov/International Energy Agency
- DEFRA - the Department for Environment, Food & Rural Affairs - for water consumption and gaseous emissions comparison available at http://www.defra.gov.uk/
- UK Energy Sector Indicators from the Department of Trade and Industry available at www.dti.gov.uk/energy/
- Electricity Association available at http://www.electricity.org.uk/
- World Nuclear Association for the uranium data, available at http://www.world-nuclear.org

The amount of oxygen required for complete combustion was adjusted to include other oxygen consuming elements, for example, nitrogen and sulphur.

The air required was calculated as the stoichiometric ratio related to the adjusted carbon content of the fuel.

11.3 The Overall Mass Balance for the United Kingdom

The following are the overall mass balances for the UK electricity generation business.

Table 11-2

The Overall Mass Balance for the U K Generation of Electricity

	Per Annum		Per kWhe	
	Amount	Units	Amount	Units
Inputs				
Coal	47,456,703	Tonnes	0.132773	kg/kWhe
Oil	1,335,711	Tonnes	0.003737	kg/kWhe
Gas	23,257,578	Tonnes	0.065069	kg/kWhe
Uranium	567	Tonnes	0.000002	kg/kWhe
Uranium Oxide	2,392	Tonnes	0.000007	kg/kWhe
Air	1,016,236,760,881	m^3	2843.20	l/kWhe
Water	11,513,195,000	m^3	32.21	l/kWhe
C	49,891,481	Tonnes	0.139585	kg/kWhe
O_2	62,867,349	Tonnes	0.175889	kg/kWhe
Outputs				
Gaseous Emissions				
Water lost to steam	100,095,264	m^3 (Water)	0.280044	l/kWhe
CO_2	181,940,790	Tonnes	0.509029	kg/kWhe
CO	26,688	Tonnes	0.000075	kg/kWhe
CH_4	8,454	Tonnes	0.000024	kg/kWhe
NMHC	8,130	Tonnes	0.000023	kg/kWhe
NO_x	598,002	Tonnes	0.001673	kg/kWhe
SO_x	1,472,944	Tonnes	0.004121	kg/kWhe
PM_{10}	68,457	Tonnes	0.000192	kg/kWhe
Benzopyrene	42,361	Tonnes	0.000119	kg/kWhe
HCl	57,172,204	Tonnes	0.159955	kg/kWhe
Hg	31	Tonnes	8.67934E-08	kg/kWhe
Rn & Ra	158,059,155,552,083	kBq	442.21	kBq/kWhe
Liquid Emissions				
Chloride	1,806,392	Tonnes	0.005054	kg/kWhe
Sulphate	1,388,243	Tonnes	0.003884	kg/kWhe
Phosphate	33,388	Tonnes	0.000093	kg/kWhe
Ammonia	911	Tonnes	0.000003	kg/kWhe
Oils- freshwater	101	Tonnes	2.836E-07	kg/kWhe
Oils - seawater	3,578	Tonnes	0.000010	kg/kWhe
Zinc	2,798	Tonnes	0.000008	kg/kWhe
Ra	53,587,126,686	kBq	0.149925	kBq/kWhe
H_3	4,382,610	kBq	0.000012	kBq/kWhe
Radionucleides	3,956,812,775	kBq	0.011070	kBq/kWhe
Actinium	3,352,839,635	kBq	0.009380	kBq/kWhe
Solid Emissions				
Inert waste	57,523,583	Tonnes	0.160938	kg/kWhe
Other waste	4,999,639	Tonnes	0.013988	kg/kWhe
Radio active waste	23,286	Tonnes	0.000065	kg/kWhe
Waste to incinerator	9,554	Tonnes	0.000027	kg/kWhe
Other waste	32,979	Tonnes	0.000092	kg/kWhe
Ash	5,694,804	Tonnes	0.015933	kg/kWhe

Percentage of Total Inputs and Outputs for each of the Four Main Generating Methods

	Coal	Oil	Gas	Nuclear
% Electricity Produced	33.56%	1.57%	41.07%	23.80%
% Produced Excluding Nuclear	44.04%	2.05%	53.90%	
Inputs				
Air	95.43%	4.45%	0.12%	0.00%
Water	32.38%	1.61%	23.51%	42.50%
C	61.38%	2.31%	36.31%	0.00%
O_2	18.27%	4.89%	76.84%	0.00%
Outputs				
Gaseous Emissions				
Water lost to steam	32.38%	1.61%	23.51%	42.50%
CO_2	61.71%	2.32%	35.96%	0.00%
CO	57.99%	3.06%	38.95%	0.00%
CH_4	8.51%	0.60%	90.89%	0.00%
NMHC	38.36%	2.34%	59.30%	0.00%
NO_x	84.85%	3.48%	11.66%	0.00%
SO_x	94.72%	5.28%	0.00%	0.00%
PM_{10}	96.73%	3.27%	0.00%	0.00%
Benzopyrene	0.00%	0.00%	100.00%	0.00%
HCl	99.58%	0.16%	0.00%	0.26%
Hg	99.56%	0.10%	0.00%	0.34%
Rn & Ra	4.39%	0.09%	0.00%	95.51%
Liquid Emissions				
Chloride	95.57%	1.50%	1.67%	1.25%
Sulphate	86.23%	0.10%	1.36%	12.31%
Phosphate	32.38%	1.61%	23.51%	42.50%
Ammonia	36.04%	4.47%	3.34%	56.16%
Oils- freshwater	33.18%	6.32%	57.75%	2.75%
Oils – seawater	60.78%	24.84%	12.11%	2.27%
Zinc	98.08%	0.06%	1.34%	0.53%
Ra	4.39%	0.06%	0.11%	95.43%
H_3	4.27%	0.00%	0.00%	95.73%
Radionucleides	7.90%	0.00%	0.00%	92.10%
Actinium	5.93%	0.00%	0.00%	94.07%
Solid Emissions				
Inert waste	97.40%	0.47%	1.37%	0.76%
Other waste	97.24%	0.03%	1.21%	1.53%
Radio active waste	75.54%	17.49%	4.61%	2.37%
Waste to incinerator	27.11%	67.08%	1.55%	4.26%
Other waste	68.89%	26.95%	1.15%	3.01%
Ash	100.00%	0.00%	0.00%	0.00%

Note: Gaseous emissions have been adjusted to account for the fact that using nuclear power creates no gaseous emissions during the generation stage of the fuel cycle.

The Mass Balance for the UK Generation of Electricity using Coal

	Per Annum		Per kWhe	
	Amount	Units	Amount	Units
Inputs				
Coal	47,456,703	Tonnes	0.395604	kg/kWhe
Air	969,760,742,843,562	Litres	2494.47	l/kWhe
Water	3,728,302,910,213	Litres	31.86	l/kWhe
C	30,622,516	Tonnes	0.680727	kg/kWhe
O_2	11,483,444	Tonnes	0.255273	kg/kWhe
Outputs				
Gaseous Emissions				
Water lost to steam	32,413,718,700	Litres (Water)	0.270204	l/kWhe
CO_2	112,282,560	Tonnes	0.936000	kg/kWhe
CO	15,475	Tonnes	0.000129	kg/kWhe
CH_4	720	Tonnes	0.000006	kg/kWhe
NMHC	3,119	Tonnes	0.000026	kg/kWhe
NO_x	507,431	Tonnes	0.004230	kg/kWhe
SO_x	1,395,135	Tonnes	0.011630	kg/kWhe
PM_{10}	66,218	Tonnes	0.000552	kg/kWhe
Benzopyrene	0	Tonnes	6.79E-07	kg/kWhe
HCl	56,932,215	Tonnes	474.59	kg/kWhe
Hg	31	Tonnes	0.000257	kg/kWhe
Rn & Ra	6,945,396,315,639	kBq	57.90	kBq/kWhe
Liquid Emissions				
Chloride	1,726,441	Tonnes	0.014753	kg/kWhe
Sulphate	1,197,108	Tonnes	0.010230	kg/kWhe
Phosphate	10,812	Tonnes	0.000092	kg/kWhe
Ammonia	328	Tonnes	0.000003	kg/kWhe
Oils- freshwater	34	Tonnes	2.87E-07	kg/kWhe
Oils - seawater	2,174	Tonnes	0.000019	kg/kWhe
Zinc	2,744	Tonnes	0.000023	kg/kWhe
Ra	2,353,497,501	kBq	0.020111	kBq/kWhe
H_3	187,303	kBq	0.000002	kBq/kWhe
Radionucleides	312,713,855	kBq	0.002672	kBq/kWhe
Actinium	198,703,595	kBq	0.001698	kBq/kWhe
Solid Emissions				
Inert waste	56,027,899	Tonnes	0.478769	kg/kWhe
Other waste	4,861,723	Tonnes	0.041544	kg/kWhe
Radio active waste	17,590	Tonnes	0.000150	kg/kWhe
Waste to incinerator	2,590	Tonnes	0.000022	kg/kWhe
Other waste	22,721	Tonnes	0.000194	kg/kWhe
Ash	5,694,804	Tonnes	0.016615	kg/kWhe

The Mass Balance for the UK Generation of Electricity using Oil

	Per Annum		Per kWhe	
	Amount	Units	Amount	Units
Inputs				
Oil	1,335,711	Tonnes	0.238648	kg/kWhe
Air	45,246,339,427,271	Litres	2025.03	l/kWhe
Water	185,707,292,602	Litres	76.93	l/kWhe
C	1,152,626	Tonnes	0.205936	kg/kWhe
O_2	3,073,669	Tonnes	0.549164	kg/kWhe
Outputs				
Gaseous Emissions				
Water lost to steam	1,614,531,890	Litres (Water)	0.288464	l/kWhe
CO_2	4,226,295	Tonnes	0.755100	kg/kWhe
CO	817	Tonnes	0.000146	kg/kWhe
CH_4	50	Tonnes	0.000009	kg/kWhe
NMHC	190	Tonnes	0.000034	kg/kWhe
NO_x	20,815	Tonnes	0.003719	kg/kWhe
SO_x	77,809	Tonnes	0.013902	kg/kWhe
PM_{10}	2,239	Tonnes	0.000400	kg/kWhe
Benzopyrene	0	Tonnes	5.33E-07	kg/kWhe
HCl	90,856	Tonnes	16.23	kg/kWhe
Hg	0	Tonnes	0.000006	kg/kWhe
Rn & Ra	143,946,836,444	kBq	25.72	kBq/kWhe
Liquid Emissions				
Chloride	27,147	Tonnes	0.011246	kg/kWhe
Sulphate	1,346	Tonnes	0.000557	kg/kWhe
Phosphate	539	Tonnes	0.000223	kg/kWhe
Ammonia	41	Tonnes	0.000017	kg/kWhe
Oils- freshwater	6	Tonnes	0.000003	kg/kWhe
Oils - seawater	889	Tonnes	0.000368	kg/kWhe
Zinc	2	Tonnes	0.000001	kg/kWhe
Ra	33,284,915	kBq	0.013788	kBq/kWhe
H_3	0	kBq	0	kBq/kWhe
Radionucleides	0	kBq	0	kBq/kWhe
Actinium	0	kBq	0	kBq/kWhe
Solid Emissions				
Inert waste	271,473	Tonnes	0.112458	kg/kWhe
Other waste	1,346	Tonnes	0.000557	kg/kWhe
Radio active waste	4,072	Tonnes	0.001687	kg/kWhe
Waste to incinerator	6,409	Tonnes	0.002655	kg/kWhe
Other waste	8,888	Tonnes	0.003682	kg/kWhe
Ash	0	Tonnes	0	kg/kWhe

The Mass Balance for the UK Generation of Electricity using Natural Gas

	Per Annum		Per kWhe	
	Amount	Units	Amount	Units
Inputs				
Gas	23,257,578	Tonnes	0.158423	kg/kWhe
Air	1,229,678,610,499	Litres	3564.54	l/kWhe
Water	2,706,413,019,478	Litres	20.89	l/kWhe
C	18,116,339	Tonnes	0.129726	kg/kWhe
O_2	48,310,236	Tonnes	0.345936	kg/kWhe
Outputs				
Gaseous Emissions				
Water (Steam)	23,529,448,227	Litres (Water)	0.160275	l/kWhe
CO_2	65,431,935	Tonnes	0.434300	kg/kWhe
CO	10,396	Tonnes	0.000069	kg/kWhe
CH_4	7,684	Tonnes	0.000051	kg/kWhe
NMHC	4,821	Tonnes	0.000032	kg/kWhe
NO_x	69,756	Tonnes	0.000463	kg/kWhe
SO_x	0	Tonnes	0	kg/kWhe
PM_{10}	0	Tonnes	0	kg/kWhe
Benzopyrene	42,360	Tonnes	4.828E-07	kg/kWhe
HCl	0	Tonnes	0.288545	kg/kWhe
Hg	0	Tonnes	9.783E-07	kg/kWhe
Rn & Ra	0	kBq	0	kBq/kWhe
Liquid Emissions				
Chloride	30,234	Tonnes	0.000233	kg/kWhe
Sulphate	18,915	Tonnes	0.000146	kg/kWhe
Phosphate	7,849	Tonnes	0.000061	kg/kWhe
Ammonia	30	Tonnes	2.345E-07	kg/kWhe
Oils - freshwater	59	Tonnes	4.518E-07	kg/kWhe
Oils – seawater	433	Tonnes	0.000003	kg/kWhe
Zinc	37	Tonnes	2.885E-07	kg/kWhe
Ra	60,468,671	kBq	0.000467	kBq/kWhe
H_3	0	kBq	0	kBq/kWhe
Radionucleides	0	kBq	0	kBq/kWhe
Actinium	0	kBq	0	kBq/kWhe
Solid Emissions				
Inert waste	789,369	Tonnes	0.006093	kg/kWhe
Other waste	60,320	Tonnes	0.000466	kg/kWhe
Radio active waste	1,072	Tonnes	0.000008	kg/kWhe
Waste to incinerator	148	Tonnes	0.000001	kg/kWhe
Other waste	378	Tonnes	0.000003	kg/kWhe
Ash	0	Tonnes	0	kg/kWhe

The Mass Balance for the UK Generation of Electricity using Uranium

	Per Annum		Per kWhe	
	Amount	Units	Amount	Units
Inputs				
Uranium	567	Tonnes	0.000032	kg/kWhe
Uranium Oxide	2,392	Tonnes	0.000037	kg/kWhe
Air	0	Litres	0	l/kWhe
Water	4,892,771,777,707	Litres	57.52	l/kWhe
C	0	Tonnes	0	kg/kWhe
O_2	0	Tonnes	0	kg/kWhe
Outputs				
Gaseous Emissions				
Water lost to steam	42,537,565,183	Litres (Water)	0.5000713	l/kWhe
CO_2	0	Tonnes	0	kg/kWhe
CO	0	Tonnes	0	kg/kWhe
CH_4	0	Tonnes	0	kg/kWhe
NMHC	0	Tonnes	0	kg/kWhe
NO_x	0	Tonnes	0	kg/kWhe
SO_x	0	Tonnes	0	kg/kWhe
PM_{10}	0	Tonnes	0	kg/kWhe
Benzopyrene	0	Tonnes	5.436E-08	kg/kWhe
HCl	149,132	Tonnes	1.753200	kg/kWhe
Hg	0	Tonnes	1.224E-06	kg/kWhe
Rn & Ra	150,969,812,400,000	kBq	1774.80	kBq/kWhe
Liquid Emissions				
Chloride	22,569	Tonnes	0.000265	kg/kWhe
Sulphate	170,875	Tonnes	0.002009	kg/kWhe
Phosphate	14,189	Tonnes	0.000167	kg/kWhe
Ammonia	511	Tonnes	0.000006	kg/kWhe
Oils - freshwater	3	Tonnes	0.000000	kg/kWhe
Oils - seawater	81	Tonnes	9.54E-07	kg/kWhe
Zinc	15	Tonnes	1.732E-07	kg/kWhe
Ra	51,139,875,600	kBq	0.601200	kBq/kWhe
H_3	4,195,307	kBq	0.000049	kBq/kWhe
Radionucleides	3,644,098,920	kBq	0.042840	kBq/kWhe
Actinium	3,154,136,040	kBq	0.037080	kBq/kWhe
Solid Emissions				
Inert waste	434,842	Tonnes	0.005112	kg/kWhe
Other waste	76,250	Tonnes	0.000896	kg/kWhe
Radio active waste	551	Tonnes	0.000006	kg/kWhe
Waste to incinerator	407	Tonnes	0.000005	kg/kWhe
Other waste	992	Tonnes	0.000012	kg/kWhe
Ash	0	Tonnes	0	kg/kWhe

