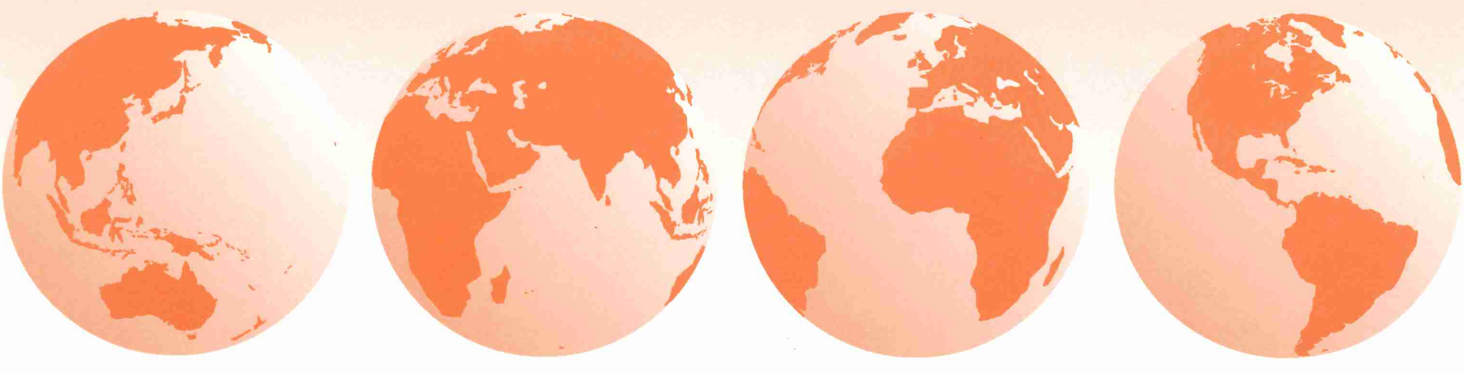
Renewable energy



Number one, 1994

Renewable energy

World requirements for energy are growing, especially in the developing world where demand is likely to double over the next 30 years. Fossil fuels will remain the backbone of energy supplies for the foreseeable future, but other types of energy resources may find increasing use, providing they are economically and environmentally sustainable.

This Shell Briefing Service describes the current contribution of renewable sources of energy to world energy requirements and discusses their future potential. In the first section, the problems of meeting the world's growing demands for energy in a sustainable fashion are described. The following two sections describe the various sources of renewable energy, in particular the 'new' renewables – solar, wind, modern biomass, geothermal and water-based systems other than conventional large scale hydropower. The final section outlines some of the initiatives taken by governments and other institutions to promote sustainable energy development, including the use of renewables. It concludes that a gradual evolution towards a more complex energy supply pattern is more likely than sudden dramatic changes in energy supplies.

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Note on units of energy

The standard unit for measuring energy is the joule (J). Multiples such as the gigajoule (10^9) are used throughout the energy industry. The electricity industry more commonly uses units based on the kilowatt hour (1kWh = 3600 kJ).

A kilowatt (kW) is a *flow* of energy.

A kilowatt hour (kWh) is a *stock* of energy.

kWe	= kilowatt of electricity
bdoe	= barrel a day oil equivalent
toe	= tonne of oil equivalent
k (kilo)	= thousand (10^3)
M (mega)	= 10^6
G (giga)	= 10^9
T (tera)	= 10^{12}
P (peta)	= 10^{15}

As a rough guide:

1 kWh	can run one cooker hotplate for one hour.
1MWh	can run a motor car for 1000 km.
1GWh	is the energy typically used by a medium-sized town in one day.
1TWh	is the energy supplied by a large nuclear power plant over about two months when operated at full load.

Energy and the environment

People need energy to meet basic needs such as heating and lighting, but also to provide the services which contribute to modern standards of living including rapid transportation, global communications and the manufacture of consumer goods. For more than a century, the world's commercial energy needs have been met predominantly by fossil fuels – first coal, then oil and also, more recently, natural gas. Fossil fuels account for 85% of world demand. Nuclear energy contributes just over five per cent, hydropower some six per cent, while commercial renewables – biomass, solar power, wind, geothermal – account for some four million bdoe or less than two per cent (Figure 1). However, if non-commercial energy is included, biomass is estimated to contribute some 25 million bdoe – equivalent to some 14% of the world's energy. Much of this is in the developing world which depends on biomass energy for more than a third of its total energy requirements.

Demand for energy is growing to meet the needs of growing populations. The current world population of five billion could rise to almost eight billion by 2020, more than three-quarters of whom will live in developing countries. For these people, economic development is the key to alleviating widespread poverty and the environmental degradation that is associated with it – poor housing and sanitation, polluted water supplies, deforestation caused by reliance on non-sustainable use of fuelwood. In developing countries, the services provided by energy are directly linked to a better environment and quality of life.

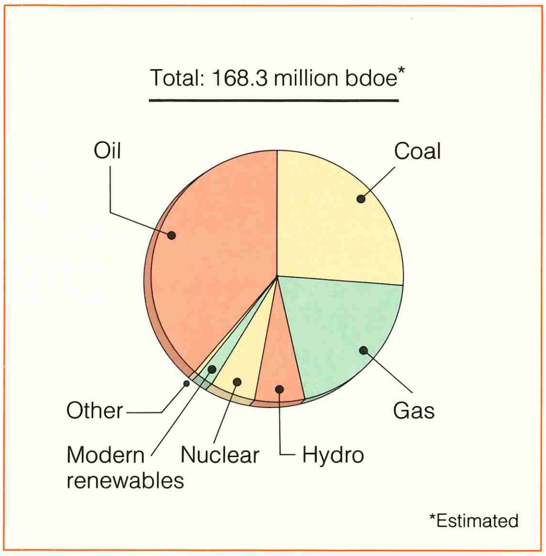
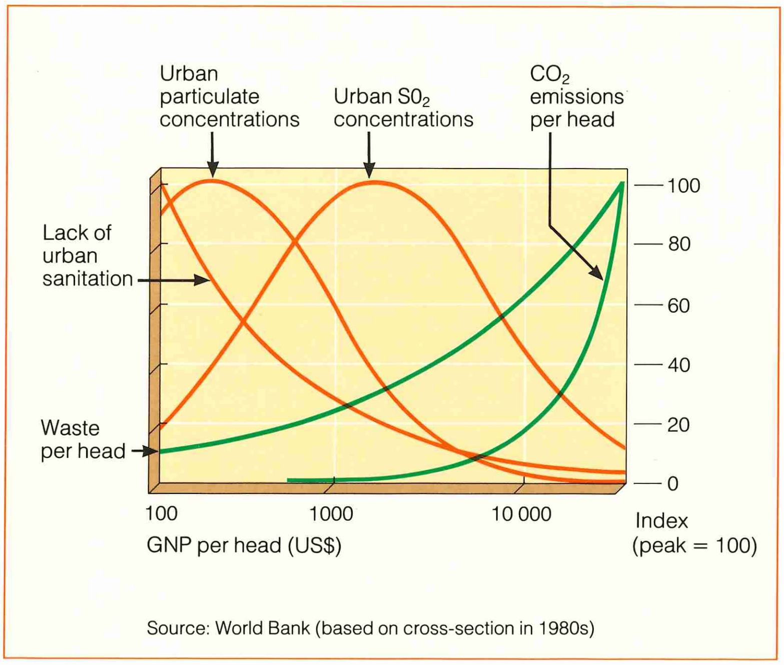


Figure 1 World commercial energy demand

Figure 2 Development and environment



In the developed world, the focus is on reducing the impact of energy use on the environment. Burning fossil fuels results in emissions of sulphur dioxide, nitrogen oxides and volatile organic compounds which contribute to 'acid rain' and photochemical smogs. Fossil fuels also emit carbon dioxide (CO_2), one of the main 'greenhouse gases'. There is concern that increased concentrations of CO_2 in the atmosphere could lead to an augmented greenhouse effect and possible global warming. Figure 2 shows how environmental priorities differ depending on a country's state of economic development.

