The industrial revolution was largely fuelled by coal. As industrialization developed, a close relationship between the increase in demand for energy and economic growth was established, particularly in the West. Demand for electricity rose even more sharply than the demand for primary energy – this has persisted through to the present century. Petroleum demand has steadily increased with transport, both road and air, the biggest user. In fact, growth in the transport sector has been especially rapid with a five-fold increase in the number of cars, currently 600 million but anticipated to rise to about 3 billion by the year 2020. The increase in air traffic has been and will continue to be even more spectacular. The potential for the future growth in energy demand is *enormous*

The Need for Energy

Ian Fells
University of Newcastle upon Tyne, UK

The World Energy Council (WEC) expects the demand in energy to have increased by between 50 and 70 per cent over 1992 figures by the year 2020. The reasons for this are clear: 50 per cent of the countries of the world are in the process of industrialization with economies growing rapidly, some at 10 per cent or more. This calls for an ever-increasing supply of coal, oil and now natural gas. China, for instance, which sustained a 10 per cent growth rate in its market economy for over a decade burns 1.2 Gt of coal a year (1996 figures) and expects to burn 1.4 Gt of coal a year by the year 2000. In addition, it imports oil, has an embryonic nuclear industry, and is seeking to diversify its renewable energy supplies beyond hydroelectric power.

The global situation is made more challenging by the expected rapid increase in the world population. UN figures suggest that today's population of nearly 6 billion will increase to over 10 billion by 2050; 80 per cent of that population will be in developing countries where, to put matters into perspective, 50 per cent of the population do not have an electricity supply connection (neither do they have safe drinking water) so their demand for the services provided by energy and an improved life-style is undeniable.

All this points to a steady rise in the demand for the services provided by energy through to the first century of the next millennium. Of course, renewable energy and nuclear energy have made important supplements to traditional fossil fuel sources during the second half of the present century, with renewable energy (including non-commercial fuel such as wood) currently providing 18 per cent and nuclear 6 per cent of the world's energy—all the rest comes from the combustion of coal, oil and gas.

There are two imperatives which will drive the logical expansion of renewable energy, nuclear energy and fusion energy, if it can be made available at competitive prices. The first is the realisation that resources of oil, gas and coal are finite and will eventually become scarcer and more expensive. The second is perhaps a more immediate motivator: the threat of global surface temperature warming resulting from the combustion of hydrocarbon fuels and the consequent formation of carbon dioxide, which is building up in the atmosphere.

Europhysics News November/December 1998

The WEC in association with the Austrian-based International Institute of Applied Systems Analysis (IIASA) published a report in 1995 entitled "Global Energy Perspectives to 2050 and Beyond". The technique of developing scenarios of possible futures was used with a high-growth scenario *A*, middle-way scenario *B* and an ecologically-driven scenario *C*. *Figure* 1 shows the increase in primary energy use (*ie* use of source fuels such as coal, gas, wood) from 1850 to the present day, and then the three cases to 2100; a comparison is made with previous and anticipated population growth, measured in billions of population.

Scenario *A* shows world energy demand rising from 9.2 Gtoe (giga-tonnes of oil equivalent) in 1990 to 24.8 Gtoe by 2050, almost a three-fold increase. Scenario *B* gives a doubling of demand to 19.7 Gtoe, and even the heavily-constrained, ecologically-driven scenario *C* requires energy demand to increase by 50 per cent to 14.2 Gtoe. All scenarios postulate a spectacular increase in renewable energy—to 35 per cent of demand in case *C* and 20 per cent in case *A*. Nuclear power comes out at a maximum of 14 per cent. Hydrocarbon fuels continue to provide the lion's share of energy supply.

Economic growth

Economic growth and the associated increase in gross domestic product clearly play a central role in the make-up of any energy scenario. Economic growth is uneven across countries and over time. There is convergence over time with developing countries in the process of catching up with industrialized economies, although this is not always the case. Some particularly disadvantaged countries have actually slipped back over the last two decades. But in general, the poor get richer and the economies of rich countries slow down. It is important to realize that the three case scenarios begin to diverge strongly after 2020. This means that firm elements of change in strategy and energy policy must be in place well before 2020.

Energy supply and the environment

The world appears to be at something of a watershed as far as energy demand and consumption is concerned. There is no shortage of fossil fuel resources; nuclear power has the potential to provide a much higher proportion of world energy than it does at present, but it is held back by the lack of public confidence (fusion power could make an important impact here, given time); renewable energy sources are increasing, although their potential will take many decades to develop to a really substantial size. Furthermore, prices have been driven down by deregulation and competition, which is good for economic growth but bad for improvements in end-use energy efficiency—this has hardly improved in the developed world over the last decade. World consumption of primary energy has risen steadily from 5000 Mtoe in 1970 to nearly 10 000 Mtoe in 1997. Provided there are no interruptions in oil and gas supplies arising from war or political action, hydrocarbon fuels will continue to be readily available for 50 years or so and coal for rather longer. Thereafter, increasing reliance will need to be placed on unconventional oil and natural gas supplies, unless non-fossil fuel resources or truly clean coal technologies are available.