11.8 Definitions

Air emissions	
CO_2 kg	Carbon dioxide associated processes with combustion
Methane (CH_4) kg	Methane emissions
SOx kg	Emissions of SO_2, SO_3, SO_4^{2-}
NOx kg	Emissions of all oxides of nitrogen
NMVOC kg	Non-methane volatile organic compounds Emissions of organic compounds other than methane
Hydrogen chloride kg	Emissions to air of hydrogen chloride
Mercury kg	Emissions of mercury
Radionucleides kBq	Emission of radionucleides in terms of their activity (1kBq = 1000 decays/second)
Noble gases kBq	Emission of noble gases in terms of their activity
Aerosols kBq	Emission of aerosols in terms of their activity
Actinides kBq	Emission of actinides in terms of their activity

Water emissions	
Chloride kg	Emission to water of chloride ions
Sulphate kg	Emission to water of sulphate ions
Ammonia kg	Emission of ammonia to water
Phosphate kg	Emission of phosphates to water
Oils-freshwater kg	Emission of oils to freshwater bodies
Oils-seawater kg	Emission of oils to seawater bodies
Radionucleides kBq	Radioactivity of substances emitted to water

Solid Emissions	
Inert waste kg	Mass of chemically inert waste
Other waste kg	Mass of non-inert waste
Radioactive waste kg	Mass of radioactive waste

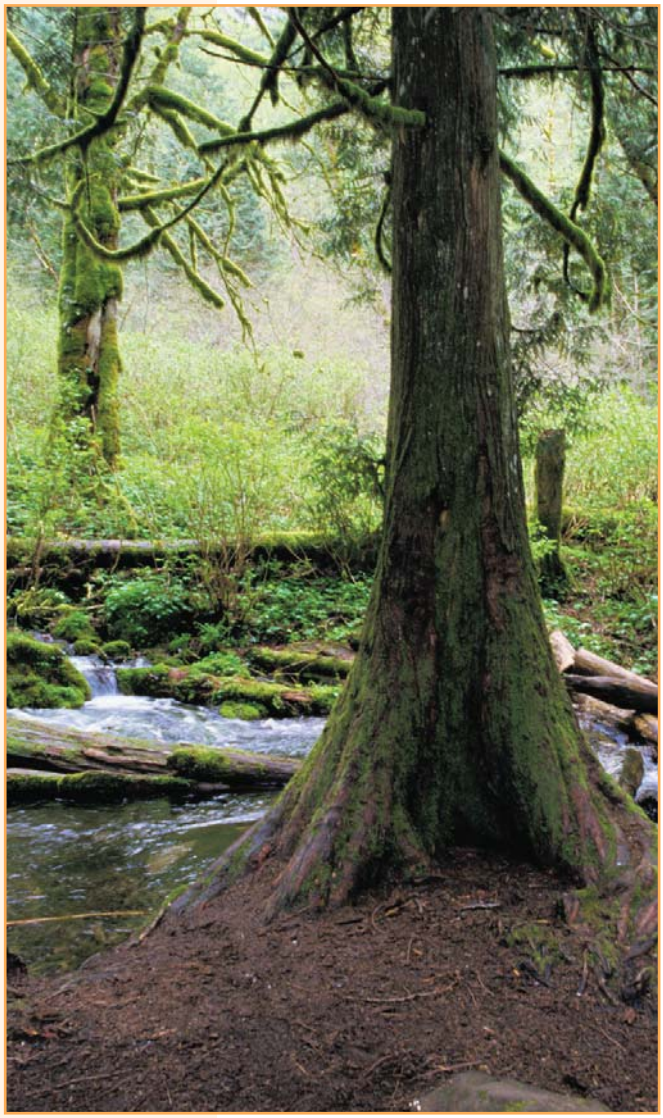
11.3 Using the Overall Electricity Generation Mass Balance

The data presented in this section of the report has been designed to fulfil two criteria, namely:

1. Provide information on the total annual inputs and outputs for the electricity generation industry.
2. Provide information on the mass (or volume) per kWhe (kilowatt-hour of electricity generated).

It is the second set of information which is focused on the use of the data gathered for this report by the other Biffaward Mass Balance Studies, which have been published, or in preparation. In these studies the electricity consumption has been noted as kWh per unit, the information in this report can now quantify inputs and emissions for each kWh.

Although the information presented here is detailed, on, for example, gaseous emissions associated with each kWhe, the author would suggest the consideration of the three main greenhouse effect causing emissions, namely, carbon dioxide, methane and nitrous oxide.



12

This chapter examines the current status of the renewable market in the UK, and comparisons are made with the world wide situation where relevant. An outline of the different, relevant technologies is made, followed by an assessment of the current market position and pertinent legislation.

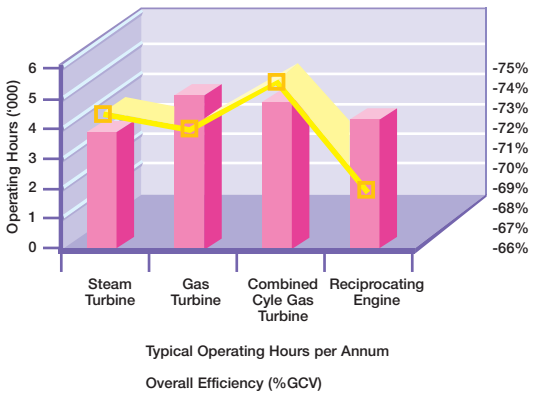
The Use of Emerging Technologies for Renewable Energy

12.1 Combined Heat and Power (CHP)

12.1.1 Introduction

CHP is the simultaneous generation of usable heat and power (usually electric) in a single process. CHP uses a variety of fuels and there are many different sizes of engine and places it is used. There are 4 main types of CHP scheme: steam turbine, gas turbine, combined cycle systems and reciprocating engines. CHP plants tend to be much smaller than conventional power plants and are connected to the lower voltage distribution system. CHP generation doesn't suffer from transmission and distribution losses, and can provide important network services such as black start, improvements to power quality and the ability to work alone if the grid goes down. There are several types of engine used in CHP, each with their own efficiency and average operating hours.

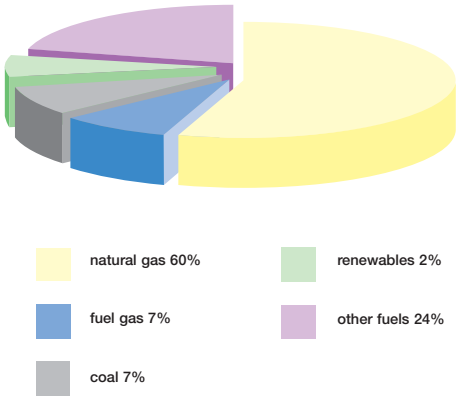
Figure 12-1
CHP Performance by Main Prime Mover



12.1.2 Fuel Use

The main fuel used by CHP systems is natural gas. The percentage of coal use has increased over the last year and gas decreased, due to a raise in gas prices in 2001. Other fuels, for example renewables, waste products etc. account for approximately a quarter of fuel use in CHP. Because of the process of combustion used for these fuels, the overall efficiency when using them will always be lower, yet there are many environmental benefits to consider. The Fig 12.2 shows the proportion of fuels used in CHP in the UK in 2001:

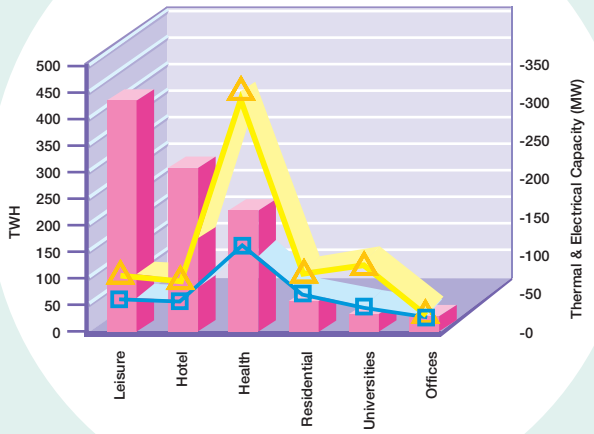
Figure 12-2
Types of Fuel Used by CHP Schemes in 2001



12.1.3 Current Status

In the last ten years capacity has more than doubled for CHP, and the average growth rate has been 8% per annum. Approximately 6% of electricity generated in the UK was produced by CHP in 2001. The main user of this electricity is the industrial sector, with 91% of the capacity. The remaining 9% is used in the commercial, public and residential sectors.

Figure 12-3
Number and Capacity of CHP schemes by sector



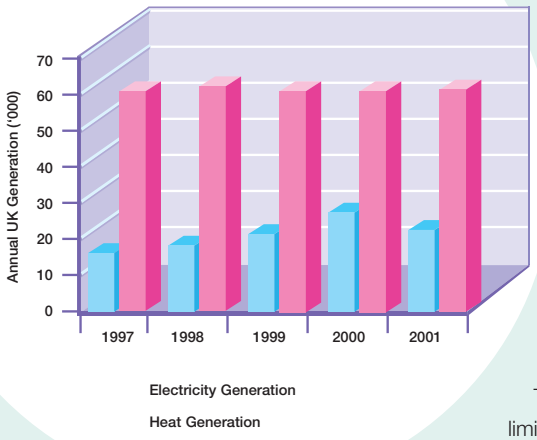
The majority of schemes in the above chart are based on spark ignition reciprocating engines fuelled with natural gas.

12.1.4 Government and Economics

The Government has set a target of achieving at least 10,000 MWe of Good Quality CHP capacity by 2010. This is to help reduce carbon emissions and deliver the UK's Climate Change Program. Like most alternative generation technologies, the main obstacle facing CHP is the cost of the electricity produced. The cost of the fuel is also a problem. The total generation capacity in the UK is above demand so there is little effort to invest in new CHP capacity.

The graph below shows how heat and electrical generation from CHP in the UK has changed over the last five years:

Figure 12-4
Recent Generation Developments of CHP in the UK



As can be seen, the amount of heat and electricity generated by CHP has remained relatively constant over the last five years. The Government is doing several things to help reach the 10,000 MWe target previously mentioned, including:

- Climate Change Levy exemption on fuel inputs to Good Quality CHP
- Business Rates exemption for CHP power generation plant and machinery.
- A reduction in VAT on certain grant-funded domestic micro-CHP installations.
- The launch of the £50m Community Energy Programme to encourage CHP use in the community plus other measures.

By modelling various energy price scenarios, Cambridge Econometrics suggests that capacity will reach 9,300 - 10,300 MWe by 2010 under measures currently in place and recently announced.

12.1.5 Non-domestic CHP (mini-CHP)

Conventional CHP is currently viable in niche segments in sizes down to perhaps 30 kWe, limited mainly by maintenance costs.

New technologies claim to have significant increases in availability, reliability and reduced maintenance requirements.

The main technology used is the internal combustion engine (ICE). They typically require servicing every 600 hours.

Fuel cells, micro-turbines, and Stirling engines have fewer moving parts than the ICE, therefore reliability and availability are better and service cost is reduced.

Mini-CHP could grow significantly in Europe's electrical system within the next few years.

Tightening greenhouse gas emission limits and widening market competition are helping this to occur.

12.1.6 Maintenance

Maintenance makes a significant contribution to the running of mini-CHP systems, particularly on smaller units. Five-year rolling maintenance contracts are offered for some emerging mini-CHP technologies guaranteeing 95% availability at £2500 per year for a 45kWe unit operating for 6000h.

Table 12-1
Comparison of Purchase and Operational Costs for Certain Emerging Technologies

	Stirling	Fuel Cell (PEM)	Micro Turbine	IC Engines	
				Trad.	New
Size (kWe)	10	1 - 200	30 - 200	30 - 200	1 - 10
Cost (€/kWe)	1000	4000	750 - 1000	1000	2400
Efficiency	20%	30 - 45%	15 - 30%	25 - 30%	25%
Reliability	Very Good	Fair	Excellent	Good	Very Good
Service Cost (€/kWh)	1.2	2	1.2	2.5	1.5
Generation Cost (€/kWh)	4	5	4	6	5



Figure 12-5
A Typical CHP Plant

12.1.7 Residential CHP (Micro-CHP)

Micro-CHP is different from conventional CHP in that it is used in the highly changing electrical loads in individual homes. Therefore the power cannot always be provided from the micro-CHP unit, and the house must be connected to a grid. A variety of technologies exist to implement micro-CHP, including Stirling engines, fuel cells, thermo-electric effect, thermo-photovoltaic effect and long-life IC engines. Of these, only Stirling engines and fuel cells appear to be at a realistic demonstration stage for the residential market.

Thermally, micro-CHP is likely to be as efficient, or better, than conventional heating systems. Initial assessments of micro-CHP units, suggest that they will be a highly cost effective solution for residential properties that cannot be insulated further (to reduce thermal demand), and will be more cost effective than most lighting and appliance energy efficiency measures.

12.1.8 Prospects

12.1.8.1 Mini-CHP

With government support, cheap gas and no major administrative barriers, prospects for mini-CHP appear to be good.
Gas central heating, or air conditioning with gas heating, are the most popular systems in most buildings and these are well suited to replacement with mini-CHP systems. However, sales and progress may be hindered by a lack of willingness to look into and use new technologies. The best prospects may lie with innovative ESCos who can turn mini-CHP into a profitable business within the privatised energy markets.

12.1.8.2 Micro-CHP

The significant heating load, very large potential market and pump priming subsidy of 5% VAT indicate that the UK should have an excellent market for micro-CHP. This is somewhat counteracted by the low price of electricity. The spread of heating demand suggests that around 50% of gas heated homes will have heating demands large enough to support a micro-CHP unit.
An estimate is that the likely potential market is around 20 million homes, about most of which could operate on gas. Therefore it is expected that units will be generally available in 2003-4 with sales of up to 300,000 units per annum by 2010.

12.2 Fuel Cells

12.2.1 Introduction

In the last decade there has been a big effort to develop fuel cells. The concerns about emissions and environmental issues with the desire for greater electrical efficiency have led to large research and development projects being initiated by many governments. There has also been a very rapid growth in the amount of industrial investment, as the commercial prospects for fuel cells have become clearer.

There are four main components that a fuel cell power plant consists of: the stack, the fuel reformer, the power electronics and the balance of plant.

12.2.2 Typical Fuel Cell Stack - Technology

There are several types of fuel cell, each having a different stack with its own characteristics (see Table 12-2):



Figure 12-6
Typical Fuel Cell Stacks

12.2.3 Advantages of Fuel Cells

The main advantages of fuel cells are their high electrical efficiency and very low emissions. They also have the ability to change their output to suit demand, which can allow the efficiency to be raised further.

Electrical efficiency

Fuel cells have electrical efficiencies ranging from 35% to around 50%, with the potential for up to 70% for larger systems. This is the highest of all plant considered, and is generally higher than the current, overall network efficiency in the UK at around 36%. This can be a very attractive feature for premises or processes with low heat to power ratios, which have previously been unable to find a suitable CHP plant to suit.

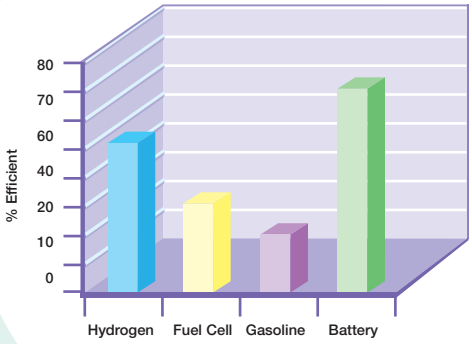
Table 12-2

Status and Comments on the Different Fuel Cells Available

	Status	Comments
Solid oxide fuel cells (SOFC)	Tubular and planar technology under development.	Best suited for large-scale stationary power generators, and smaller continuous systems. High electrical efficiency.
Molten carbonate fuel cell (MCFC)	250kW-1MW systems being demonstrated.	Suited for larger stationary power generators
Phosphoric acid fuel cell (PAFC).	200kW system offered for sale, but not commercially competitive in the UK.	Most developed of fuel cells, with over 200 demonstrations of this technology. Used in stationary power generation.
Alkaline fuel cell (AFC)	Highly developed for space systems and suitable for some smaller applications.	Low temperature fuel cells. Contain no platinum in the cell stack, which gives a competitive advantage over PEMs. Susceptible to contamination. Very expensive.
Proton exchange membrane fuel cell (PEMFC)	250kW CHP, residential CHP, cars and buses being demonstrated but not yet commercially viable.	One of the most promising technologies. Potential for rugged low cost units.