Reconciling such different priorities has become a matter of increasing international debate. In the Brundtland report 'Our Common Future' published in 1987, the concept of 'sustainable development' was defined as ' meeting the needs of the present without compromising the ability of future generations to meet their own needs'. In June 1992, the UN Conference on Environment and Development (UNCED) adopted Agenda 21 which contains many proposals concerning the role of energy in sustainable development. For instance, governments are encouraged to promote greater efficiency in the use of energy and resources, to develop urban transport policies to reduce transport demand and hence traffic congestion, and to look at the implications of pricing policies which fully take into account environmental costs. A new UN Commission on Sustainable Development has been set up which will meet regularly to review governments' progress towards implementing Agenda 21.

To ensure adequate energy supplies for the future, all types of energy resources which are economically and environmentally sustainable will need to be considered. Although fossil fuel resources are ultimately finite, there will be no shortages of fossil fuels for the foreseeable future. At current rates of production, the world's proven oil reserves will last for more than 40 years, natural gas for some 60 years and coal for more than 200 years. These figures do not take into account the fact that new reserves are still being discovered and technologies developed which enable a greater proportion of the resources to be extracted. Ultimate hydrocarbon resources, which include deposits as yet undiscovered, are even greater.

The inherent benefits of fossil fuels are such that they are likely to continue to form the backbone of energy supplies well into the future, providing they are extracted and used efficiently and the negative impact of their products and any polluting discharges are minimised.

In the longer term, nuclear power may make a major contribution to meeting increased energy demands. However, problems of weapons proliferation, plant safety, waste disposal and rising costs have still to be solved.

At present, most renewables are generally too expensive, despite the fact that the costs of some technologies have already decreased and are expected to continue downwards. For example, it is still more expensive to generate electricity from renewables than from fossil fuels and the established renewable, hydro (Figure 3). However, as modern renewable technologies progress down the 'cost learning curve', they benefit from the economies already achieved by mature technologies such as fossil fuel extraction. Figure 4 shows this trend for wind, which is already competitive on many sites, and photovoltaics.

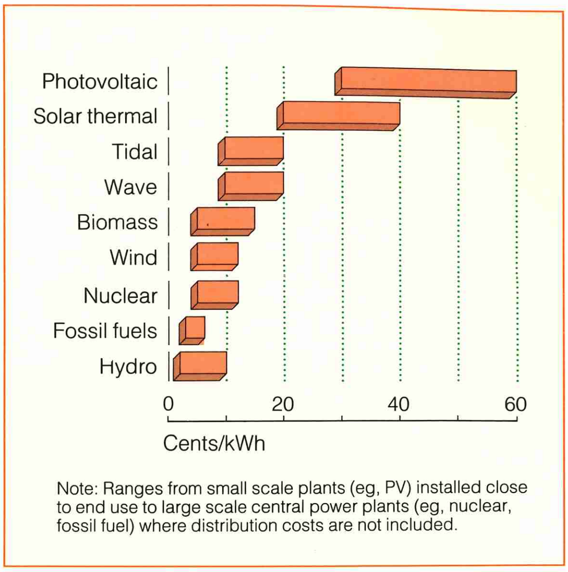
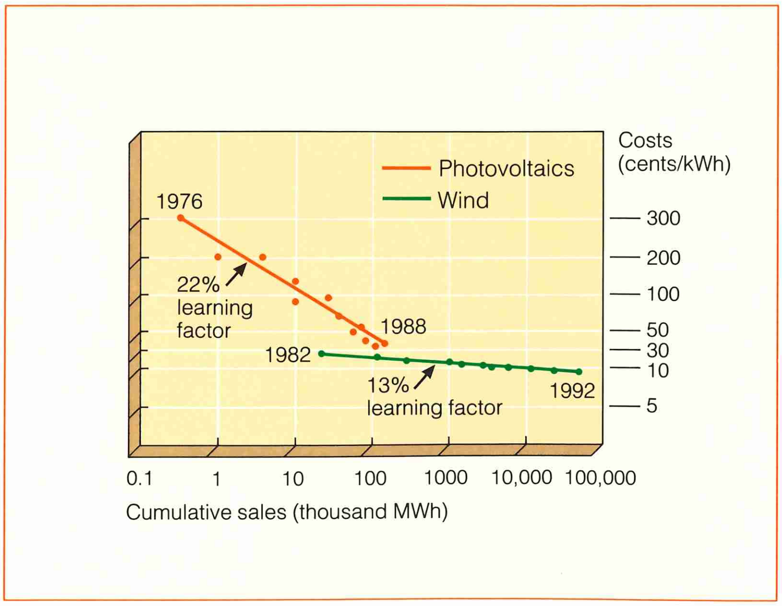


Figure 3
Electricity generation costs, 1993

Although renewables offer some environmental benefits over fossil fuels, they are not free from environmental problems. For instance, wind farms occupy large land areas, have a negative visual impact, may be noisy and cause electromagnetic interference. Some of the materials in photovoltaic (PV) cells are toxic which may cause hazards during production and disposal or if accidents such as fires occur. Pollutants, including dioxins and chlorine, are released during direct combustion of biomass, especially in the case of municipal solid waste. The impact of tidal barrages is similar to that of hydroelectric schemes – namely loss of land and disruption of habitats for wildlife. If more widespread, large scale applications of renewables are introduced, the balance between their environmental benefits and drawbacks may change. Trade-offs between costs and environmental impact, familiar in the context of conventional energy supplies, will apply increasingly to renewables.

Figure 4
Electricity from renewables – cost learning curves



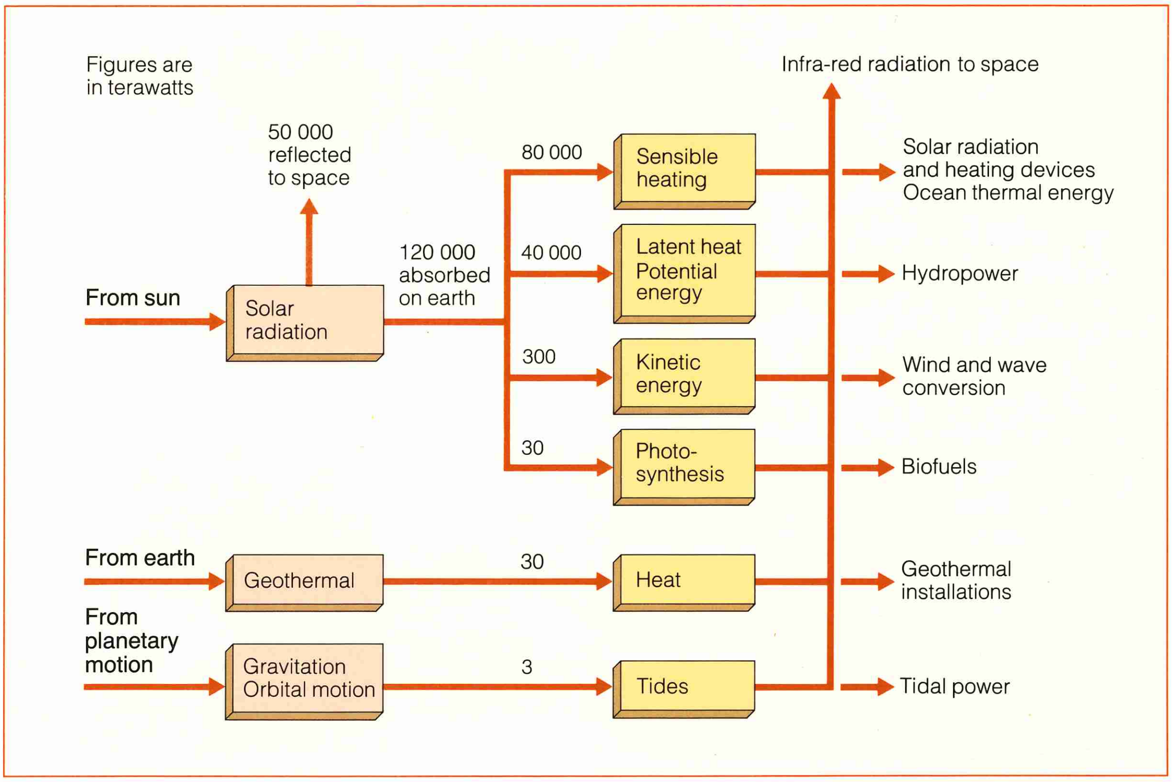
Energy from the sun

Renewable energy is derived mainly from the sun, but also from planetary motion and from the Earth (Figure 5). Finite sources of energy are derived from the sun, nuclear reaction on the Earth and chemical reactions from mineral sources. (Fossil fuels, for instance, are stores of solar energy converted millions of years ago.)

for industrial processes and to generate electricity.