The polluting nature of hydrocarbon fuels was emphasized at the Kyoto climate conference in 1997, where it was agreed that world-wide greenhouse gas emissions should be reduced by 5.2 per cent (in carbon dioxide equivalent terms) over 1990 figures. Understandably the developed, industrialized countries point to the importance of having strong, successful, growing economies, and that tough legislation on greenhouse gas emissions could derail the world economy. But, are the following not just as alarming? Prospects, through the next century, of a rise in sea level of 50 cm and in temperature of around 2.5°C, with unpredictable changes in climate, particularly rainfall patterns, increasing severity and frequency of storms and changes in the circulatory currents in the oceans (such as the El Niño Southern Oscillation and the Gulf Stream).

The two largest identifiable carbon dioxide polluters are the electricity supply industry (ESI), particularly coal-fired power stations, and transport. Some governments find it difficult to impose controls on the ESI, particularly following deregulation and privatisation of the ESI in some countries, and even more difficult to stem the increasing flow of transport. Transport and the ESI together account for around 50 per cent of carbon dioxide emissions.

In the case of transport the answer is surely a switch to electric traction, public transport, alternative fuels and fuel cells for cars and vans, and increased rail freight.

There is some hope that as the ESI switches away from coal and towards gas, carbon dioxide emissions will reduce. This has happened to some extent in Western Europe, but will be difficult to accomplish in China and India, which have large reserves of coal on which they rely for electricity generation. A better move in pollution terms would be, of course, to switch to nuclear power. Better still would be to use fusion power.

Growth of fossil-fuel demand

The growing demand for energy services in the next century, it seems, will be unstoppable without draconian measures stimulated by climatic catastrophes and chronic local environmental impacts—unless dramatic technological advance permits higher efficiency and lower pollution. The oil, coal and gas producers around the world, therefore, can anticipate increased business.

As far as oil is concerned the well-endowed Middle East is likely to continue to provide around 30 per cent of world supply. Diversification of supply is important and the search for new oil fields and improved production will benefit from the new technology now being applied to oil extraction offshore in the North Sea. Russia, in particular, with around 10 per cent of world oil reserves (the Middle East

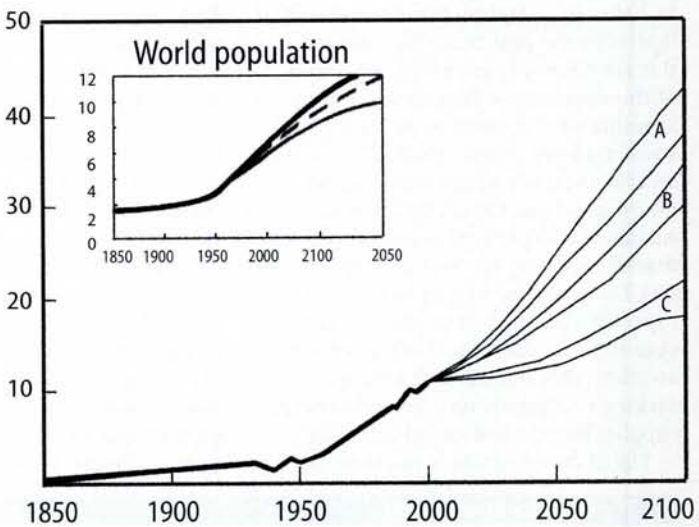

Fig 1 Global energy use 1850 to the present, and three scenarios *A*, *B* and *C*, which predict energy use to the year 2100 (in giga-tonnes oil equivalent). **Also shown** is the rising world population in billions of population

has 65 per cent), is becoming a very important supplier of oil, and of gas, to Europe.

Gas is beginning to play an increasingly important role not only in Eastern Asia but globally, but it is more susceptible to control by cartels than oil supply and this may be of concern in the future. The price of natural gas will undoubtedly rise. The question is, how soon?

Coal reserves are spread evenly between regions, with Europe, Russia and its nearby neighbours, North America and Asia Pacific all in the range of 150 to 300 Gt, Asia Pacific having the highest share. As demand for fossil fuels increases, shortages are anticipated in the second half of the century. This predicted growth in the use of fossil fuels will make the Kyoto agreement to reduce carbon dioxide emissions extremely difficult to implement.

Low pollution energy sources

There are four energy sources, all of which have enormous potential, which might give us confidence that the world's energy needs will be met in the second half of the next century. These are nuclear energy, renewable energy, nuclear fusion and (a very long shot) gravitation. They have the advantage that they are also environmentally clean and do not emit large quantities of greenhouse gases.