Fuel cells also look highly attractive for cars if production costs can be lowered to around $30-$50/kW:

Figure 12-7
Comparison of Efficiency of Different Powered Cars



Benefits

Other than efficiency, fuel cells have significant environmental advantages in that they have very low emission levels of pollutants such as nitrogen or sulphur oxides. This means that fuel cells don't contribute to smog or acid rain like other technologies. A large percentage of heat produced by fuel cells can be captured and reused, instead of being released into the air. Unlike most generation technologies fuel cells have no moving parts and are quiet in operation. They never need to be recharged or replaced and will work continuously if supplied with hydrogen or another fuel.

Problems

Because fuel cells use hydrogen, this presents several problems. Hydrogen has some limitations that make it impractical for use in most applications. It is difficult to store and distribute. Using a device called a reformer, other fuels such as natural gas and gasoline can be converted to produce hydrogen. It should be noted that reformers generate heat, produce other gases besides hydrogen and reduce efficiency.

12.2.4 Applications

Table 12-3 shows the applications of several different fuel cells:

Table 12-3
Applications of Fuel Cells

	Power Generation					
	Commercial	Residential	CHP	Space	Transport	Portable
PEM	X	X			X	X
PAFC	X	X	X			
MCFC	X	X	X			
SOFC	X	X				
AFC				X	X	
DMFC						X

Automobiles

A fuel cell car is very similar to a battery car but with a fuel cell (and reformer if required) instead of a battery. Methanol, gasoline, and hydrogen are all potential fuels.



Figure 12-8
An Example of a Fuel Cell Car

Portable Power

Fuel cells are already being used in laptops, mobile phones and could even be used in hearing aids. They have an advantage over batteries in that they have a much longer life, and can be recharged quicker with fuel.

Buses

Fuel cell buses are already operational in a few countries. Numerous fuel cell buses are already on trial across America and Europe.

Residential Power Generation

This system has the potential to produce up to seven kilowatts of power, and requires a gas or propane reformer. A large amount of heat is also produced, and this can be used to heat the house and water.

Hundreds of systems are already on trial worldwide.

Large Power Generation

Fuel cells are more efficient than conventional power plants. The heat generated by the fuel stack can also be used. Fuel cell plants are quieter, and produce fewer pollutants than conventional fossil fuel plants. One 200kWe plant has been on commercial sale now for over 10 years with over 200 units sold worldwide.

12.2.5 The Fuel Cell Market

Initial market entry is widely expected to be in areas that can stand a higher cost per kWh of energy, such as portable applications and battery replacement. Early markets are probably going to be in North America.

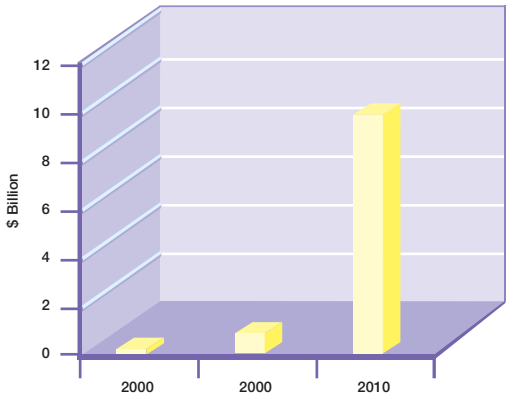
The bus industry is expected to be a major fuel cell application, as the requirements are less demanding than the car industry and refuelling and maintenance are easier to implement. Cars have the potential for a huge fuel cell market, but cost is holding this technology back. Most automobile manufacturers have R&D schemes in place, and are forecasting initial sales around 2004, with significant sales around 2010.

The potential of distributed power generation and CHP for fuel cell technology isn't as good as for cars or buses, yet the demands required for the technology are easier to meet. Sales in the distribution power sector have already begun. The stationary heat and power markets for fuel cells are expected to grow by around £1.9billion per year by 2020.

Prospects for the UK

There is a growing interest in fuel cells in the UK, and it is believed they could make a contribution to energy production in the future. The UK has green house gas commitments and the use of fuel cells could allow these to be met, although their contribution would probably come into affect around 2010. Like most new technologies demonstration and operating experience are vital, but government support is needed. Fuel cells are a rapid growth industry and one that is unlikely to slow, but the problem lies in that there are a commercial and financial risks in fuel cells, and UK industry needs assistance before it invests in this technology. The graph below shows the predicted value, from Environmental Business International, of the global fuel cell market over the next decade:

Figure 12-9
Predicted Global Fuel Cell Market



12.3 Micro-turbines

12.3.1 Introduction

Micro-turbines have a long history as automotive power units. Today, with improved high-temperature turbine blade materials allied to high-frequency solid-state electronic drives, the gas turbine is challenging the reciprocating Internal Combustion engine market. Modern micro-turbines generally have just one moving part, the rotor/compressor assembly, with two bearings. This offers advantages of compactness, reliability, low weight, low emissions and low maintenance. The high exhaust temperature in gas turbines can be utilised to raise process steam or feed an absorption chiller for refrigeration and air-conditioning duties, effectively providing Combined Heat, Power and Cooling (CHPC).

12.3.2 Power Plant

Gas turbines are now becoming commercially available in packaged generation only and mini-CHP units in the 20-200 kWe range. Competing units have been developed from aircraft auxiliary power units (APUs) and turbo-compressors. High rotational speed and compactness are features of these two units, and they are more suited to industry. The micro-turbine market stands to benefit from the improved efficiency of units, derived from using high frequency permanent-magnet alternators mounted directly to the rotor shaft (that also double as starter-motor), where output is converted to mains frequency and voltage by modern power electronics. Along with fuel cells, it is looking increasingly likely this technology may compete with IC engines in the transport sector in the long-term. Table 12-4 shows how the micro-turbine compares to other technologies:

12.3.3 Costs

Capital costs are currently similar to those of conventional reciprocating engines at ~ €750/kWe - €1000/kWe for a micro-turbine, but if production rises, these prices may fall.

Maintenance costs, although low compared to reciprocating IC engines, are still a large proportion of running costs.

Manufacturers Cost

Pricing of micro-turbines has specific economics for viability. Capstone's Model 330 (30 kWe) has a list price of around $27,000 ($900 per kWe). In 2001, the Honeywell model had a price of $800 - $825/kWe and the Turbec unit is priced between $650 and $700 per kWe. Complete CHP systems such as Bowman Power Systems are targeted to be approximately $750-$800 per kWe.

Table 12-4
Comparison of Micro-turbines and Other Technologies

	Stirling engine (Solo)	Fuel Cell PEM)	Micro-Turbine (Capstone)	IC Engines	
				Traditional	New
Size (kWh)	10	1-200	30-200	30-200	1-10
Current Capital Cost c€/kWe	1000	4000	750-1000	1000	2,400
Fuel	Liquid/Gas /Solid	H_2,NG Methanol	Liquid/Gas	Liquid/Gas	Liquid/Gas
Steam Raising Ability	No	Yes	Yes	Some	No
Efficiency (HCV)	20%	30-45%	10-30%	25-30%	25%
Noise (dBA)	70@1m	65@1m	75@1m	90@10m	55@1m
NO_x (mg/kWh)	100	10	150	1000	1000
Reliability	Very Good	Fair	Very Good	Very Good	Very Good
Service Life (h)	5,000	5,000	5,000	1,000	3,500
Service Cost (c€/kWh)	1.2	2.0	1.2	2.5	1.5
Overhaul (h)	20,000	40,000	50,000	5,000	8,000
Life (h)	80,000	50,000	100,000	50,000	80,000
Power Density (kW/m^3)	10	2.5	25	20	20
Generation Cost (c€/kWh)	4	5	4	6	5



Figure 12-10
The Turbec Micro-Turbine

12.3.4 Advantages of Micro-turbines

Micro-turbines require low maintenance, have a long life, are relatively cheap, compact, and reliable and can have variable output and recuperation (using heat in the exhaust to pre-heat the compressed air prior to combustion). These can be summarised as follows:

Low maintenance:
Micro-turbines require significantly less maintenance than traditional IC engines of a similar size.

Long life:
As there is generally only one moving part within the unit, a long life can be expected due to the reliability of that part.
The main rotor should last at least 40,000 hours before replacement is required, and sometimes longer.

Low unit costs:
The units are generally cost competitive with IC engines on capital cost alone.
This provides a competitive advantage when maintenance costs are included.

Variable output and recuperation:
The output can be modulated to some extent without a large loss in efficiency.
Recuperation can also be modulated to help match the thermal load.

12.3.5 Disadvantages of Micro-turbines

The units can be quite noisy (70 - 80 dBA) and generally are designed to run once per day. They are not designed for repeated stop / starts.

Micro-turbines tend to be limited to particular market sections where they offer distinct operational advantages. The heat to power ratio of the plant determines the typical application, so it can be concluded that different types of plant may be more suitable for specific countries. Micro-turbines (with a heat to power ratio of approximately 2:1 to 5:1) would also be more suitable in countries with a large difference between electricity and gas prices. However, as the ratio rises, electricity price becomes less important.

12.3.6 Efficiency

Basic efficiencies of ~15% are typically achieved but this can be improved significantly by using some of the heat available in the exhaust to pre-heat the compressed air prior to combustion (recuperation). However, without an improvement in heat exchanger performance, this can be at the expense of overall efficiency in CHP applications.
Some micro-turbine CHP systems are able to vary the amount of recuperation to boost thermal output as required. Micro-turbines can also give a range of power output dependent upon the level of recuperation, i.e. more recuperation gives greater electrical efficiency (more kWe); less recuperation gives lower electrical efficiency and higher heat output. The graph below shows how efficiency can vary with recuperation:

As can be seen in figure 12-11, the overall efficiency is greater in the simple cycle micro-turbine, but the electrical conversion efficiency is less. The following graph shows the power input and thermal output for the same Micro-turbine:

Table 12-5 shows the simple cycle micro-turbine has a greater heat input and a greater thermal output.

Figure 12-11
Performance of a Micro-Turbine with/without Recuperation

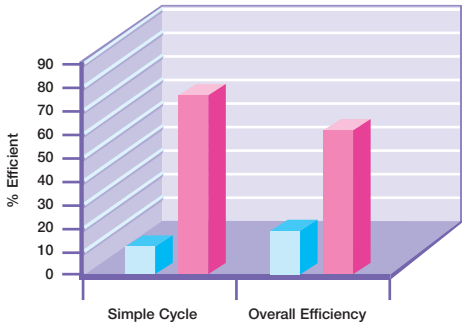


Figure 12-12
Performance of a Micro-Turbine with/without Recuperation
(Electrical Conversion)

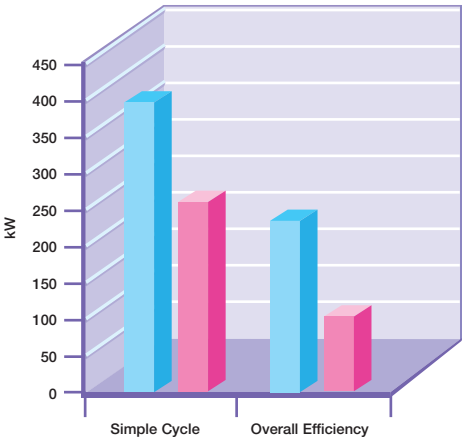


Table 12-5
Properties of Leading Micro-turbines

Company	Model	Net Elec. Output (kW$_e$)	Net Thermal output (kWh)	Fuels	Overall Efficiency	Noise Level
Bowman Power Systems Ltd	TG 35	32.9	-	Natural Gas	63	-
	TG 80	80	150-420	Nat. Gas/LPG Propane/Butane	74-86	77dBA@1m
Capstone Turbine Corp.	Micro Turbine 330	30	-	Nat. Gas/LPG Propane/Diesel	24-28(LHV)	65dBA@10m
Ingersoll Rand Energy Systems	Powerworks	30-250	-	Nat. Gas/Others	80	<78dBA@1m 58dBA@10m
The Turbo Genset Company Ltd	TG 50	45	-	Diesel, Kerosene Nat. Gas	90(Net. Elec. Conv.Eff.)	85dBA@1m
Turbec AB	T 100	105(+/-3)	167(+/-5)	Nat. Gas	78	70dBA@1m
Elliot Energy Systems	TA 80	80	-	-	80	<65dBA@10m

As can be seen, the simple cycle micro-turbine has a greater heat input and a greater thermal output.

12.3.7 Potential Markets

Below is a list of the potential markets micro-turbine technology could enter:

- On-site CHP
- Uninterruptible Power Supplies
- Distributed Power Generation
- Auxiliary Power Units for vehicles
- Portable Generation
- Hybrid Electric Vehicles
- Transport & Remote Generation

In particular, new technologies such as micro-turbines are capable of providing relatively high-grade waste heat, well above the 120°C ceiling produced by conventional low temperature technologies.

Research has shown that there is scope to use such a technology in tandem with absorption cooling facilities. Such an application could be particularly useful in the food retail and manufacturing sectors.

Current Products

Micro-turbine packages including absorption chillers are being developed for CHP and chilling applications. The main micro-turbine products are:

Capstone's, Model 330

Bowman Power Systems Turbogen family, TG45, TG60, TG80

Ingersoll Rand Energy Systems, Powerworks™

Turbec's, T100

Table 12-5 shows the characteristics of these and other models (figures from company websites, correct at 10/02/2002):

12.4 Solar Cells

12.4.1 Introduction

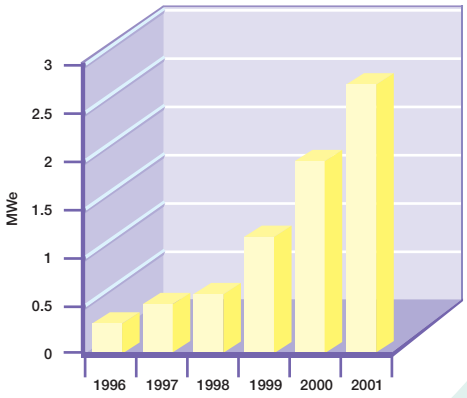
Solar cells are mainly placed on the roofs of homes, apartments, low rise offices, small shops, schools, government buildings, barns and garages. They allow people to obtain the benefits of making their own electricity whilst having the knowledge they are still connected to, and have the backup of, a major grid. Solar cells could in the future play a useful role by taking the demand off other equipment and therefore prolonging its life span. For example, solar cells could be used to extend the life of overload transmission circuits and delay the need for capacity increases.

Currently, most solar cells use multicrystalline silicon. This technology has undergone a major effort by governments to increase its use and development, but high prices for the cells mean it is not as commercially viable as other renewable sources and therefore has a niche market. Developments in this technology are looking to lower costs and help integrate solar energy generation techniques into the major grids.

12.4.2 Current Status

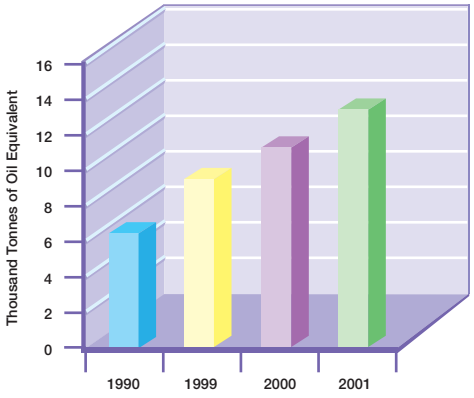
The capacity of solar generation has risen every year in the UK and stood at 2.75 MW in 2001. Developments in this technology are looking to lower costs and help integrate solar energy generation techniques into the major grids.

Figure 12-13
Declared Net Capacity of Solar Generation in UK



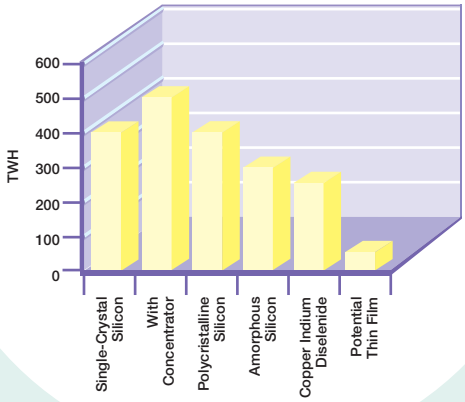
The following DTI statistics show the increase in quantity of electricity produced by photovoltaics over the past eleven years:

Figure 12-14
Quantity of Electricity Produced by Photovoltaics in the UK



Presently, there are many different materials that solar cells can be made from. These all differ in price.