PV systems convert sunlight directly into electric current in a semi-conductor. Solar cells, grouped together and packaged into protective enclosures called modules, form the basic building blocks of such systems. They are generally made from silicon, the

Figure 5
Energy flows



Source: Twidell & Weir "Renewable Energy Resources" published by Chapman & Hall, UK.

Renewables can be divided into:

- Solar energy:
  - solar thermal systems and photovoltaics
  - biomass
  - wind power
- Hydropower and other water-based systems
- Geothermal energy.

Solar thermal systems use sunlight to heat water or air either directly or indirectly. Systems range from simple thermal collectors which provide low temperature heat for domestic water heating or space heating to more sophisticated systems using parabolic mirrors to provide high temperature heat

second most common element in the Earth's crust.

Biomass is a collective term for plant matter created by photosynthesis and derivatives such as forest and crop residues, animal wastes and the organic content of domestic and municipal solid waste. Biomass can be used as a direct source of heat (the oldest and still the main utilisation), to produce electricity or as a feedstock to produce gaseous or liquid fuels.

Wind is an indirect form of solar energy since it is a result of the expansion and convection of air as solar radiation is absorbed on the Earth. Wind energy systems can be stand alone – to provide mechanical energy (eg, for irrigation or drainage) or to generate electricity for local use – or grid-connected, in which case a number of wind turbine generators are linked together to form part of a large electricity network.

Water-based systems include hydropower, tidal power, wave power and ocean thermal energy. Hydropower is the most highly developed of all renewables and is used to generate about a fifth of the world's electricity. The technology used in both large scale and 'mini' hydroelectric schemes is well established. Tidal power is similar to conventional hydroelectricity schemes apart from the fact that the head of water is obtained from the rise and fall of the tide instead of from rivers. Wave power uses the motion of water in ocean waves to move floating devices and generate electric power either directly or indirectly. Ocean thermal energy exists as a result of the temperature difference between the warm water at the surface of the ocean and the cold water of the ocean depths.

Geothermal energy uses heat from the Earth's interior – such as warm water or steam trapped in underground reservoirs. It is 'renewable' only if the heat extracted does not exceed that replenished from the centre of the earth and if the water which brings the heat to the surface is reinjected. Geothermal heat can be used directly for space and water heating and agriculture or to generate electricity.

History

For thousands of years, renewables were virtually the only forms of energy available to humankind. Fuelwood has been used for fires since time immemorial while wind energy was used for sailing vessels in the Mediterranean some 5000 years ago. Windmills may have been used in India some 2500 years ago and the ancient Greeks probably used solar energy in minor ways – using burning mirrors for instance. The Renaissance in Europe brought a renewed interest in technology and with it the introduction of several energy supply techniques based on wind and hydro power. In the 18th century, as a result of increasing shortages of wood fuel, new processes were developed which enabled coal to be used on an indus-

Figure 6
Characteristics of renewables

		Direct solar	Biomass	Wind	Small hydro	Geothermal	Ocean
Resource	Magnitude	Extremely large	Very large	Large	Large	Large	Large
	Distribution	Worldwide	Worldwide	Coastal, mountains, plains	Worldwide, mountains	Tectonic boundaries	Coastal, tropical
	Variation	Daily, seasonal, weather-dependent	Seasonal, climate dependent	Highly variable	Seasonal	Constant	Seasonal, tidal
	Intensity	Low 1 kW/m^2 peak	Moderate to low	Low average 0.8 MW/km^2	Moderate to low	Low average up to 600°C	Low
Technology	Options	Photovoltaics, low to high temp. thermal systems, passive systems	Combustion, fermentation, digestion, gasification, liquefaction	Horizontal and vertical-axis wind-turbines wind pumps sail power	Low to high head turbines and dams	Steam and binary thermodynamic cycles, total flow turbines geopressured magma	Low temp. thermodynamic cycles, mechanical wave oscillators tidal dams and turbines
	Status	Developmental, some commercial	Some commercial, more developmental	Many commercial, more developmental	Mostly commercial,	Some commercial, some developmental	Developmental
	Capacity factor	<25% w/o storage, intermediate	As needed with short-term biomass storage	Variable most 15-30%	Intermittent to base load	High, base load	Intermittent to base load
	Key improvements	Materials, cost, efficiency, resource data	Technology, agriculture and forestry management cost	Materials, design, siting, resource data cost	Turbines, cost, design, resource data	Exploration, extraction, hot dry rock use, cost	Technology, materials, and cost

Based on World Energy Council (WEC) Report 1993 'Renewable Energy Resources: Opportunities and Constraints 1990 – 2020

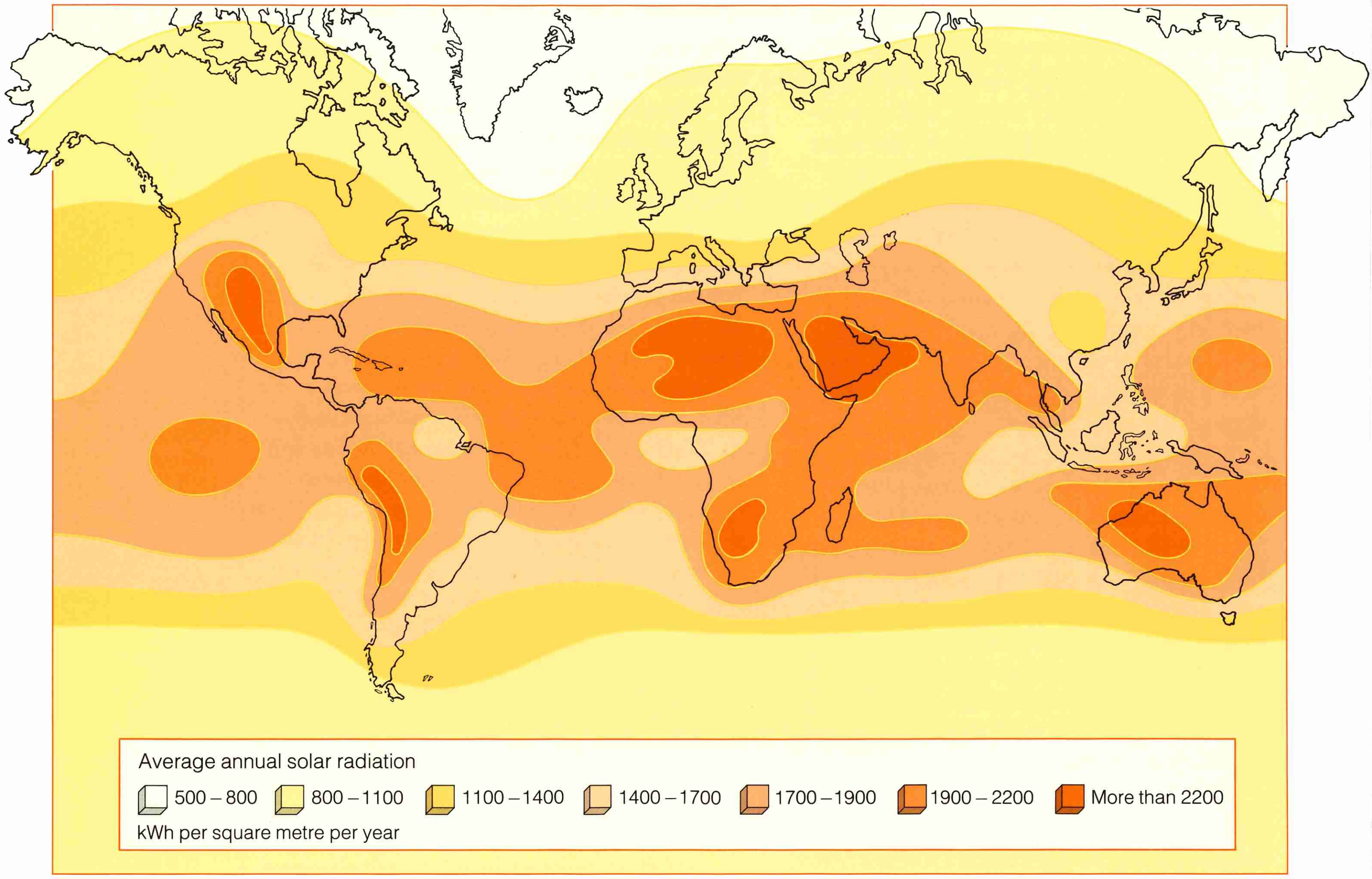


Figure 7
World average solar radiation

trial scale, thus heralding the industrial revolution in northern Europe. Fossil fuels – first coal, then later oil and gas – became increasingly dominant as industrialising societies began to enjoy the benefits of high quality, highly concentrated and transportable forms of energy. As fossil fuels became more widely available, energy use increased dramatically and renewable energy conversion technologies such as water and wind power were largely abandoned in newly industrialised societies due to their low power density and relative inefficiency.