The possibilities for energy supply post-2050 and in the next millennium are the subject of speculation and some very expensive research and development. Nuclear fusion has enormous potential, but will be very difficult to achieve from an engineering point of view. Nuclear fusion experiments such as JET in the UK hover on the brink of 'break even', but will require a good deal of new investment in R&D before the first fusion power station comes on stream. Some unlikely possibilities include harnessing the great tidal streams of the oceans such as the Gulf Stream or, even more futuristic, controlling the force that powers the cosmos, gravitation. It is prudent to rely, for the time being at any rate, on the growth in renewable and nuclear energy. They are not, incidentally, mutually exclusive but complementary, and it is very difficult to imagine any future scenario post-2050 without a large slice of energy from both sources. Nuclear power in particular plays an important role in controlling carbon-dioxide emissions. If the industry were phased out for whatever reason and replaced by fossil-fuel power stations, carbon emissions would rise by about 15 per cent, which makes it a potent force in controlling and reducing enhanced global warming.

The nuclear future may well lie with the fast breeder reactor which uses uranium some 60 times more efficiently than current fission reactors. Prototype breeder reactors are in operation in Russia and Japan and were so until recently in the UK and France. They will be required post-2030 or so if a major new nuclear programme is embarked on, as uranium resources are predicted to start running into short supply at about that time.

Public perception of nuclear power

The problem with the continuing growth in nuclear power is the public's perception of its safety, particularly the safety of radioactive waste disposal. If the spent nuclear fuel is reprocessed, as happens in the UK and France, and the high-level radioactive waste glassified and stored in metal cylinders in a dry rock store, there is general international consensus that it will be very safely contained. And the method of reprocessing recovers plutonium as well as unused uranium, both of which can be recycled as fuel for fission reactors. The other method of dealing with spent nuclear fuel is to merely store it either in cooling ponds or directly in a dry store. This presents a less tidy legacy for the future but is the preferred method in some countries, fearful that reprocessing will lead to proliferation.

Sustainable development

The popular consensus seems to be that renewable energy—solar, wind, biomass and so on—will take over the role that fossil fuels have played in the past, once these fuels are in short supply in the second half of the next century. But despite over 30 years of development, 'new renewables' (which excludes large-scale hydroelectric power) still provide only 2 per cent of the world's energy, and much of that remains expensive and has to be subsidized. Moreover, the use of large-scale modern biomass brings the risk of a loss of biodiversity, use of tidal power risks a loss of estuarine habitats, hydropower results in inundation of land and species, and windpower encroaches on visual amenity, so renewables are not without their adverse impacts on a local environment.

Nevertheless, with the drive towards 'sustainable development' the role of renewable energy is crucial in any scenario purporting to deliver 'sustainable development'. It is worth noting that current total world energy use is just under 10 Gtoe. Even the most ecologically constrained case *C* scenarios give a figure of 14.2 Gtoe by 2050, of which 5 Gtoe would be renewable, which is 35 per cent. Fossil fuels will continue to play a dominant role. By 2100 renewables are envisaged to contribute about 13 Gtoe (or more) and the fossil fuels less than 4 Gtoe in ecologically-driven scenarios.

Some large international energy companies predict a higher percentage share for renewables. The Shell oil company suggests that renewable sources could provide over 50 per cent of the world's energy by mid-century next millennium. But this is at variance with WEC projections, and may contain an element of wishful thinking.

In conclusion, energy supply will pose increasing problems through the next century as world population and life-style expectations rise. Replacements for fossil fuels will become imperative and both renewable energy and nuclear energy will play increasingly important roles past 2050. It is here that nuclear fusion could play a very important part in energy supply, provided that fusion power stations really can be constructed based on the scientific demonstrations at JET and elsewhere.

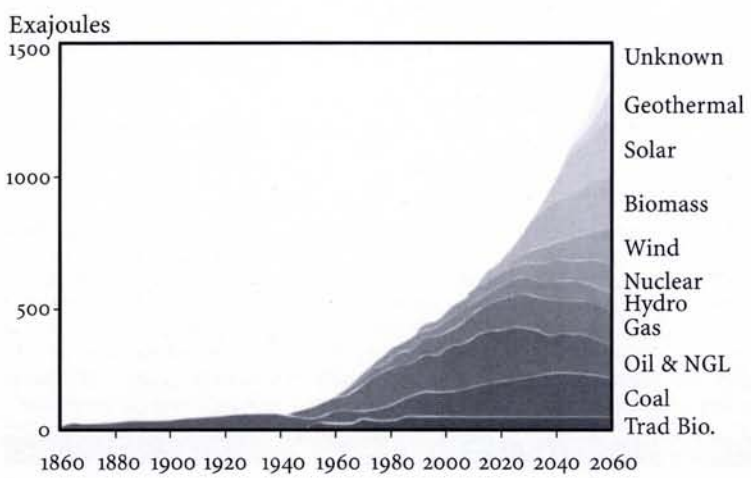

Fig 2 The Shell oil company's scenario for sustainable growth in 2060

Further reading
Rooke, Fells, Horlock editors "Energy for the Future" F.N. Spon. for the Royal Society 1995
Ian Fells, Lisa Woolhouse "Global Warming" Financial Times Energy Publishing 1996