Figure 12-15
Quantity of Electricity Produced by Photovoltaics in the UK



The latest solar cells are getting close to bringing the cost levels to an acceptable figure, and current crystalline cells can be built for manufacturing costs of $3.50 to $4 per watt generated. Many people developing these cells expect newer thinner films to do even better; stating that newer devices could produce power for less than $0.50 per watt.

Table 12-6
Comparison of Photovoltaic Cell Characteristics

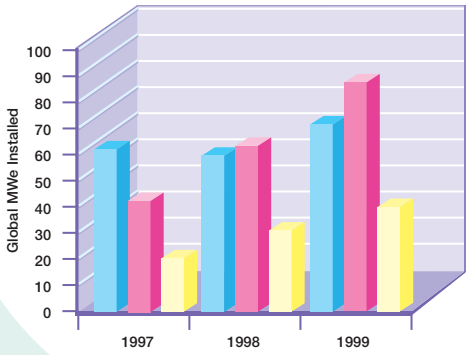
Cell Material	Theoretical Efficiency (%)	Lab Efficiency (%)	Commercial Efficiency (%)
Single-Crystal Silicon	30	23.5	12 to 14
With Concentrator	37	28.2	13 to 15
Polycrystalline Silicon	25	17.8	11 to 13
Amorphous Silicon	17	13	4 to 6
Polycrystalline Thin Films	27	15.8	6
Copper Indium Diselenide	19	16.4	11
Gallium Arsenide	28	27.6	-
With Concentrator	39	29.2	-

As can be seen from the table above, gallium arsenide with concentrator is the most efficient material, with amorphous silicon being the worst of those that are being considered.

12.4.3 Technologies

Crystalline Silicon is the leading commercial material for photovoltaic cells, and is used in several forms.

Figure 12-16
Materials Used in Solar Cells



Thin Film

Thin film photovoltaic cells use layers of semiconductor materials only micrometers thick attached to an inexpensive backing such as glass, flexible plastic or stainless steel. The cost of manufacturing thin films is a lot less than standard PV cells due to the small amount of semiconductor material required.

Single Crystal

Group III-V Photovoltaic (based on Group III and V elements in the periodic table) technologies have high conversion ratios of sunlight to electricity under either normal sunlight or sunlight that is concentrated. These single crystal cells are normally made from gallium arsenide

High-Efficiency Multi-junction Devices
Multi-junction devices stack individual solar cells on top of each other to maximise the capture and conversion of solar energy. The top layer captures the highest-energy light and passes the rest on to be absorbed by the lower layers. Much of this area uses gallium arsenide.

Advanced Solar Cells

A variety of advanced approaches to solar cells are under investigation. Dye-sensitised solar cells use a dye-impregnated layer of titanium dioxide to generate a voltage, rather than semiconducting materials used in most solar cells. This technology is cheap and therefore has the potential for lower cost.

12.4.4 Problems

The main problem facing this technology is cost. As with most renewable plant, the source is not as reliable as fossil fuels and this means a storage system may have to be integrated. Also, the safety of the cells is a concern when used in public areas, as they only witch off with the absence of sunlight.

To overcome these problems research needs to be done on new materials, and like wind production, the normalisation of design would help lower costs and problems.

Additional Problems

An installed PV system requires balance of plant (BoP) technologies, for example, inverters, electrical switches and wiring, mounting structures etc. On average, these systems make up half the final cost of the PV system. The BoP technologies are not normally made by the manufacturers of the PV cells, meaning the PV industry has little to do with the cost of the BoP.

12.4.5 Forecast - Growth

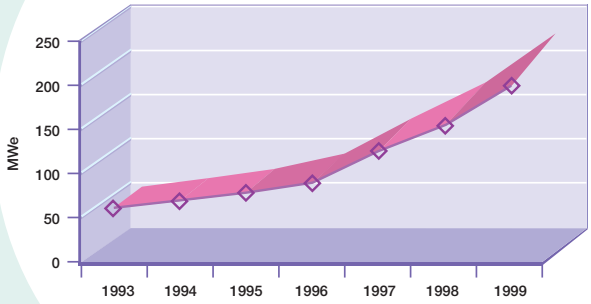
The rate of market growth in the PV industry will depend on discussions across Europe and the USA on market support mechanisms for renewable energy expansion. However, the rate of growth will depend on the advancement in technology that will ultimately lead to an improved price for electricity produced by PV cells. The buildings and utility segment are believed to expect a large volume increase in the use of photovoltaics due to the concern about energy and the environment in the industrialised world. The Rural Off-Grid segment is expected to show similar expansion. The following table shows the projected capacity and generation from solar power in Europe:

Table 12-7
Forest Solar Capacity (GW) and Generation (TWh) in Europe

2010		2020	
Capacity	Generation	Capacity	Generation
1.6	3.6	3.8	8.2

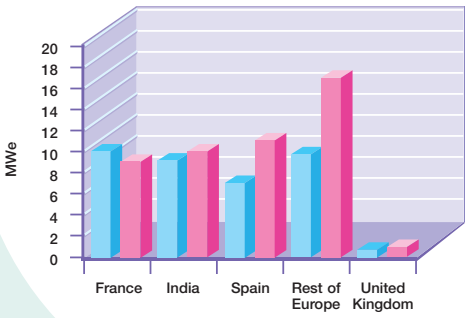
The graph below shows how the PV market has grown over six years, from 1993 to 1999:

Figure 12-17a
Growth of Global PV Market



The following graph shows the main countries that manufacture photovoltaic cells:

Figure 12-17b
Growth of Global PV Market



12.4.6 Forecast - Cost

The average price for energy generated by solar technology is expected to be approximately 4-6p/kWh by 2020. If solar generation techniques could reach this price, then solar technology would be able to compete with other technologies in the Renewables Obligation.

One of the main influences on the PV system is the effect on the distribution system. As a PV system generates on-site, emission free electricity, transmission and distribution losses are negligible. Yet if there were a lot of on-site generation, it would require a lot of change to grid support, and the Distribution Network Operators would incur large additional costs.

12.4.7 Future

The British government has approved the first projects under its £20 million 'Major Photovoltaic Demonstration' program. Eight medium and large-scale projects, representing a total PV capacity of 350 kW, will share £1.32 million from the Department of Trade & Industry. The £20 million for the first phase of the program was announced in March, but the government has already provided £5.4 million to develop 500 solar-powered homes and £4.2 million for 18 solar powered public buildings.

12.5 Stirling Engines

12.5.1 Introduction

The Stirling engine is an engine that is very different from the internal-combustion engine. Stirling engines are used only in some very specialised applications, like in submarines or auxiliary power generators for yachts, where quiet operation is important. Stirling engines are classed as external combustion engines. They are sealed systems with an inert working fluid, usually either helium or hydrogen. In its simplest form the Stirling engine comprises a cylinder, regenerator, piston and displacer, however, units with outputs higher than ~1kWe tend to be multi-cylinder. Stirling Engines are generally found in small sizes (1 - 25 kW) and are currently being produced in small quantities for specialised applications.

Figure 12-19
Stirling Engine



Fuel is burned continuously outside the engine to maintain the upper-cylinder at high temperature while circulating water around it cools the lower end. Power is derived from the pressure swing as a fixed quantity of gas (generally air, nitrogen or helium) is alternately heated and cooled, forcing it back and forth between the two temperature zones, via the regenerator. The displacer moving approximately 90° in advance of the working piston moves the gas. The regenerator is a heavy matrix of fine wires that acts as repository for heat during the cooling pass, to be returned on the heating pass. Based on this concept there are many different combinations, all either Kinematic or Free-Piston Stirling Engines (FPSEs). FPSEs are single-cylinder machines that tend to be small and are used in micro-CHP technology.

Table 12-8
Characteristics of Stirling Engines

Size Range	<1kW-25kW
Fuel	Natural Gas primarily but broad fuel flexibility is possible
Efficiency	12-20% Target:30+%
Environmental	Potential for very low emissions
Other Features	Cogen (some models)
Commercial Status	Commercial availability 2002-2005

12.5.2 Applications

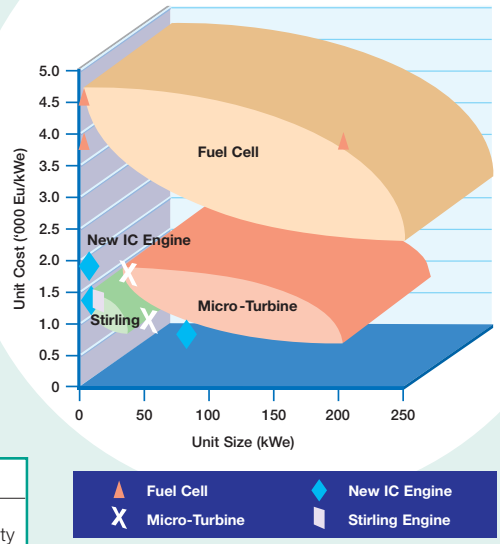
There are wide ranges of applications for Stirling engines with development occurring in several key areas. Residential or portable small-scale power generation is an area where these engines could compete, and engines are being developed to provide cooling for equipment such as microprocessors and superconductors. Submarines have been using Stirling engines for some time due to their low noise levels when running.

12.5.3 Cost

Capital costs of Stirling engines ($2,000-$50,000/kW) are relatively high, meaning they find it hard to compete with other technologies. The high capital cost can be attributed to a lack of mass production. Because of the nature of the engine, some components are very expensive.

High temperature heater head assemblies require large surface areas, and must be made from exotic materials that are particularly difficult to machine, braze and weld. The cooler section also requires large surface areas to allow for sufficient heat transfer with minimal void volumes.

Figure 12-20
Actual Current Cost/Size Map for Mini-CHP



The regenerator assembly has a need for very fine mesh heat-transfer matrices that can operate near heater head temperatures, and therefore requires high-temperature materials. The most expensive Stirling engines are for specialised uses (e.g. space). Research and development is ongoing into new materials and design improvements and the aim has to be to lower the cost of the engines.

Figure 12-20 shows how the cost can vary with size for CHP units using Stirling engines, compared to other technologies.

12.5.4 Advantages

There are several advantages in using Stirling engines. The engine operates with relatively few moving parts. This makes it easy to maintain and allows for quiet and low vibration operation. Low emissions from the engine and a high overall efficiency should make it more appealing to companies and the government, as it could help them deliver the UK's Climate. Change Programme via a large-scale roll out of residential CHP boilers. Stirling engines are efficient down to sub kW_e levels, and have multi-fuel capability.

12.5.5 Disadvantages

The reputation for high costs has prevented the Stirling engine from becoming more widely used. Doubts over their power output capability has also contributed to the problem. Also, the engines inability to modulate output and the length of time and power input required to start the unit are not helping the commercialisation of these engines. Research and development in this field has helped manufactures overcome these problems and engines are now beginning to reach performance figures that should be acceptable in some applications.

12.5.6 Non-domestic CHP (mini-CHP)

Stirling engines have the capability to meet the requirements of mini-CHP. They operate without valves or an ignition system, and in some cases without oil lubrication, thus permitting long service intervals and low running costs. Stirling engines can maintain reasonable efficiencies even at small-scale. Stirling engines today tend to be sized at the lower end of the mini-CHP range, generally under 25 kWe.

Modern Stirling engines can run at a similar speeds to Internal Combustion (IC) engines and, like their IC counterparts, tend to operate at lower speeds for CHP applications to extend operating life. In practice most kinematic Stirling engine micro-CHP systems run at 1500 rpm driving 4-pole generators to deliver power at 50 Hz. Of all reciprocating engines, Stirling engines appear best suited to small-scale CHP applications.

12.5.7 Micro-CHP

Table 12-10 lists the technical capability of companies that are leading contenders in the micro-CHP market.

Table 12-9
Comparison of Significant Stirling Engine Developments

Engine	Cylinders	Power [kWe]	Electrical Conversion (LCV)	Heater Temp. [°C]	Gas
WhisperGen PPS16AC	4	0.75	10%	650	N_2
SunPower/BG RE100	1 FPSE	1.0	28%	550	He
STC/ENATEC RE100	1 FPSE	1.0	23%	650	He
SIG1 (Switzerland)	1.0 FPSE	1.2	15%	650	He
Sigma PCP1-130	1	3.0	23%	700	He
Solo 161	2	3-10	30%	650	He
Kawasaki Model V	1.0 FPSE	1.2	27%	(650)	He
Mitsubishi NS-03M	1	3.8	36%	(780)	He
Toshiba NS-03T	2	4.1	34%	(820)	He
Tamin TESE004	1	1	(22%)	650	Air

Table 12-10
Leading Companies in Micro-CHP Production

	Cylinders	Gross Elec. Output	Overall Eff. (LCV)	Net Elec. Conv. Eff.	Net Thermal Output
Microgen	1	1kW	-	28	15kW
ENATEC	1	1kW	28%	-	14kW
SIG-SEM	2	-	23%	-	6kW
Sigma PCP 1-3CA	1	3kW	96	23	9kW
Whisper Tech PPS1 6AC	4	0.75kW	-	-	6.2kW

Figure 12-21
Whispergen Stirling Engine



12.6 Wave and Tidal Energy

12.6.1 Introduction

The main obstacle for wave and tidal energy is the cost per kWh produced. The equipment needed for tidal power may damage the environment; also there is a lack of efficient air turbine generation systems for waves. To overcome these obstacles, research needs to be carried out on new generation devices.
The installation of new under-water transmission lines would also benefit matters.

12.6.2 Technology

Tidal Power

To produce electricity from the tides, an area of water is sealed off and the large quantities of water that come in and out are used to generate electricity. This is a well-established technology in operation in several countries.

Wave Power

The kinetic energy in the waves is converted to electrical energy on floating platforms via air turbines. This technology is mainly being developed in Europe and Japan. Wave energy generation devices fall into two general classifications, Fixed and Floating.

12.6.3 Generating Devices

Fixed generating devices

Fixed generating devices, which are mounted either to the seabed or shore, have some significant advantages over floating systems, particularly in the area of maintenance. However, the number of suitable sites available for fixed devices is limited. LIMPET (Land Installed Marine Powered Energy Transformer), the world's first commercial wave power station, has been connected to United Kingdom's national grid.

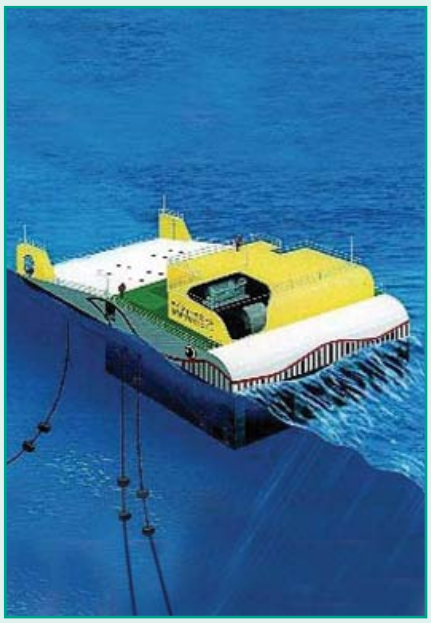
Figure 12-22
Limpet Wave Energy Turbine



Located on the Island of Islay, off the West Coast of Scotland, the site will generate 500 kW. The company feels offshore is the way forward, because waves are more powerful before they hit land. There is a bigger market for offshore wave power, as more power can be generated, and it has a lower visual signature.

Much research is occurring internationally to develop oscillating water columns, including the OSPREY and floating columns, such as the Japanese Mighty Whale, (see figure 12-23).

Figure 12-23
Japanese Mighty Whale



Researchers at Lancaster University are developing an offshore wave-powered electricity system, the Frond Wave Generator. A floating paddle-like collector surface is located on the end of a long lever to capture wave movement due to its buoyancy.
The lower end of the lever drives a hydraulic power system that is fixed to the seabed, and the floating section can rotate to face prevailing waves at all times.
The manufacturers responsible have also launched the Stingray tidal power generator off the coast of the Shetland Islands.

Another technology, the TAPCHAN, or tapered channel systems, consist of a tapered channel that feeds into a reservoir that is constructed on a cliff. The waves increase in height and enter the reservoir. The stored water is then fed through a Kaplan turbine. Unfortunately, TAPCHAN systems are not suitable for all coastal regions.