Since that time, developments in renewables technologies have resulted in lower costs and increased efficiency so that they can be regarded as potential contributors to world energy demand where the emphasis is on high quality, concentrated energy supplies.

Characteristics of renewables

Renewable energy technologies range from ideas still on the drawing board to well developed techniques, from local small and medium scale systems to large engineering projects such as hydro schemes. Nevertheless, some common characteristics may be identified (Figure 6).

Firstly, the potential resource from renewables is enormous. For instance, the total energy flow of sunlight intercepted by the Earth is 170 000 terawatts or about 2.5 x 10^6 million bdoe – more than 10 000 times man's annual energy requirements (Figure 5). The average annual solar radiation available at the Earth's surface varies from about 1000 kWh/m^2 a year in Northern Europe to more than 2000 kWh/m^2 a year in desert areas (Figure 7). Resources of renewables are difficult to quantify accurately as adequate surveys are not available for many countries. For instance, wind maps are often inadequate as wind regimes are affected by a range of local effects still improperly understood. Although a rough estimate of biomass resources from existing forests and crops can be made, the energy potential of these is rarely quantified on the basis of possible conversion technologies. (Much biomass use – eg, for fuelwood and charcoal burning – is highly inefficient.) There are few surveys of deep aquifers which may be a source of geothermal energy. The difficulty in collecting data on renewable energy use, especially where non-commercial sources are involved, means that much of the contribution of renewables goes unrecorded.

Unlike fossil fuels, which are highly concentrated stores of energy, most renewables are diffuse energy sources. The more diffuse an energy flow, the harder it is to capture. As renewables have a large capture area, the collecting devices and storage systems required to harness the energy may occupy considerable land space. Capital costs of equipment are generally high, as large material and energy inputs are needed to access the wide capture area and achieve acceptable power capture.

The intermittent nature of many renewable resources may be a limitation as satisfactory storage methods have still to be found in some cases. However, such limitations may be overcome by using renewable supplies to meet peak daytime demands in conjunction with conventional sources or by integrating several renewables into a system where they can 'complement' each other – eg, photovoltaics for peak daytime demand and biomass for base load.

The potential for renewables varies on a regional scale as it is closely linked to local geography and environment. In many cases, there are 'niche' opportunities which suit particular local or regional conditions which prove economic at that level even if they do not have more general potential. Renewable energy systems are typically small to medium scale dispersed developments tailored to meet specific local needs. These are in complete contrast to fossil fuel developments which are based on large, international systems with a well-established infrastructure.

Potential markets for renewables

The most promising markets for renewables are in heat and power generation, currently dominated by coal and gas. Between 1980 and 1990, world electricity demand increased from some 8300 TWh a year to more than 11 500 TWh a year. The greatest increase was in developing countries where the average annual increase in demand was three times that of developed countries. The World Bank estimates that some 600 000 MWe of new electricity generating capacity will be needed by the end of the 1990s, more than half of which will be required by the developing countries, India and China in particular. Demand for rural electrification schemes for remote areas is likely to increase, especially in developing countries where many inhabitants have no access to an electricity grid.

Renewables will probably take longer to make an impact on the transportation market which is currently dominated by oil products which are versatile, easy to store and transport and have a high energy density. The internal combustion engine, run on gasoline or diesel, will continue to be the preferred choice of motorists for many years, especially given the progressive reduction in vehicle emissions achieved through improvements in vehicle technology and fuel quality. A significant breakthrough in vehicle technologies – such as the development of cost-effective fuel cells or electricity storage devices – would be required for renewables to make a major impact on transport applications.

Solar thermal

The simplest systems for low temperature applications (less than 100°C) consist of a 'flat plate' collector and a storage tank. For example, in a solar water heater, water runs through pipes or channels in a collector. As the sun heats the collector, the hot water produced inside rises by natural convection to be replaced by colder water. Solar water heaters for domestic and commercial use are manufactured in many countries, especially in Australia, Israel, the USA and Japan. Solar heat can also be used as process heat for industry or agriculture (eg, crop drying) and for space heating and cooling.

Where large amounts of low temperature heat are required, a solar pond may be more economic than a flat plate collector. Solar ponds consist of several layers of salty water, with the saltiest layer on the bottom. The fresh water on top traps the heat in the higher density lower layers. As these ponds have built-in energy storage, they can be used to heat buildings in winter. They can also be used to generate electricity.

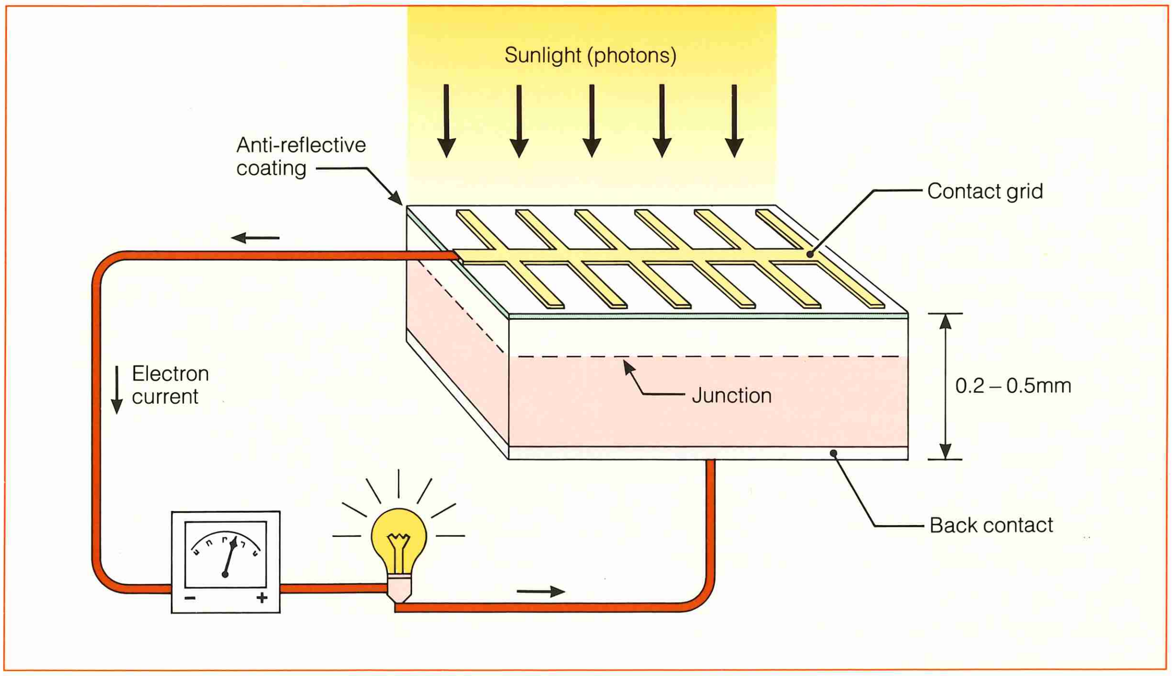
To achieve higher temperatures, a solar thermal system may incorporate parabolic mirrors to concentrate sunlight. To generate electricity, the most common system is one which uses mirrors mounted in parabolic troughs to focus sunlight on pipes in which oil circulates. The heated oil provides energy to drive a turbine generator. An alternative is the 'solar power tower' which uses sun tracking mirrors called 'heliostats' to focus concentrated sunlight on to a central receiver. Demonstration 'power tower' projects have been constructed in France, Italy, Spain and the USA.

Photovoltaics

PV cells are semiconductor devices which were first produced in the 1950s to provide power for space satellites. Although solar cells can be produced using a variety of semiconductor materials, most are made from silicon. The development of thin film photovoltaic technologies with low manufacturing costs is the focus of considerable research worldwide. Figure 8 illustrates the design of a typical PV cell.

Most PV power devices produce energy in small quantities for a variety of purposes such as rural electrification schemes in developing countries, power supplies for

Figure 8
A photovoltaic cell



instrumentation and telecommunications, and power for consumer goods such as calculators and watches.

Over the past 20 years, the cost per peak Watt of PV modules has fallen from more than US$20 to around US$5. At the same time, production capacity has risen from around 5MW to about 60MW a year. Solar cell production capacity has been doubling every five years. PV is already cost effective for small applications and further cost reductions will pave the way for wider applications.

If PV module costs could be reduced to between one and two US$ per peak Watt, PV could in many cases become cost competitive with centralised fossil fuel based power generation and could possibly meet up to a fifth of world electricity demand without the need for storage. Even in temperate zones, this would require less than 1.5 million hectares of land, which compares favourably with land requirements for some of the world's major food crops (Figure 9).

At present, there are a few large PV arrays installed as demonstration projects, representing just a few megawatts. An alternative would be to integrate rooftop arrays into existing grids – for instance to help reduce daytime peak demand. As the power would be produced in densely populated areas, it would be used closer to production, thus minimising distribution costs.

This alternative has been pursued in Switzerland where there is a policy to obtain 0.5% of the country's primary energy from 'new' renewables by the end of the century. Residential buildings have been fitted with roof mounted modules which are used in conjunction with dc/ac inverters and which provide metered supply in parallel with the public electricity supply system.

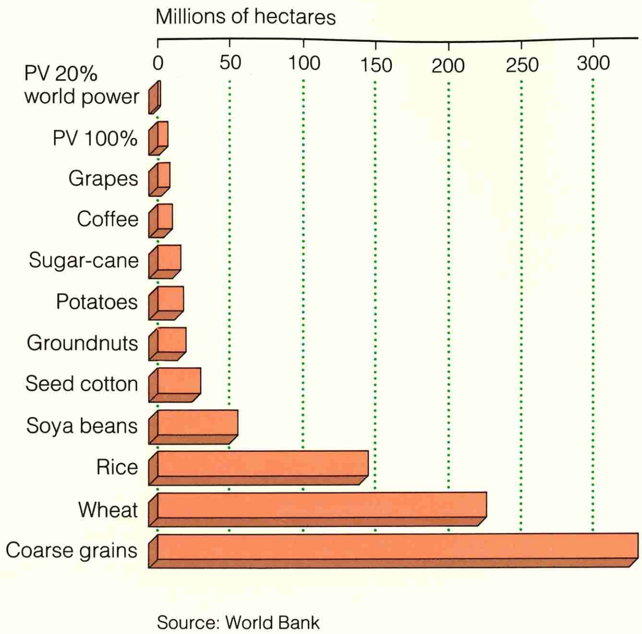


Figure 9
Solar energy land requirements

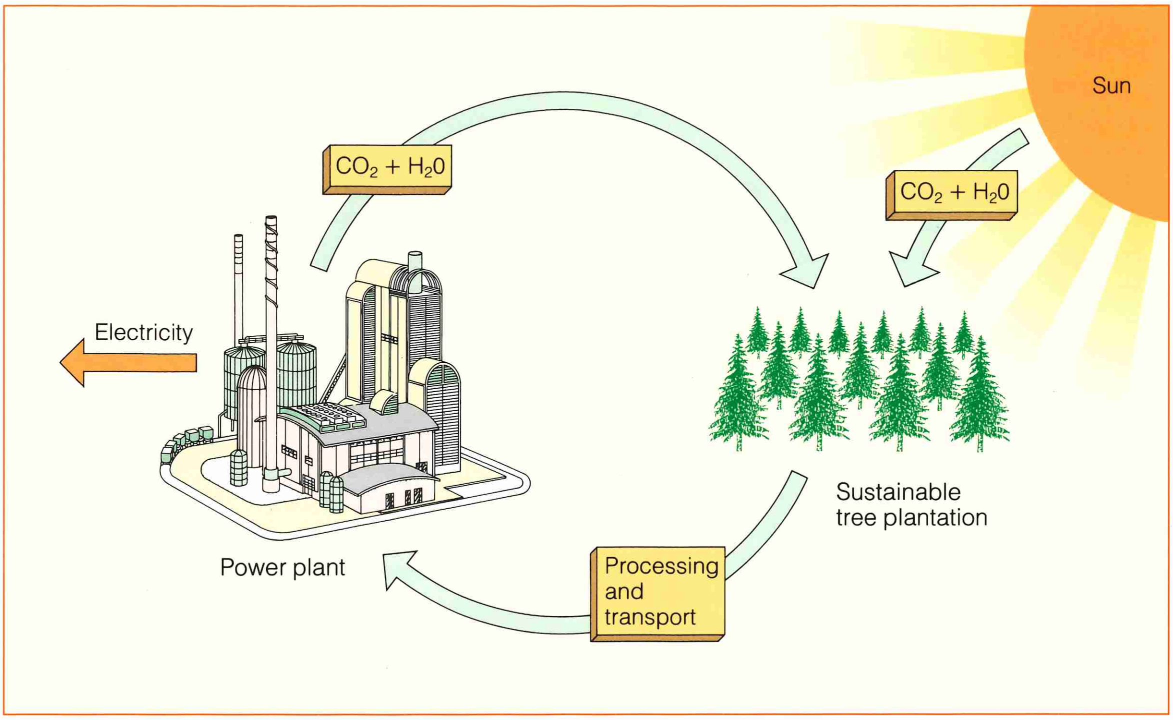
Biomass

Biomass is the world's fourth largest energy source and has an energy potential far exceeding current world energy use. It is available in most countries and represents a valuable indigenous resource, especially in developing countries. Providing the biomass is produced at a sustainable rate, the CO_2 emitted during processing and combustion balances the CO_2 consumed during photosynthesis. Thus biomass is not a net contributor to CO_2 in the atmosphere – except for the fuel used in its transport – and does not contribute to possible global warming (Figure 10).

Biomass can be divided into two categories – traditional and modern. Traditional biomass is mainly fuelwood, the 'poor man's oil', used for domestic heating and cooking and the main source of energy for almost half the world's population. Other traditional forms of biomass include charcoal, straw, rice husks, plant residues and animal waste. Traditional biomass can represent some 90% of energy use in some developing countries where it is not usually acquired via commercial markets and so rarely appears in commercial energy statistics. In parts of the world, fuelwood gathering is leading to shortages (so that fuelwood is no longer a renewable resource) and is causing forest damage and other environmental deterioration. Where fuelwood is scarce, animal dung may be used as a fuel rather than as a fertilizer, thus reducing agricultural efficiency.

Modern biomass such as wood residues from industrial processes, bagasse (fibre residue from sugar-cane), energy crops and urban waste may be used on a commercial scale as solid, liquid or gaseous fuels or in power generation where they substitute or complement conventional sources of energy. Recently, interest has increased in growing energy crops on agricultural land taken out of production ('set aside' land) in Europe and the USA. Short-rotation, fast growing trees and herbaceous plants for heat and power generation are the crops receiving most attention and appear to have the best economic potential. Other proposed crops include sugar/starch crops (eg, sugar-cane, cassava, sorghum and Jerusalem artichoke) used in the production of ethanol and plants which yield oil for possible use as fuels in diesel engines such as sunflowers, soya,

Figure 10
Biomass – recycling carbon



groundnut, cottonseed, rapeseed, palm oil and castor oil.