Floating Devices

Ocean Power Delivery (Edinburgh) is developing Pelamis, a 750 kW floating offshore device. OPD plans to deploy its device in 2002, and it is presently taking forward research and development projects to reduce risk and tackle areas of outstanding uncertainty to maximise the opportunity for a successful Scottish Renewable Orders project. OPD plans to evaluate a 1/7th-scale model in the sea later this year.

The Salter Duck, Clam, Archimedes wave swing and other floating wave energy devices generate electricity through the harmonic motion of the floating part of the device, as opposed to fixed systems which use a fixed turbine which is powered by the motion of the wave. In these systems, the devices rise and fall according to the motion of the wave, and electricity is generated through their motion. The Salter Duck is able to produce energy extremely efficiently, however its development was stalled during the 1980s due to a miscalculation in the cost of energy production by a factor of 10 and it has only been in recent years when the technology was reassessed and the error identified.

Figure 12-24
Archimedes Wave Swing



12.6.4 Current Status

Wave

Costs of wave power equipment are significantly higher than wind generation plants, due to the developmental nature of the plant. It is however felt possible that costs could ultimately fall to a similar level to smaller wind plants. The current status of these technologies is fairly advanced.
There are several fully operational demonstration and commercial plants for both tidal and wave electricity generation.

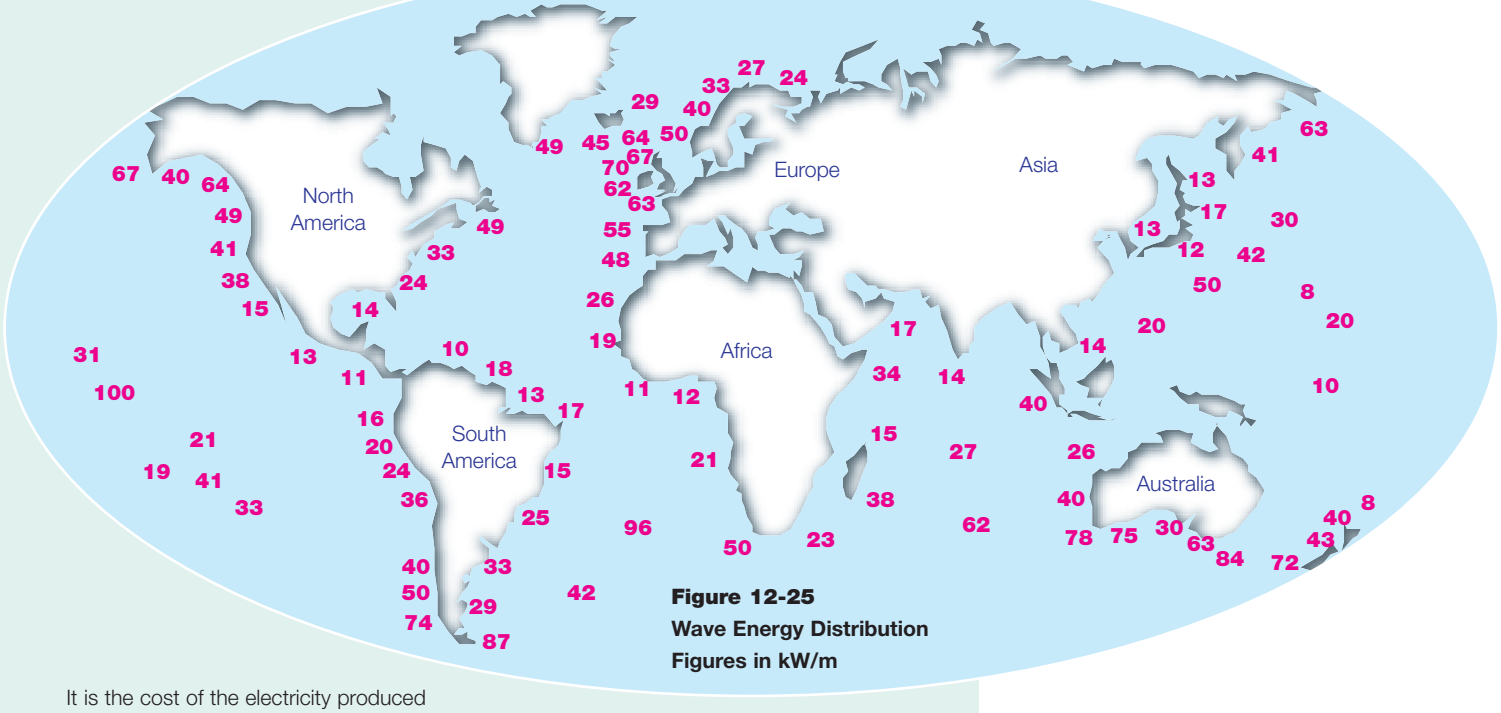


Figure 12-25
Wave Energy Distribution
Figures in kW/m

It is the cost of the electricity produced that is preventing this power source from competing with fossil fuels. Under the third Scottish Renewable Orders there are currently 3 wave energy projects contracted for a declared net capacity of 2 MW. Unfortunately under the fifth Non Fossil Fuel Obligation (NFFO) in England, Wales and Northern Ireland there are no wave energy projects in 2002.

There are several advantages for wave energy production. Wave energy doesn't create or emit greenhouse gases. The production of electricity by waves is not affected by changes in the weather, is predictable and is in phase with seasonal demands, i.e. more electricity produced in winter.

Tidal

Several devices have been proposed, yet there is no agreement on the best design. Tidal generation devices do work, it is finding the method of generating electricity that is cheap enough to compete with other generation sources that is proving difficult. There is currently very little information on long-term operating figures and little operating experience to give evidence whether one system works better than another does. The most advanced tidal generator concept is that proposed by Marine Current Turbines Ltd. (MCT). MCT propose to demonstrate its concept at~300kW scale near Lynmouth in North Devon. European Commission (EC) funding has been given and MCT is preparing a proposal for further DTI funding to this scheme. This project should help us understand the commercial challenges and outlooks for this specific device.

Independent studies on the MCT concept have shown that predicted energy costs from it could be between 3.4p/kWh (5% discount rate) and 6p/kWh (15% discount rate). This is a lot lower than earlier estimates of the price of electricity from tidal technologies. At these prices, tidal energy could become, or would be close to being, economically viable within the Renewable Energy Obligation. These predictions now need to be verified through a demonstration project. Even if these predictions are verified, tidal technology devices would still not be truly commercially competitive with electricity supplied from the grid at today's costs; further development would be required to achieve true commercial competitiveness with the grid today.

The United Kingdom has the potential to produce all of its electricity by harnessing just 0.1% of the energy of its shores due to waves, according to a European Commission Study. The wave power levels in the UK are among the highest in the world.

12.7 Wind Energy

12.7.1 Introduction

Wind power has become economically viable in the last few years in some regions due to advances in technology. Electricity is generally generated from wind by a horizontal axis system with the alternator being linked directly with the rotor.

Electricity generation from wind is still very much in the demonstration and investigation stage. Time is needed to see if the techniques being used are correct for different environments, and the cost is still a problem, as is linking the turbines to a grid system. The unreliability of using a source such as wind means this technology may not be suitable for many communities, and the need for electrical storage for those not connected to a grid poses a major hurdle. However, the UK has some of the best wind profiles in the world, making it an ideal testing ground for this rapidly advancing technology.

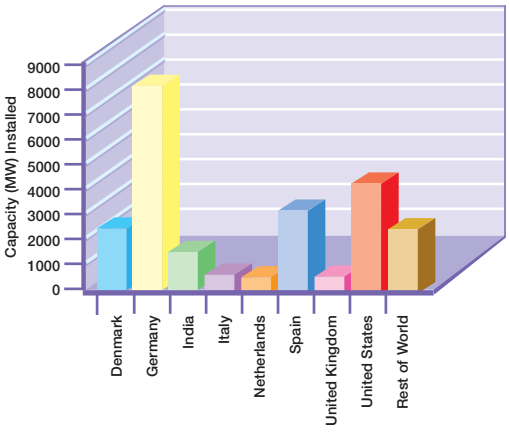


Figure 12-26 Typical Wind Farm

12.7.2 Technology

Of all the renewable energy production techniques wind is the most cost effective in terms of £/kWh. Almost all countries can exploit wind power and it can be used to serve remote communities. Below shows the installed wind capacity of the leading wind generation countries around the world:

Figure 12-27
Installed Wind Capacity in January 2002



12.7.3 Current Status

Denmark has traditionally led the market in the manufacture of wind turbines. There were 13 turbine manufacturers in Denmark in 1997. Wind turbines can range from those in the low kW area right up to 3 MW turbines. The commercialisation of larger units has been delayed due to the lack of demand from the electric utilities. There is a need to produce standard equipment in this generation system and new storage systems are required to accompany the turbines. This would help reduce the capital outlay and make wind generation more financially sound. Further economic incentives made by the government to electric utilities to use wind energy would help this technology.

Running and Costs

Modern wind turbines are expected to run for about 12,000 hours, and are designed to last approximately 20 years. The average price for a fully installed wind farm is £640/kWe. The time taken to service the turbines is very small and done when the turbines are not in use (no wind). The newer equipment has lower maintenance costs of around 1.5% - 2% per year of the original investment.

The standard turbines used are the 600 and 750 kW machines, although the bigger megawatt machines are used where area for the turbines is limited, or offshore.

Capacity

Figure 12-28 shows the trend in installed wind capacity and generation in the UK in the last six years. As can be seen there is a steady rise in both.

On-shore wind turbines have a declared net capacity of 0.43 in the UK This means that a 1MW turbine would be expected to make, on average, 430 kW of electricity every hour. No figures are available for offshore units.

In 1999, the wind capacity in the UK was nearly three times the capacity in 1994, while electricity generated from wind has increased by more than threefold over the same period. This is attributed to improvement in technologies together with the better siting of wind farms.

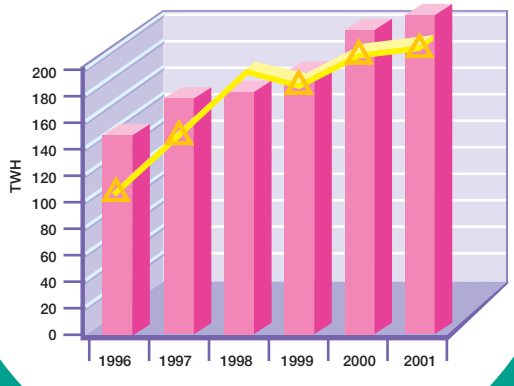
Figure 12-29 shows a comparison of average growth rate per year between different technologies. As can be seen wind technology is growing faster than any other sector, with solar photovoltaic technology also growing rapidly, in second place. As can be seen from Figure 12-30, the number of contracted projects for wind power has steadily risen every year. Projects contracted within NFFO account for roughly half the total installed capacity in the UK, but this value does fluctuate as contracts expire.

Figure 12-31 shows the amount of energy produced from wind power in terms of thousand tonnes of oil equivalent:

12.7.4 Future

British energy supplier Bizzenergy has created a new company to raise £50 million to build six wind farms with 100 MW capacity. Most of the facilities will be situated in western Scotland, with the first expected to be in operation within 18 months.

Figure 12-28
Total UK Installed Wind Power Capacity and Generation



The Renewables Obligation forces electricity companies to supply 10.4% of their power from renewables by 2011.

Utilities in Scotland have already announced investment plans of £1 billion in renewables over the next decade, and 5,000 new wind turbines are planned in addition to eleven wind farms currently in operation.

The British government has approved the largest offshore wind farm in the country, to be based 7 km off the North Wales Coast. National Wind Power Ltd will construct the North Hoyle facility by autumn 2003, with 30 Vestas turbines and a total capacity of up to 90 MW. The future growth of wind energy is difficult to predict, but it is fairly certain the UK will see a substantial increase in its use. Figure 12-32 shows the IEA's prediction for wind energy.

12.8 Market Evaluation

This section looks at the maximum potential markets for the emerging technologies covered below. In many cases figures are given also for likely penetration of those markets, but only where that information is readily available. Finally a brief section on market penetration problems aims to list those issues other than interconnection where difficulties are likely to be found.

12.8.1 CHP

12.8.1.1 Current Installed Capacity

The installed capacity and the amount of electricity generated by CHP schemes in 2000 in the UK, Germany and the EU are shown in Table 4.1[1,2,3]. In absolute terms, there is more cogeneration capacity in Germany than in the rest of Europe, though Germany is close to the EU average of around 11%. There is currently 4.6 GW_e of installed CHP capacity in the UK, which represents around 6% of the country's total generation capacity.

Over the last decade, capacity in the UK has more than doubled, representing an average growth rate over the period of 7% per annum. A growth rate of 9% was achieved in 1999 with a net increase in capacity of 354 MWe (this breaks down as 414 MWe of new capacity added while 60 MWe was retired) - a significant improvement compared to recent years. Growth depends on the rate of retirement of old plant as well as the rate at which new plant are built.

Table 12-11
Installed Cogeneration Capacity and Electricity Generation in 2000

	Installed Electrical Capacity		Electricity Generation	
	CHP Capacity (GWe)	CHP Share of Total Capacity (%)	Generation from CHP (TWh)	CHP Share of Generation (%)
UK	4.6	6	23.3	6
EU-15	73.6	11	29.4	10

The European Commission set a target in 1997 to double cogeneration from 9% to 18% of total EU electricity generation by 2010 (Ref. 4.2). In 2000, electricity from CHP schemes accounted for an average 11% of gross electricity production in the EU (Ref. 4.2). Countries with a high proportion of CHP electricity are Denmark, the Netherlands and Finland with around 62%, 53% and 36% of gross electricity production respectively (Ref. 4.3). However, in Germany the amount of cogeneration has fallen in recent years, due to reductions in energy costs because of liberalisation of energy markets.

12.8.1.2 Projected Cogeneration Capacity

The prospects for CHP growth in 28 countries across Europe have been examined in the recent 'future cogen' project (Ref. 4.2). Four different future scenarios were modelled as follows:

Present policies - current energy policies continue, particularly those affecting CHP, including changes expected. Energy sector liberalisation in Europe is expected to be complete by 2010.
Technology developments are evolutionary, not revolutionary.

(1) *Heightened environmental awareness* based upon present policies, but with extra benefits for 'green' technologies. This involves including the external benefits of CHP through the introduction of a carbon tax and faster technology developments.

(2) *Deregulated liberalisation* involves continued liberalisation of European energy markets, but with no incentive for smaller decentralised generation. Consequently, a few centralised generators, who strongly influence electricity prices, will dominate the electricity market. The result is that CHP becomes un-competitive, with plant being closed, leading to less CHP out put. This is the worse case scenario.

(3) A post-Kyoto world where CHP benefits are fully included in the technology cost. Micro-CHP becomes technically and economically feasible, and fuel cell CHP becomes possible, with increased investment into 'cleaner' technologies in a world tied to Kyoto. Flexible mechanisms, such as emissions trading and Joint Implementation, provide new finance for CHP. Economic and energy policies are focused on decentralised generation and Europe achieves major environmental benefits from increased generation mix efficiency. This is the best case scenario.

The results from the model for the UK and the European Union are summarised in Table 12-12. It should be noted that scenario 4 assumes the wide-scale uptake of micro-cogeneration. However, it is only under this scenario that significant growth occurs and the European Commission's target of 18% electricity generation from CHP by 2010 is achieved.

12.8.2 Fuel Cells

Markets such as portable applications and battery replacement, where a high cost per kWh of energy is prevalent, hold some of the largest, near-term potential markets for fuel cells. Buses and cars have the potential for a huge, longer-term fuel cell market, and most automobile manufacturers have an R&D scheme in place. Significant sales are expected to be in place around 2010, with the market at around $10 billion.
It is believed that fuel cells can make a contribution to energy production in the UK in the medium-term.