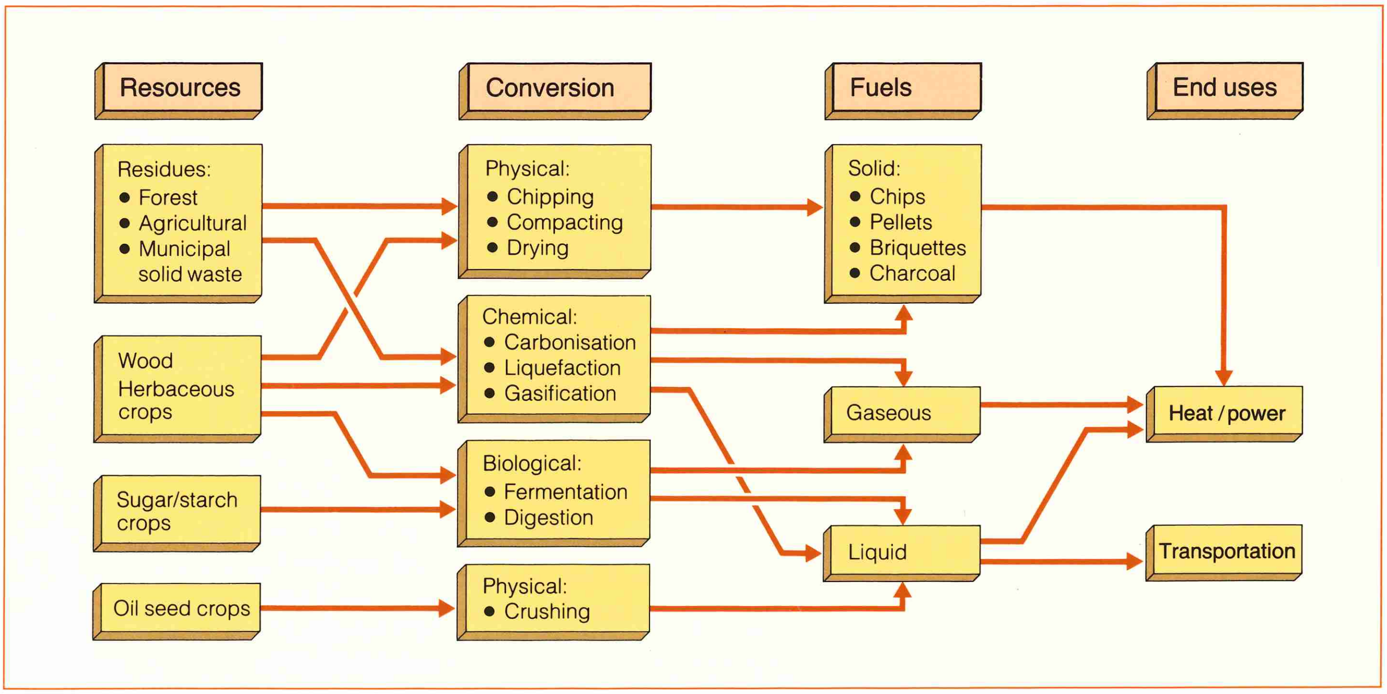
Direct combustion to CO_2 and water is the main process used to convert biomass into useful energy. Biomass can also be used indirectly following a thermochemical or biological conversion process. The main thermochemical processes are pyrolysis, liquefaction and gasification. Pyrolysis is where a feedstock is degraded by heat to produce gas, liquid and char. Carbonisation, used for centuries to produce charcoal, is an example of slow pyrolysis. Much research has been conducted into new processes of fast biomass pyrolysis but as yet none has gone beyond the demonstration stage.

The liquefaction process, where high pressure hydrogen is injected to liquefy the feedstock, is not yet economically viable, due to a number of engineering and technical obstacles. In a gasification process, a feedstock is converted into a mixture consisting mainly of carbon monoxide and hydrogen. Equipment for biomass gasification is already commercially available.

The two main biological conversion processes are anaerobic digestion, used to produce biogas from various organic wastes and fermentation which uses starch or sugar feedstocks to produce fuel ethanol.

Figure 11 shows various conversion routes for biomass resources.

Figure 11
Converting biomass



Biomass in power generation

Biomass is already widely used to generate electricity in the forest products industries using wood wastes as fuel for steam-turbine systems. However, steam turbines are relatively expensive and inefficient at the small scale to which biomass use is best suited. In addition, readily available resources of low-cost biomass are needed to make this approach economic. Integrated gasification/gas turbine technology offers a more promising route to biomass power. Hot fuel gases are generated from the biomass and used to drive a gas turbine which in turn generates electricity. Shell companies are involved in a development programme to construct a 30 MWe biomass power demonstration plant in Brazil fuelled by biomass from a eucalyptus plantation. The project has financial support from the UN Global Environmental Facility (GEF). If the equipment development trials are satisfactory, construction is scheduled to start in 1995. If successful, the project could expand the potential of biomass in Brazil, especially in the sugar/alcohol industries, and encourage the use of dedicated fuelwood plantations as an important source of primary energy worldwide.

Biogas

Biogas, produced by anaerobic digestion and consisting mainly of methane and CO_2, is used principally for direct combustion and to fuel stationary internal combustion engines. Both China and India have a long history of biogas use while in Denmark, several large biogas plants produce gas – mainly from manure – for use in combined heat and power production.

Biofuels

Biomethanol, bioethanol, vegetable oils and vegetable oil esters are all potential transportation fuels. Bioethanol has been used neat or in blends with gasoline, notably in Brazil. Under the Brazilian Proalcool project, heavily subsidised by the government keen to reduce dependence on foreign oil supplies, ethanol produced from sugarcane provides more than half the country's automotive fuel. There are also ethanol programmes in the USA (ethanol from maize), Zimbabwe and Malawi. Vegetable oil esters have lower viscosities and higher cetane numbers than pure vegetable oils and thus have greater potential as diesel fuel substitutes or blends. In Europe, interest is being shown in rapeseed oil methyl ester either on its own or in a blend with diesel.

Although the technical performance of liquid biofuels is generally satisfactory, they have little environmental benefit over modern oil-based transportation fuels and require very large subsidies to compete with established fuels. Several studies have shown that it is more cost effective to grow energy crops for use as solid fuels for heat or power rather than for liquid transportation fuels.

Wind power

Traditional windmills have been used for centuries to drive machinery for grain milling and for simple irrigation schemes. A typical modern windmill used for electricity generation consists of a two or three-bladed rotor which rotates about a horizontal axis and is mounted at the top of a tall tower. Multiblade rotors may be used for applications which require low frequency power, such as water pumping.

The best sites are in remote rural, island or coastal areas where consistently good wind speeds may be expected. Figure 12 shows the areas of the world which are most attractive for wind power development.

As wind generators have to be situated at an optimum distance from each other to avoid interference with wind flow patterns, wind farms tend to require large land areas. Although the land may still be used for agriculture, siting wind farms in areas of scenic beauty may arouse opposition. One solution might be a wind farm based offshore, although it would have to be more robust, more corrosion resistant and need less maintenance than a land based installation. A demonstration plant has been built offshore Denmark to investigate the technical problems in detail.

Horizontal axis wind turbines are technically proven and may be commercially attractive for electricity production in areas with good wind conditions and local maintenance facilities as long as the wind energy share is less than about a quarter of total demand (to avoid the need for dedicated storage). Wind turbine technology has been developed intensively over the past 20 years and larger turbines, in the 0.25 MWe to 0.5 MWe range are now available. Developments such as variable speed rotors offer potential for further cost savings. Installed generating capacity has also been increasing. Current world capacity of grid-connected turbines is estimated at around 2500 MWe, more than half of which is in

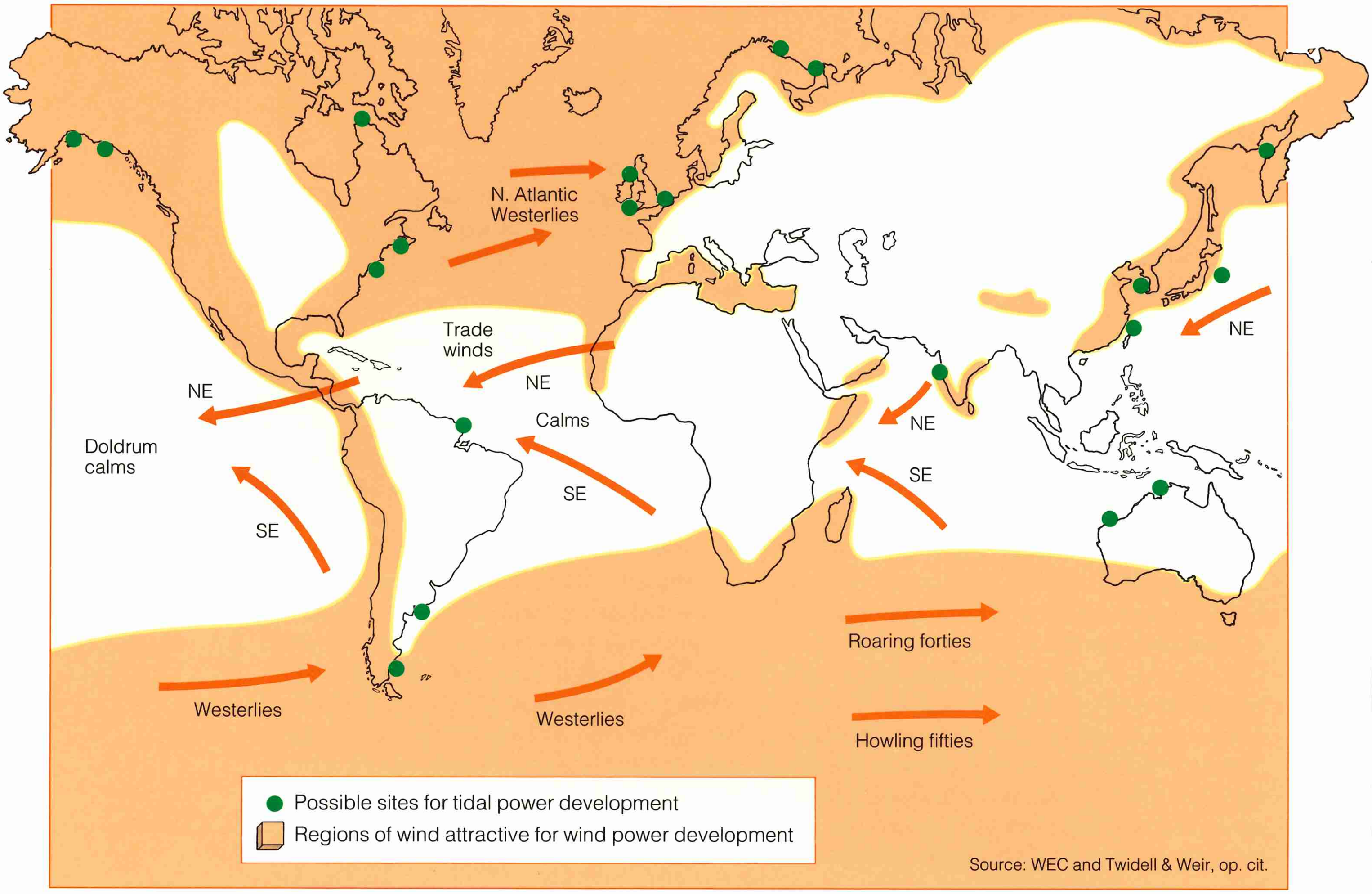


Figure 12
Developing wind and tidal power – possible sites

California. The growth of wind power in California in the early 1980s was largely due to tax incentives. Although these were discontinued following the oil price collapse of 1986, wind power continues to grow in California but at a slower rate.

Outside the USA, the largest user of wind energy is Denmark where about two per cent of electricity production is generated from wind. Denmark currently has more than 400 MWe of installed capacity, equivalent to some 65% of Europe's total and plans to expand this to 1500 MWe by the year 2005. Denmark is also a leading manufacturer of wind turbines, supplying about three-quarters of Europe's needs and an estimated 45% of the world market.

In some parts of the world, 'hybrid' systems consisting of wind turbines and diesel generators have been developed to overcome the problem of the intermittency of wind power. They are of particular interest in remote areas far from public grids where diesel generators have been used in the past for local power production. Multiple hybrid arrangements have also been designed which incorporate wind power, solar photovoltaic energy, diesel generation and conventional batteries.

Over the past ten years, wind power costs have fallen, mainly as a result of improved equipment production methods, better siting and maintenance scheduling. Technical improvements, such as the development of advanced materials to provide lighter, stronger components, could reduce costs further.

Water based systems

Small hydro schemes

Historically, hydropower was developed on a small scale to meet local needs. As transmission efficiency increased, power generation became concentrated into ever larger units and large scale hydro schemes benefited from the resulting economies of scale. Today, world hydropower capacity is estimated at some 600 000 MWe, of which around three per cent comprises small hydro schemes (ie, less than 10 MWe). World production is about 2280 TWh a year, around two-thirds of which is in industrialised countries. Small hydro schemes account for just under four per cent total production.

A small hydro development consists of a dam, diversion weir and powerhouse containing the equipment which transforms the energy of the water into electrical energy. New schemes are usually 'run-of-water' developments with no water storage reservoir. As small projects lack the economies of scale of larger developments, costs per installed kWe may be quite high. However, they may be attractive in rural communities not connected to a grid, especially if they serve to boost other uses of water such as irrigation. Most of the world's small hydro plants are located in China where few areas are served by transmission grids.

Energy from the ocean

Most technologies for harnessing energy from the ocean are immature.

Tidal power

Extracting energy from the tides is practicable only where the tides are large enough and there are favourable sites for plant construction (Figure 12). Of the very few schemes in operation around the world, the largest is in La Rance in France which has operated reliably and with a low maintenance requirement since the mid-1960s. Further development of tidal power is hampered by high capital investment requirements, long construction times and a potentially severe impact on the environment around possible sites.

Wave power

Using the power of the waves has stimulated the imaginations of many inventors. More than 1000 patents exist worldwide for wave power devices, though few have reached prototype stages. A number of designs use an oscillating water column as an energy collector. Although some small scale devices have operated satisfactorily, the problems of large scale operation such as large storms and resistance to corrosion and marine fouling, have still to be resolved. Most research into wave power has been conducted in the UK, where the conclusion is that effort should focus on developing small shoreline devices, as large scale offshore designs are unlikely to become economic for some considerable time.

Ocean thermal energy

Ocean thermal energy conversion (OTEC) plants operate on an open, closed or hybrid cycle and can be mounted on a vessel or built onshore. Unlike wave or tidal energy, OTEC is not intermittent and plants are suited to baseload operation. The first test plant was built in the 1930s, but there was no further interest until the 1970s when rising oil prices triggered the search for alternative sources of energy. Projects are underway or planned in a number of countries to design demonstration plants to test the reliability and technical performance of the technology. However, costs would have to be reduced significantly before OTEC could compete with conventional baseload power generation.

Geothermal energy

Geothermal energy has long been used for therapeutic hot baths, space and water heating and agriculture. Over the past few decades, dry steam and high temperature water have been used to generate electricity on a commercial scale. Resources are concentrated along the boundaries between tectonic plates in the Earth's crust which are prone to volcanic activity or earthquakes. Countries known for their geothermal potential include Italy, (where electricity was first generated from geothermal power in 1904), Japan, New Zealand, the Philippines, China, Iceland, the former Soviet Union, Mexico and the USA.

The past decade has seen developments in the use of medium temperature geothermal water for power generation using binary cycle plants. At the beginning of the 1990s, world geothermal electric capacity was estimated at almost 6000 MWe, representing a small but not insignificant 'niche' in the power generation market. Geothermal energy is also used directly for space and water heating, for example in district heating, greenhouse heating, crop drying and various industrial processes. Leaders are Iceland where four-fifths of the population use geothermal space heating and Hungary, where geothermal sources are widely used to heat greenhouses. Total direct use of geothermal energy is estimated at around 5.6 million toe.

Technologies to find and extract geothermal resources are based on those used in the oil and gas industries, modified to take into account the high temperatures and salinity of the resource. To date, only hydrothermal resources (hot water and/or steam trapped in porous or fractured rock at depths between 100 and 4500 metres) have been exploited on a commercial scale. The development of technologies to extract energy from hot dry rock, geopressured resources (hot water aquifers) and magma (molten rock) could increase the potential of geothermal energy in the longer term.