Figure 12-29
Global Trends in Energy Use (1990-1999)

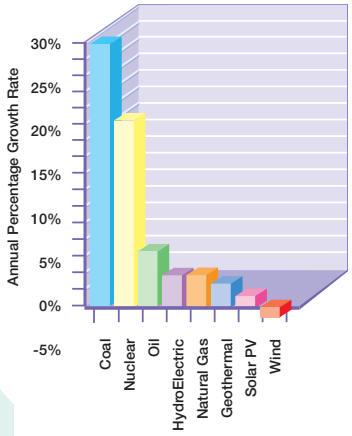


Figure 12-30
Contracted Projects for Wind Generation in England and Wales

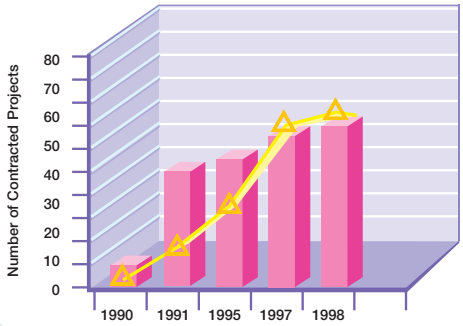


Figure 12-31
Total equivalent Energy Produced from Wind Power in the UK

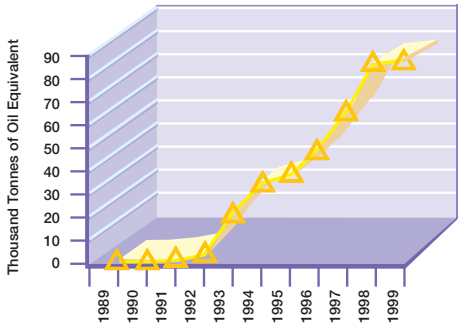


Figure 12-32
Forecast Wind Capacity and Electrical Generation in OECD

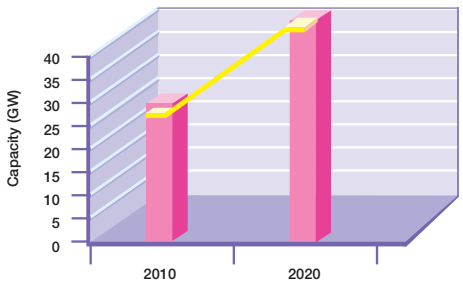


Table 12-12
Forecast CHP Capacity (GWe) under Different Scenarios [12.2]

	Scenario 1: Present Policies				
	2000	**2005**	**2010**	**2015**	**2020**
UK	4.6	5.4	6.5	8.1	10.6
EU-15	73.6	76.7	80.6	88.6	94.7
	Scenario 2: Heightened Environmental Awareness				
	2000	**2005**	**2010**	**2015**	**2020**
UK	4.6	6.3	8.8	11.5	15.3
EU-15	73.6	80.3	90.7	105.3	124.3
	Scenario 3: Decentralised Liberalisation				
	2000	**2005**	**2010**	**2015**	**2020**
UK	4.6	5.0	5.1	6.2	7.5
EU-15	73.6	71.2	69.6	73.5	81.4
	Scenario 4: Post-Kyoto				
	2000	**2005**	**2010**	**2015**	**2020**
UK	4.6	8.3	15.9	22.2	27.2
EU-15	73.6	87.9	134.8	166.1	194.8

The UK has green house gas commitments, and fuel cells could play a major role in meeting these.

Problems associated with this technology are:

- Cost
- System complexity and the need for reformers in many applications
- Commercial and financial risks

12.8.3 Micro-turbines

Like fuel cells, the transport industry is a large potential market for this technology, particularly with the arrival of hybrid vehicles. However, in the near-term, micro-turbines are likely to be limited to niches in the market where they offer a distinct operational advantage. They would be suited in countries with a large difference between electricity and gas. This technology is also capable of produce high-grade waste heat, making it highly beneficial to the combined heat, power and cooling market.

Problems associated with this technology are:

- Noisy
- Designed to run once per day
- Not designed for repeated start/stops

12.8.4 Solar Cells

The rate of growth of this renewable technology depends on two issues: Discussions across Europe and the USA on market support mechanisms and advancement in technology. The largest potential market for PV lies within the buildings and utility segment, and the Rural Off-Grid sector is also a major potential market.

Generation from the use of solar photovoltaic in the United States is forecast to increase by 26.7% a year over the next 25 years, according to the US Department of Energy. PV output will rise to 880 GWh by 2025, from 40 GWh in 2002. Utilities and private power producers will increase generating capacity of PV from 20 MW in 2002 to 360 MW in 2025, representing an annual increase of 13.9%[12.4].

Problems associated with this technology are:

- Cost primarily
- Unreliable in some cases
- Storage system may be required

12.8.5 Stirling Engines

A large market for Stirling engines lies in the residential or portable small-scale power generation area. The marine area has consistently provided a steady market for this technology and the cooling for equipment such as microprocessors and superconductors is another potential market. Market sizes for CHP are covered in section 4.1.

Problems associated with this technology are:

- Reputation for high costs
- Doubts over power output
- Inability to modulate output
- Length of time and power input to start the unit are poor

12.8.6 Wave and Tidal Energy

Currently the high cost of equipment, and high cost of electricity produced, is preventing this technology from competing with fossil fuels. The latest concepts in tidal technology do allow energy to be produced for 3.4 to 6p/kWh and at these prices tidal energy would be close to being economically viable with the Renewable Energy Obligation.

A recent report has however recommended that Britain should re-consider an 8 GW tidal barrage, as declining costs have made a tidal barrier in England worth reconsidering. The report claims it would cost £6.2 to £8.4 billion to build an 8,640 MW tidal barrier across the Severn Estuary, which could generate 6% of England's electricity[12.5]. That is 40% less than the cost forecast 16 years ago.

True competitiveness with today's grid would require further reduction in cost. However, wave power levels in the UK are among the highest in the world and the UK is therefore one of the most promising markets.

Problems associated with this technology are:

- Cost of equipment and electricity produced

12.8.7 Wind Energy

The UK has some of the best wind profiles in the world, giving it a large potential market for wind generation technology. Wind is the most cost effective of all the renewable technologies considered here, and because of the ability of every country to exploit wind power, it has one of the largest markets. Wind is the fastest growing technology, with an average growth rate of nearly 25% between 1990 and 1995. The Renewables Obligation forces electricity companies to supply 10.4% of their electricity power from renewables by 2011 and wind could be responsible for a large quantity of this.

The global market for wind turbines is forecast to surpass US$16 billion by 2007. A total of $5.5 billion was invested in new large turbines around the world in 2001 and in 2002, and a new report predicts that the global market will grow at an average annual growth rate of 24% to reach $16 billion by 2007[12.6].

Problems associated with this technology are:

- Unreliable
- Electricity storage may be needed

12.9 Other Problems

All generation technologies suffer from interconnection problems. A list of typical connection problems is given below:

- The cost of interconnection
- Synchronisation to the grid
- VAR Control
- Effect of harmonics (c.f. power electronics interface)
- Protection requirements (O/U voltage & frequency, LOM, reverse power)

Traditionally, a connection "box" has been required to deal with the technical issues. Such boxes are expensive, and require individual approval from the local electricity distributor. In the future some smaller systems may use simpler, cheaper equipment – see section 3 for more details.

12.10 Legislation

There is a significant amount of legislation and guidance notes that have affected the installation of newer alternative technology generation plant. This section aims to cover areas where such issues have not only hindered, but also helped with their introduction. This section does not cover governmental issues such as OFGEM, NETA and renewables legislation.

Legislation is currently focused on reducing emissions of greenhouse gases and other harmful emissions. As regards generation, reduction of CO2, NOx and SOx is fundamental to policy though other emissions do not escape attention. In particular, the UK has a legally binding commitment under Kyoto protocol to reduce greenhouse gas emissions by 12.5% by 2008-2012 against the 1990 levels and a domestic goal of reducing CO2 emissions by 20% by 2010. In addition, the UK has introduced a climate change levy, which is based on energy rather than carbon content of fuels, and will not be imposed on households. This approach is unlikely to encourage less carbon-intensive fuels.

Aside from these governmental drivers, the issue of electrical interconnection is likely to be the main issue for installation of plant. CE marking is also covered, as it is both a barrier for introduction, but also a safety screen for customers.

12.10.1 Electrical Interconnection

The main issue affecting the introduction of new emerging technologies is that of electrical interconnection to the network.

The existing guidelines, G59/1, which are accepted by network operators, apply to plant of 5 MWe (MW electrical) or less, and refer primarily to rotating plant. The constraints applied by these guidelines are generally considered to be far too onerous for smaller plant of under say 50 kWe, and especially for residential generation at around the kilowatt level. As a result, two new sets of recommendations have been written:

G77: Photovoltaic plant under 5 kWe (planned to be replaced by G83)

G83: Small generating plant up to 16A per phase (Issued 2002)

Engineering Recommendation G77 has been published by the Electricity Association to provide simplified guidance for the connection to the mains power network of small PV generators on domestic residences. G77 covers the connection of inverter-connected single-phase PV generators up to 5kVA to public distribution networks. Its aim is to encourage the use of 'approved' inverter equipment and recognised connection procedures in order to lessen the need for DNO (Distribution Network Operator) personnel to perform local tests. It doesn't cover practical or safety issues. (The DTI has recently published a Guide to the installation of PV systems that does cover practical and safety issues.) Although G77 is only a 'recommendation' and therefore not mandatory, it has been agreed by all the DNO companies. Applications that stick to G77 are likely to be processed more quickly.

From G77, G83 was developed to cover domestic interconnection in general. Whilst G83 has now been issued, it has not yet replaced G77 as of the beginning of 2003. When this does happen, it is believed G83 will be reissued as G83/1. The introduction of these guidelines should greatly assist the introduction of smaller generating plant. Previously the cost of complying with G59/1 could be almost as much as the cost of the small generation plant. It is now believed that this cost should be cut substantially. It is also believed that up to 2 consortiums may be attempting to develop a low cost interconnection device for smaller plant.

12.10.2 CE Marking

The manufactured unit when sold into Europe should be marked with a CE mark.

Essential requirements for this are compliance with the Machinery Directive, the EMC Directive and the Low Voltage Directive. In addition, the manufacturer should keep a technical file, risk assess the equipment and address any problems, and finally should produce a statement of conformity. Compliance with the three directives listed above is compulsory, so minimal extra work should be required to achieve conformity, with the onus on the manufacturer or importing agent to show that conformity.

The mechanical design is primarily covered by "The Supply of Machinery (Safety) Regulations", which implements "The Machinery Directive". It covers a wide range of health and safety requirements from design, to maintenance and operating instructions. Most machinery supplied in the UK must comply with its requirements, and generation plant should be expected to be included in this. Guarding should conform to the guidelines given in BS EN 292 "Safety of Machinery", and the manufacturer should risk assess the plant as shown in BS EN 1050, "Safety of Machinery". In addition, the site operation of the plant must also be risk assessed before operation, and the manufacturer should maintain a technical file, detailing calculations and other technical information.

The precautions necessary to avoid danger from electrical systems, equipment and apparatus are entailed in the Electricity at Work Regulations 1989. The onus of these regulations is to assess the activities that use electricity and to define all foreseeable risks. All electrical equipment must therefore be designed, constructed, installed and tested to meet the technical requirements of the Electricity at Work Regulations, the Low Voltage Directive and the Electromagnetic Compatibility (EMC) Directive. In addition, wiring should conform to the Institution of Electrical Engineers (IEE) Wiring Regulations 16th Edition 1992.

Whilst the regulations above may sound onerous, compliance with them should be fairly straightforward if safe and sound design practices have been used throughout. The main burden will be the cost of CE marking assessment by third parties. Whilst this is a real cost, the achievement of a CE mark can be beneficial as a marketing tool to show how far advanced the equipment is.

13

The Role of Effective Energy Efficiency

Energy efficiency became an increasing part of the collective consciousness with the OPEC oil embargo in 1973, when both politicians and average citizens realised the economic importance of energy (as well as the risks associated with foreign oil dependence). Following the Rio Earth in 1992 the world in general embarked on a global effort to address the damaging effects of climate change, caused in the main by the inefficient use of energy, primarily that in transport (cars etc.) and in electricity generation and utilisation.

Many organisations have been set up, both nationally[13.1] and internationally[13.2], in an effort to address the damaging effects of climate change (for more information on this please see Chapter 10).

For example the current priorities of the Energy Saving Trust[13.1] are:

- To stimulate energy efficiency in UK households and achieve social, economic and environmental benefits
- To create a market for clean fuel vehicles which will deliver local and global environmental benefits
- To stimulate a market for renewable energy which will achieve social, environment and economic benefits.

The main reason for focusing on energy efficiency is that, for example, an inefficient process may use twice as much energy as an efficient process, and every additional unit of energy consumed results in power station needing to burn more fossil fuels in order to generate it. Therefore by reducing the amount of energy required, we can reduce the requirement for (additional) power stations and reduce the damage inflicted on the environment. For example, one quarter of the UK's carbon dioxide emissions every year originates from the energy we use to heat and light our homes and run an increasing number of household appliances[13.1].

In fact the average home emits more carbon dioxide (in the UK) than the average car.

There are three levels at which the message of energy efficiency is being directed, and each of the three levels has an important role to play. The levels are:

- Government
- Industry (both generating and consumptive)
- Individuals

An energy efficient economy, that is government, individuals and industry can grow without using more energy. For example, from 1970 to 2000, US energy consumption grew by 45% whilst the gross domestic product (GDP) increased 160%. In other words the amount of energy used per dollar of GDP decreased 44 percent from 1970 to 2000[3]. Aligned with that is the fact that using less energy in general produces less emissions, emissions in the US increased 13% by 1999 above the 1990 levels, however, during that same period, energy use increased 14.9%.

Finally, it should be recognised that, on average, energy efficiency and renewable energy schemes create more local employment than large scale power production, making a further difference in the local communities who adopt these schemes.

13.1 The Role of Government

The current UK government is publicly committed to lowering carbon dioxide emissions in order to achieve its 20% reduction target by 2010. There are a number of initiatives being promulgated.

Working with energy suppliers so that they invest around £450 million through the Energy Efficiency Commitment on improving the energy efficiency of their customer's homes by 2005.

- Introduction of the Climate Change Levy. This is where businesses pay tax on their energy use, but those who use renewable energy are exempt from the Levy.
- Introduction of a 'Renewables Obligation' so that all gas and electricity companies must provide 10% of the energy they sell from renewable sources by 2010.
- A promised £100 million in new renewable technology such as that discussed in Chapter 12.
- It has also lowered value-added tax (VAT) from 17.5% to 5% on some energy saving materials; namely insulation and heating controls if professional installers fit those.

13.2 The Role of Industry

Industry uses on average one-third of all the energy used, and some industries, for example, steel production consumes a large amount of energy per unit product. It is in these industries that the focus has been for energy-efficient efforts and programmes.

Apart from the direct introduction of renewable energy schemes (for which the use of combined heat and power has been the most widely accepted) other measures industry can take include the use of energy efficient motors which can save at least 12% of the energy consumed[4].

As over 45% of the fuel burned by manufacturers is consumed to raise steam for one process of another, a typical industrial facility can save 20% or more by improving its steam system. Measures such as insulting the steam and condensate return lines, returning the condensate (i.e. water) to the boiler and even something as immediately detecting and stopping any steam leaks can all contribute to improved efficiency. Optimisation of compressed-air systems which are used by many industry sectors, including tools, as power sources, and equipment used for pressurising, atomising, agitating and mixing can achieve between 20 to 50% energy efficiency improvements.

In general business can take the following actions in order to reduce carbon dioxide emissions.

- Investment in energy efficient fluorescent lighting and knowledge of the optimum way to use it.
- Build or remodel offices using energy efficient materials, insulation and alternative energy sources for the light and heat.
- Plant trees to offset the companies greenhouse gas emissions
- Invest in energy efficient manufacturing processes and equipment
- Use recycled materials where possible. Establish recycling programmes in the workplace.

13.3 The Role of the Power Producers

Many power producers and suppliers have programmes, which encourage their customers to invest in energy efficient products that:

- Lower consumer bills
- Delay the requirement for new generation
- Reduce the emission of greenhouse gases and other pollutants.

However, technologies, which maximise the efficient generation, transmission and storage of energy, are also of fundamental interest. Renewable electricity generating schemes also have the potential to play a major role (these are discussed in Chapter 12). These technologies include:

Superconductivity - these are materials which have the ability to conduct electric current with no resistance and very low electrical losses. They are being examined for application in a number of electrical devices and in electricity transmission as high voltage cables, themselves.

Energy Storage - can improve the efficiency and reliability of the electric utility system reducing the requirements for spinning reserves to meet peak power demands, making better use of the efficiency base load generation and allowing greater use of intermittent renewable energy devices, for example solar energy. Energy storage techniques include utility battery storage, flywheel storage, superconducting magnetic energy storage, pumped hydropower and supercapacitors.