Looking ahead

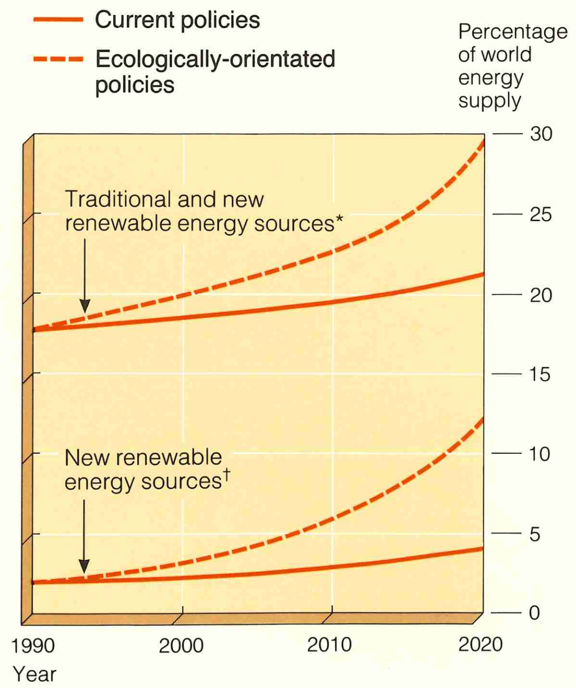
Although some renewables do offer some environmental benefits over fossil fuels, they are still generally much more expensive. Their costs have declined, however, and are likely to continue to do so as these largely modern technologies progress rapidly down their cost learning curves. The pace of development could quicken if governments elect to spend large amounts of public money on further research and development. For instance, the GEF has been set up by the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and the World Bank to provide grants for investment projects aimed at protecting the global environment. The Commission of the European Communities (CEC) launched a five year Thermie programme in 1990, with a budget of some $630 million, to promote rational use of energy by developing technologies for both fossil fuels and renewables. There are two further programmes – Joule and Altener. Joule supports research and development into advanced energy technologies: just over a third of its $250 million budget is allocated to renewables. Altener, with a budget of some $35 million, aims to promote an increased share of renewables in total EU energy consumption.

In the USA, as part of the US National Energy Strategy, support is given for research and development on renewables and applications are encouraged partly by extending investment tax credits for renewables technologies.

Opinions vary considerably as to how renewables will penetrate future energy markets. In a recent report, the World Energy Council considered two alternative cases up to the year 2020. Under the 'current policies' scenario, new renewables, led by biomass, are expected to rise from 1.9% of total commercial energy supply in 1990 to just 4% in 2020. If traditional biomass and hydropower are added, the figure would rise to just over 20% of total energy supply. The 'ecologically driven' scenario assumes large government subsidies for renewables on an international scale. Under this scenario, new renewables might account for 12%, and total renewables 30% of total commercial energy supply, with most consumption in developing countries (Figure 13).

Dramatic changes in energy supply are unlikely to occur quickly, however, given the rigidities inherent in the world's energy infrastructure, such as slow capital stock turnover. Investment in future energy supplies requires huge capital outlays with long lead times for major projects and a long-term commitment by investors. To fulfil all these requirements will result in increasingly complex trade-offs in energy policy. A gradual evolution towards a more complex energy supply pattern is the most likely path, driven by technological advances on all fronts. In the final analysis, the role of renewables will be determined by their economic and environmental performance.

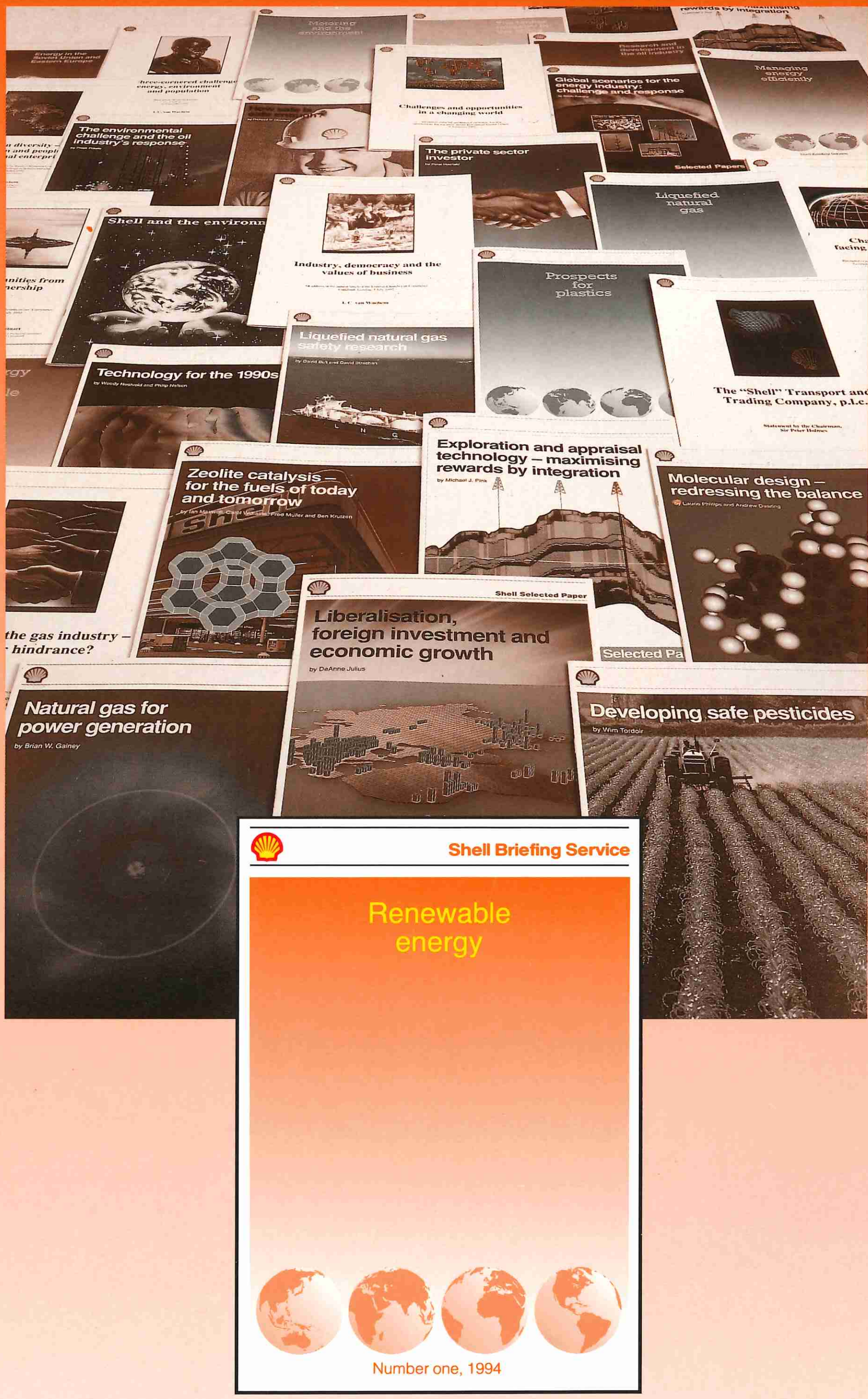
Figure 13
Renewables – future trends



* Traditional sources:
Wood-burning and large-scale hydropower

† New sources:
Biomass, solar, wind, geothermal, wave and small-scale hydropower

Source: World Energy Council op.cit.



Related publications

Renewable energy describes the current contribution of renewable sources of energy to world energy requirements and discusses their future potential. Fossil fuels will remain the backbone of energy supplies for the foreseeable future but other types of energy resources may find increasing use to meet the world's growing energy needs.

Related publications which may be of interest include:

Shell Briefing Service:

- 2/92: *Motoring and the environment*

Selected Papers:

- *Sustainable biomass energy* by Philip Elliott and Roger Booth

Speeches:

- *Fossil fuel energy – today and tomorrow* by C.A.J. Herkströter

Information on ordering these and other publications can be found on the inside front cover of this briefing.