There are other issues, which can positively, impact on an electricity generators efficiency in delivering electricity to customers. These include:

Demand side management, which are actions taken on the customer side of the meter to change the amount or timing of energy consumption. There are a wide variety of actions which can reduce energy consumption and consumer energy expenses.

Distributed generation is where small modular electricity generators are sited close to the customer load which can enable utilities to defer or eliminate costly upgrades in transmission and distribution system upgrades, whilst providing customers with more reliable energy supplies and a cleaner environment.

13.4 The Role of the Individual

As in most issues the individual often feels unable to act so as to make a significant impact on a global theme - however, with energy saving, a significant impact can be, and is made, by the individual household. Things an individual household can do include:

- Undertaking a home energy audit.
- Hand wash the dishes.
- Wash clothes in cold or warm water.
- Turn down the thermostat.
- Don't overheat or over cool rooms.
- Clean air condition filters.
- Buy energy efficient compact fluorescent bulbs for your most used lamps.
- Insulate the hot water heater.
- Install low flow showerheads to use less hot water.
- Weatherproof windows and doors.
- Where possible walk, bike, car share or use public transport.
- Reduce waste, buy goods with minimum packaging, choose reusable over disposable, and recycle.
- Recycle coolant from air conditioners.
- Insulate walls and ceilings.
- Replace windows with best energy saving models.
- As you replace home appliances, select the most energy efficient models.

13.5 Energy Efficiency in the UK

The following information, which focuses on the situation in the United Kingdom, is taken from the March 2002 document issued by AEA Technology Environment and represents an analysis of the energy efficiency trends in the UK[13.5].

The energy intensity of the UK economy has been reducing at the rate of about 1.5% per year since 1950. This trend is due to a combination of factors: improved energy efficiency, fuel switching, and a decline in the importance of energy intensive industries and the fact that some uses, such as space heating, do not increase in line with output. For percentage user consumption, please see Chapter 4 on the UK Electricity Market and note that the figures used in that Chapter relate to primary energy consumption, which makes the demands placed by the transport industry smaller.

Total energy consumption increased by over 7% over the decade. Energy use increased in all major sectors over this period, except industry, which fell by about 8%. Energy consumption in the residential sector increased by 15% between 1990 and 2000, services energy consumption by 6.5% and transport energy consumption by 13.5%.

The Department of the Environment, Food and Rural Affairs (DEFRA) continues to co-ordinate the UK's climate changes programme, with increasing assistance from the devolved administrations: the Scottish Executive, the National Assembly for Wales and the Department for the Environment in Northern Ireland.

A new Carbon Trust was set up in early 2001 to take responsibility for a programme of energy efficiency support measures for businesses.

The UK has a legally binding target under the Kyoto Protocol to reduce its greenhouse gas emissions to 12.5% below 1990 levels by 2008-2012 and a domestic goal of a 20% reduction in CO_2 emissions below 1990 levels by 2010. The policies and measures proposed to achieve these goals are listed in Table 13.1, and some of the key energy efficiency measures are described further below.

Table 13-1
UK Policies and Measures

Policy	Measures/ programmes
To improve business' use of energy, stimulate investment and cut costs.	• Climate change levy package, including negotiated agreements with energy intensive sectors, an Enhanced Capital Allowances scheme and a new Carbon Trust. • Domestic energy trading scheme. • Energy Efficiency Best Practice Programme. • Exemption of good quality CHP and renewables from the climate change levy. • Market transformation measures. • Integrated Pollution Prevention and Control.
To stimulate new, more efficient sources of power generation.	• Obligation on electricity suppliers to increase the share of electricity generated from renewable sources to at least 10% by 2010. • At least double the UK's CHP capacity by 2010.
To cut emissions from the transport sector.	• European level (ACEA) agreements with car manufacturers. • Graduated vehicle excise duty (see taxation). • Reform of company car taxation (see taxation). • Additional expenditure on public transport.
To promote better energy efficiency in the domestic sector.	• A new Energy Efficiency Commitment (successor to the Energy Efficiency Standards of Performance). • New Home Energy Efficiency Scheme in England and similar schemes in Scotland, Wales and Northern Ireland. • Affordable Warmth Programme. • Promotion of new community heating and upgrading of existing schemes. • More efficient lighting, heating and appliances.
To improve energy efficiency in buildings. To ensure the public sector takes a leading role.	• Improvements in the energy efficiency requirements of the Building Regulations. • New targets for energy management of public buildings. • Energy efficiency targets for local authorities, schools and hospitals. • Green travel plans.

The **Climate Change Levy** is a new energy tax applied to the business and public sectors from April 2001 (excluding good quality CHP and renewable energy). Revenue from the levy (expected to be around £1 billion in 2001/02) is being recycled to business via a reduction in employers' National Insurance Contributions and £150 million of additional support for energy saving measures. This additional support takes the form of an Enhanced Capital Allowances (ECA) scheme and the new Carbon Trust. Energy intensive sectors can obtain an 80% discount in levy rates if they agree to meet targets for improving energy efficiency or reducing carbon emissions.

The **Enhanced Capital Allowances Scheme** administered by the Carbon Trust gives 100% first year capital allowances for approved energy saving instruments for businesses, who will be able to take this into account when calculating their corporation or income tax bills.

The **Carbon Trust** was set up in April 2001 to provide a co-ordinated, targeted programme of support measures for businesses investing in energy saving technology and practices. It will recycle around £100 million of climate change levy receipts over three years. It is currently developing its programme, but elements will include:

- A programme to accelerate the take up of existing energy efficiency technologies building on the Energy Efficiency Best Practice Programme.
- The enhanced capital allowances scheme;
- A Low Carbon Innovation Programme to support new and emerging technologies.

The **Energy Efficiency Best Practice** Programme is the UK's main energy efficiency information, advice and research programme for organisations in the public and private sectors. The provision of site specific advice (energy audits) is a growing part of this programme.

A **Domestic Emissions Trading** scheme will begin trading in April 2002.
The Government will provide support to kick start the scheme by providing a financial incentive for companies to take on binding emission reduction targets. Participants will be able to bid in absolute levels of emission reductions at prices set through an auction to be held in April 2002.

The **Energy Efficiency Commitment** comes into force in April 2002 and will ensure electricity and gas suppliers help their domestic customers, particularly the elderly and those on low incomes, to save energy and cut their fuel bills.

The **New Home Energy Efficiency Scheme (HEES)** was launched in June 2000, and provides grants of up to £1000 for households living on low incomes for a range of heating improvements and insulation measures.

The **Affordable Warmth Programme** has been developed in conjunction with Transco and will facilitate the installation of efficient gas central heating systems and insulation in a million homes by the end of 2005 through the use of operation lease finance.

The climate change levy is a major new energy-related tax that came into operation in 2001. This is described in the section on programmes and measures, above. Rates of levy are:

- 0.15p/kWh for gas
- 1.17p/kg (equivalent to 0.15p/kWh) for coal
- 0.96p/kg (equivalent to 0.07p/kWh) for liquefied petroleum gas (LPG),
- 0.43p/kWh for electricity.

13.6 Energy Efficiency Assessment 1990 to 2000

The overall assessment of energy efficiency is presented in this section.

Two general indicators are generally used to characterise the overall energy efficiency trends: primary energy intensity (i.e. the ratio of primary consumption to GDP), and final energy intensity (ratio of final consumption to GDP). Primary intensity provides an assessment of the energy productivity of the whole economy. Final intensity characterises the energy productivity of final consumers only. Final consumption, according to the ODYSSEE definition, excludes non-energy uses.

Figure 13-1 shows a downward trend in both primary and final energy intensity over the whole period 1970-2000. Overall the last decade, primary energy intensity has fallen faster than final energy intensity, and so the ratio of final to primary energy has increased by 7.5%.

The downward trend in energy intensity suggests improvements in energy efficiency, but there may be other underlying effects such as changes in the structure of the economy.

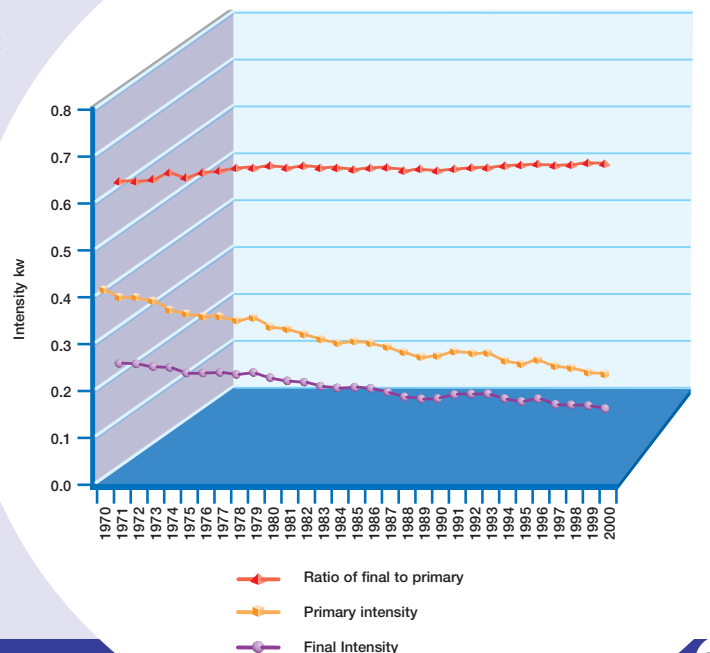
The recent increase in the ratio of final to primary energy may be explained by the increased proportion of energy use by the transport sector. In this sector, there is little consumption of electricity so the difference between final and primary energy use is much less. The efficiency of electricity generation has also increased markedly over the last decade due to the introduction of combined cycle gas turbine plant.
These effects have offset a recent trend towards increased use of electricity in the industrial sector, and increased growth of the services sector.

For **industry** energy consumption has fallen by 4% over the period 1990 to 2000, whilst electricity consumption has risen about 1% per annum. This against a background of growth in the value of the manufacturing industry over the same period.

For **households** over the same period there has been little change per average floor area, if natural fluctuations due to climate conditions are corrected for.

For the **service industry** the value of this sector rose 20% over the period 1990 to 2000, but energy consumption rose by only 7%. Electricity consumption also increased by 20% over this period due to increased equipment uses, therefore any efficiency gains came through better space heating and insulation, and turnover of old buildings.

Figure 13-1
Primary and Final Intensity for the UK, 1970-2000



14

Current Legislation

The following summarises the state of current legislation in the United Kingdom. For details of the privatisation of the UK electricity industry, please see Chapter 4, and for possible future trends, Chapter 15.

This chapter looks at the general position with respect to the Utilities Act, which received Royal Assent in July 2000, and is itself followed by a summary of more recent legislation.

14.1 The Utilities Act 2000

This Act represents one of the most fundamental changes to the regulatory framework for the industry and its structure since privatisation. The most important changes arising from the Act are:

- The creation of a new regulatory authority, the Gas and Electricity Markets Authority, GEMA
- A new consumer body, energywatch
- The separation of supply and distribution businesses
- The new electricity trading arrangements, NETA.

Whilst the Act provides the framework for the industry a significant amount of secondary legislation is also required, after consultation with interested bodies.

Originally the post of regulator was an individuals appointment for the gas and electricity industries respectively, which was then merged. It is now replaced by GEMA which is a corporate body comprising of 5 executive and 6 non-Executive members appointed by the Secretary of State and which determines strategy and decides on major issues. It is supported by the Office of Gas and Electricity Markets (Ofgem) which consults with interested parties on all key regulatory issues.

One of the Authorities key objectives is to protect the interests of the consumers, and also have due regard to the statutory guidance on the social and environmental objectives, and to take into account the broader social policies promulgated by the government.

The Act also established a Gas and Electricity Consumers Council known as energywatch as the primary body for developing and driving the consumer's agenda. It has a particular focus on protecting the disadvantaged.

The act provided energywatch with extensive powers to investigate any matter relating to the interests of consumers and to obtain necessary information. It also has the duty to investigate, seek to resolve and communicate information about complaints by consumers against service providers. It also has a duty to publish information on the performance of licensees against service standards set by the regulator.

Licenses set out the legal restrictions on the electricity and gas businesses and occasionally they may be required to be modified to regulate specific aspects of licensees holders behaviour, for example to increase the interest of consumers, or to reflect market changes. In the past several types of licenses were in existence, and they were unique and specific to the licensees. The Act introduced the concept of standard licence conditions with the intention being that all holders of a particular licence type are subject to the same conditions as far as appropriate. There will be clearly delineated groups of license for example, for generation; there is a set of conditions, which applies to Scotland and another applying to England and Wales.

The Act also separated supply and distribution activities, which were permitted to operate together in the past. The Act makes electricity supply and distribution activities separate licensable activities with a bar on the same person holding both an electricity supply and an electricity distribution licence. In Scotland this has also meant that the composite transmission and generation businesses have had to separate into 2 respective businesses.

The Act also placed an obligation to work towards the Governments social and environmental objectives. The social dimension focuses on a number of groups in society namely the disabled, the chronically sick, pensioners, those on low incomes and those living in rural areas.

The Government has set up a Fuel Poverty Strategy to ensure that by 2010 no vulnerable person need risk ill health due to a cold home. In particular the Government wishes that the benefits of increased competition in the electricity sector are fairly distributed amongst all customer groups and that the poorest should demonstrably benefit.

The environmental objectives relate to the duty to promote the efficient use of electricity and gas and to have due regard as to the impact of licensed activities on the environment. The Government has a commitment to the goals of sustainable development, which includes energy efficacy, the targets for reduction in gaseous emissions and the targets for renewable and Combined Heat and Power.

There has been an Environmental Action Plan recently published by Ofgem and the Government has requested that this is the vehicle by which to progress the environmental aspects of the work. There has been suggestions that Ofgem should focus on the potential for energy efficiency at all points in the energy chain, including electricity generation, transmission and distribution, and should also be in a position to quantify the benefits of any actions. Also mentioned is the need to promote competition in generation and removal of barriers to embedded generation.

However, the Act also makes it clear that although Ofgem has a responsibility to the government's wider policy goals, any implementation of social or environmental measures, which would have significant financial implications for either consumer or for the regulated industries must be implemented by means of specific legislation.

The following are recent legislative events relating to the electricity industry[14.1].

Renewables
On 1 April 2002, the Government introduced an obligation on all licensed electricity suppliers requiring them to supply a specified proportion of their electricity from eligible renewable sources. That proportion will rise from 3 per cent in the current year to 10 per cent by 2010.

Climate Change Levy
In the Chancellor's 2002 Budget statement he strengthened the existing policy to support business energy efficiency by announcing proposals to:

- Freeze the climate change levy rates
- Giving complete exemptions from the climate change levy for electricity generated by good quality combined heat and power (CHP) or from coal mine methane. Implementations of these exemptions are subject to EU State aids approval
- Adding of heat pumps, radiant, warm air and solar heaters, energy - efficient refrigeration equipment and compressor equipment to the list of energy-saving technologies, which can benefit from the enhanced capital, allowances against tax.

This provision is also to be extended to equipment for leasing.

Emissions Trading Scheme
The Government's emissions trading scheme was launched on 2 April 2002. Thirty four organisations successfully bid to join the scheme for permits in an auction for permits held on 11-12 March 2002.

Fuel Poverty
The Fuel Poverty Advisory Group, which had been announced in the November 2001 UK Fuel Poverty Strategy, met for the first time in March 2002. The Group is an Advisory Non-Departmental Public Body sponsored by DEFRA/DTI. Its primary task is to report on the progress of delivery of the Government's Fuel Poverty Strategy and to propose and implement improvements to regional or local mechanisms for its delivery.

The Group consists of a chairman and senior representatives from organisations such as the energy industry, charities and consumer bodies. These members would be representative ex officio members rather than individuals, who should be able to take a broad and impartial view.

In March 2002 the Department for Transport, Local Government and the Regions published revised guidance on the decent home standard and guidance on how social landlords can quantify the extent of non-decent housing within their stock to help them better deal with the problem.

A decent home is one that meets the following criteria:

- Is above the current statutory minimum standard for housing;
- Is in a reasonable state of repair;
- Has reasonably modern facilities and services;
- Provides a reasonable degree of thermal comfort.

The Scottish Executive issued its draft Fuel Poverty Statement in March 2002, inviting comments on the way the Executive plans to tackle fuel poverty in Scotland. Again in March, Ofgem published its second annual report on its Social Action Plan setting out progress towards Ofgem's aim to ensure competition benefits all customers and to develop polices to help the fuel poor.

Energy Efficiency
The Energy Efficiency Commitment is an obligation (expressed as a total energy saving in TWh) placed by the Government on gas and electricity suppliers to encourage and assist their customers to make energy savings through measures such as cavity wall insulation loft insulation, boiler replacement and energy saving light bulbs. Suppliers make a contribution to the cost of the measure at a level that will induce the customer to take it up.

The scheme, which began on 1 April, will run from 2002 to 2005 and the overall target on all suppliers has been set at a level that is expected to lead to estimated ongoing annual energy savings for consumers of around £275 million by 2005. There will be also annual reductions in carbon emissions of around 0.4 million tonnes by 2005.
It is estimated that the scheme will cost energy suppliers around £3.60 per customer, per fuel, each year. The scheme focuses help on the fuel poor and companies will be required to seek at least 50% of their target fuel savings from disadvantaged customers.

CHP
In the Budget it was announced that all CHP generated electricity would be exempt from the Climate Change Levy (CCL). This is a key measure that is likely to help set the sector on course to meet the Government's target of at least 10,000MWe of CHP capacity by 2010.

Previously, only CHP electricity used on site or sold direct to other users had qualified for CCL exemption.

In addition leased assets will now be eligible for Enhanced Capital Allowances (ECAs). This will be very supportive for CHP scheme development. Most CHP developments rely on third party finance, some of which involves leasing the capital assets. Previously leased assets were not eligible for ECAs, so this new measure will provide an added boost for CHP.

Micro CHP
In the Budget domestic micro CHP installed under the Warm Front Team will attract the reduced rate of VAT. VAT on the installation of a range of domestic energy saving products was reduced to 5% from April 2000. Micro CHP is a new technology that we expect to make a significant contribution to domestic energy efficiency in the future. Reducing VAT on the cost of installation will help to give this new technology a useful kick-start.



15 The Future

This chapter examines what may occur in twenty years time, starting with the UK government's vision of the energy system in 2020, and ending with a speculative look at alternative technologies for carbon dioxide reduction.

15.1 The Energy System in 2020

It has been accepted that in order to achieve the requirement for the reduction in carbon dioxide emissions, while at the same time as our indigenous energy supplies decline and the existing energy infrastructure requires updating, there is a need to look forward over the next 20 years. This is in order to have in place the framework capable of delivering our environmental, security of supply, competitiveness and social goals. In reducing the carbon dioxide emissions the government's priority is to strengthen the contribution of energy efficiency and renewable energy sources, while open and competitive markets will remain vital for delivering the required energy.

In order to achieve the above challenges, the UK government has established four goals for its energy policy:

1. To cut carbon dioxide emissions in 2050 by some 60%, with real progress by 2020.
2. To maintain the reliability of energy supplies.
3. To promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve the productivity; and
4. To ensure that every home is adequately and affordably heated.

So what will the energy system look like in 2020? First of all it is envisaged to be more diverse than at present, with a larger number of electricity sources and technologies inputting into the system affecting both the means of supply and the control and management of demand.

- It is thought that the majority of our energy will be imported either from or through an enlarged single European market.
- Whilst the foundation of the electricity network will still be the Grid, balancing the contributions of the large power producers, some of the power will be coming from large off-shore based plants including tidal, wave and wind farms.
- There will be a requirement for backup capacity for when weather conditions reduce or cut off supplies from these generators.
- There will be more local generation using for example biomass or local wind and tidal sources.
- These local generators will feed into local distributed networks, which in turn will feed the Grid.
- Heat will be increasingly co-generated with the electricity.
- There will also be micro-generation from CHP plant, fuel cells or photovoltaics.
- Energy efficiency improvements will reduce overall demand albeit that there is increased new demand for electricity as computers penetrate further the domestic market and air conditioning may become more widespread.
- Buildings will become less dependent on the Grid with perhaps solar panels providing much of the heating. New homes could have zero carbon emissions.
- Gas will still form a large part of the energy mix as savings from more efficient boilers are offset by demand for gas for CHP, which in turn displaces electricity demand.
- Coal fired generation will play a smaller part than today in the energy mix or be linked to CO2 capture and storage if that ever proves feasible either technically, economically or environmentally.



- The existing nuclear power stations will have almost all reached the end of their life - if new nuclear power plant is required to meet the UK's carbon targets, this will be subject to a later decision.
- Fuel cells are anticipated to be playing a greater role in the economy initially as static devices in industry or as a means of storing energy, for example to back up renewables. However, they will eventually be increasingly used in transport. The hydrogen required for their operation will be generated primarily by using non-carbon-based electricity.
- Nuclear fusion will be at an advanced stage of research and development.
- People will generally be more aware of the challenge of climate change and the part they can play in reducing carbon emissions. Carbon content will increasingly become a commercial differentiator as the cost of carbon is reflected in the price of goods and services and people will choose the lower carbon options.

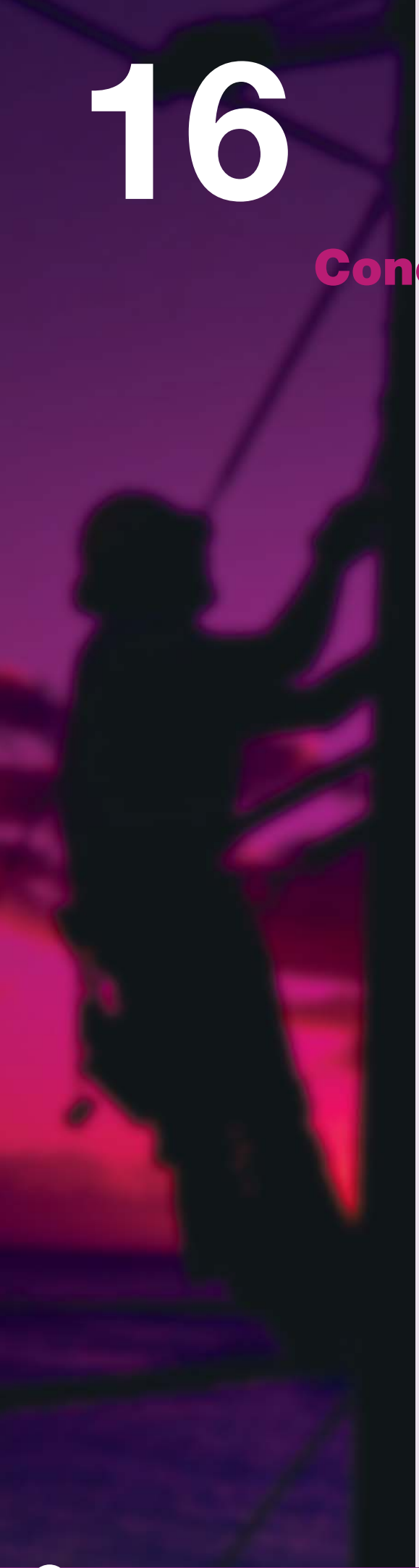
15.2 Alternative Technology Solutions

The following outlines some of the more speculative 'techno-fixes' which have been suggested in order to reduce the amount of sunlight reaching the Earth to remove the heat-trapping gases from the air[15.2]. Please note that these, often extreme, measures have not been evaluated and carry the risk of unexpected environmental side effects.

One proposed solution has been to spread millions of tonnes of iron over the ocean surface, which would stimulate the growth of algae, which in turn would consume carbon dioxide from the ocean surface. The algae would eventually die, sinking to the ocean floor taking the carbon with them, and the ocean would absorb more from the atmosphere to replace whatever the algae took. However, the ocean currents may quickly return the carbon dioxide to the environment and massive amounts of algae may have unforeseen effects on the marine (and human) food chain! An alternative to algae is to grow seaweed to absorb the carbon dioxide - however an area half the size of the United States would be required to absorb 40% of the carbon dioxide emitted at present, with unknown effects on the local ecosystems and local climate.

Another has been for aircraft to release thousands of tonnes of sulphur dioxide into the upper atmosphere every year where it would combine with water to form tiny droplets of sulphuric acid, which would reflect the sunlight. However, this could increase the amount of acid rain and even intensify the destruction of the ozone layer. Likewise a proposal has been made to burn sulphur to make clouds, but this would intensify the potential for acid rain.

Alternatively giant space mirrors could be employed to reflect sunlight away from the Earth (if it was ever technically or economically feasible to do so). If mirrors did not work they could be replaced by billions of reflecting balloons which would block sunlight. Unfortunately there would be a tendency for these to fall to Earth creating a large litter problem!



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Conclusions and Recommendations

The electricity industry plays a central role in the UK economy by producing transforming and supplying energy to all sectors. Electricity consumption as a percentage of the overall final energy consumption has risen year on year since 1970, from 11 to 18% in 2000. Electricity provided 27% of the energy consumed by industry, 21% of the domestic sector energy requirements and 37% of the service sectors total energy consumption.

However, the supply and use of energy is also a major contributor to emissions to the environment. This is not only of the greenhouse gases such as carbon dioxide, acidic gases such as sulphur dioxide and other pollutants associated with poor air quality, the energy industry also directly emits liquid and solid wastes as well as being the major industrial water extractor. Details are contained in the various individual chapters, which examine each primary fuel in turn, and then examine the different inputs and outputs. It is clear that energy use is a major building block in the compilation of any sectorial mass balance and it is anticipated that the information contained in this report will be used in existing and future mass balances within the Biffaward and other schemes, by allowing the energy usage of any process for which a Mass Balance is being performed to be related to a mass of raw fuel input and the associated emissions.

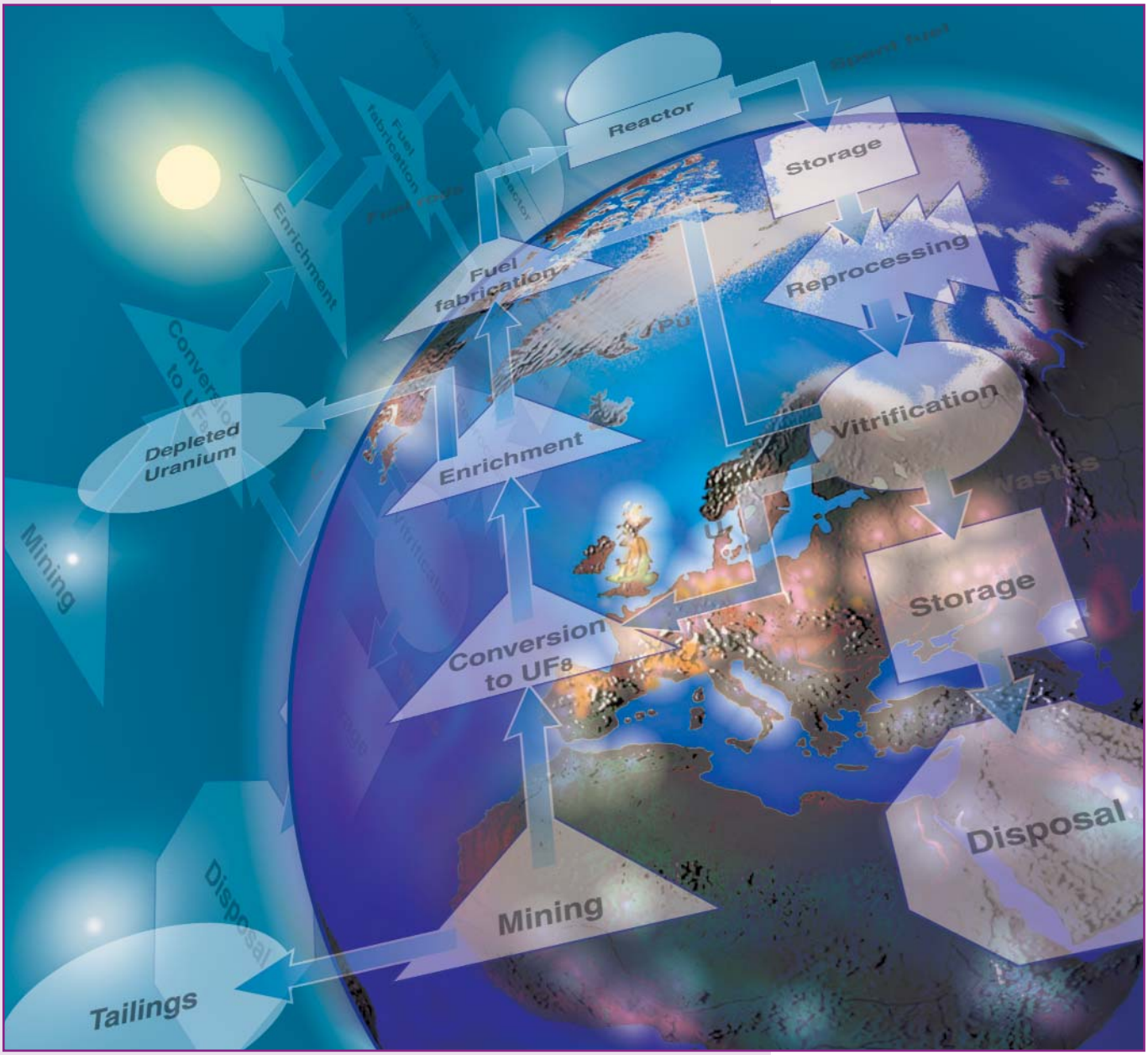
It is further anticipated that the supply and use of energy will continue, and indeed increase in for example, developing countries due to the human desire for heat, light and the ability to perform work. This study evaluated the four main power generation methods, namely the use of oil, gas, coal and uranium to produce electricity via the heating of water. The different power generation methods produce different emission levels depending primarily on the input fuel and the overall process efficiency. This leads to the least emissions arising from firstly the generation of power via nuclear methods, and secondly, the use of closed cycle gas turbines, which combines relatively low emissions with high efficiency.

The impact of electricity generation on water and land is generally overlooked - with the focus in the past decade being on global warming and gaseous emissions. For example, although nuclear power is the most beneficial in terms of actual gaseous emissions which is increasingly important in terms of the Kyoto Protocol, it is the major user of water, and although the volumes of waste produced are low, the associated radioactive solid waste will always be an issue.

The adoption of the CCGT has had a huge impact on the environmental emissions due to its high efficiency, but it is very sensitive to gas prices. Coal was thought to have been left behind in the ‘dash for gas’ but it is making something of a revival as gas prices increase. The environmental burden with coal is large, not only with gaseous emissions but those to water and landfill too.

It is clear that in the future there will be a much increased use of renewable electricity, in particular in order for the UK to honour its obligations under the Kyoto protocol. Indeed in September 2003 the DTI announced that the UK will be building enough offshore wind farms to power one in six households by 2010. The cost of renewable power installations is still relatively high and so it seems that government support will need to continue or grow in order to ensure that the number of renewable power generation installations taking place in the next few years meets its aspirations.

In the past few years the UK electricity generation and supply businesses have undergone a phase of intense restructuring and the majority of the acquisitions, mergers and de-mergers undertaken were the result of commercial considerations. This has led to the closer integration of the energy suppliers and more details are contained in the overall report.



In the UK in particular, the overall emissions associated with the power industry had been declining due to the enhanced operating efficiency of the existing nuclear power stations and the increasing use of gas to generate electricity via closed cycle gas turbine technology. However, as was pointed out in the body of the report, the increasing cost of gas is leading to an increase in the use of coal, albeit with improved environmental measures. It is considered by the IEA for example in 2002, that while the UK will probably be able to meet the Kyoto target meeting the national target will require addition effort. Attention is required particularly in the residential sector whereas the Climate Change Levy focuses on the business and public sectors.

When combined with the government's commitment to alleviating fuel poverty that particularly affects low income households in old, poorly insulated buildings, this could impact on the success or otherwise of meeting the national target.

These days there is a NEED for electricity - people will no longer accept the switching off of lights, or even temporary non-availability. Social poverty is associated with the lack of electricity and this is not considered acceptable in the 21st Century. Therefore the future decisions around electricity generation will have to balance economic, social as well as environmental aspects, let alone those concerned with the technology of fuel combustion.

The IEA in 2002 made the following governmental focused recommendations for the UK electricity market. They included allowing the industry to settle into the NETA arrangements without interference, encouraging the full participation of the demand side in balancing the market, consistency in regulation and the provision of incentives for the transmission owner to build over the long term the infrastructure needed to secure supply. With respect to nuclear power generation it recommended a more proactive attitude in the design and implementation of a national policy, increased monitoring of the availability of infrastructure, equipment and manpower to enable ongoing safe operations and clarification on how it intends to keep the nuclear option open.

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Changes in costs or prices, or further exploration, may alter measured
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