

# **New Technologies, Industry Developments and Emission Trends in Key Sectors: The Energy Sector**

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## **New Technologies, Industry Developments and Emission Trends in Key Sectors: The Energy Sector**

Australia's total primary energy consumption grew by 3.6 per cent per annum between 1993/94 and 1997/98, while primary energy use in the electricity sector rose by more than 5 per cent per year over the same period. Since 1993/94, brown coal has strongly expanded its share in the fuel mix of the interconnected electricity markets of Victoria, New South Wales, the Australian Capital Territory, and South Australia. It has become the primary fuel source for electricity generation, substituting for hydro, natural gas and hard coal. At the national level, this has meant that the long-term trend towards greater use of natural gas has stalled in favour of coal, especially brown coal. Since Victoria's brown coal plants have relatively low thermal efficiencies, this substitution has also had the effect of reducing the average thermal efficiency in the power market to the levels of the late 1980s (IEA, 2001b).

It should be noted that the economic objective of reducing the price of power which has driven the first stage of reform in the electricity industry in Australia has perversely encouraged the aggregate use of energy in the economy. This, in turn, has added to the growth of greenhouse gas emissions, reinforcing the trend associated with the change in the fuel mix for electricity generation.

This paper addresses non-transport energy-related activities including conventional and renewable forms of energy supply, cross-cutting technologies employed in the energy sector and, more briefly, energy use by the business and household sectors.

# Non-Renewable Energy: Reducing the Greenhouse Intensity of Energy Supply

## INTRODUCTION

Decarbonisation through efficiency improvements is the fundamental option for achieving environmentally compatible energy development. Efficiency improvements reduce most of the adverse environmental effects of energy, including greenhouse gas emissions, while they lead to lower primary energy inputs and therefore to lower fuel costs. However, efficiency improvements are rarely a “free lunch”. Investments in new equipment, and institutional and organisational changes are necessary to deliver energy services with lower primary energy inputs. Energy efficiency improvements also have to compete with other investments throughout the economy. This is a critical factor, especially for most of the developing economies (Energy, 1993).

### Energy Efficiency

Efficiency is usually measured as the ratio of energy output to input. Measured this way, energy efficiency improvements have already been achieved for almost all types of energy conversion facilities. For example, dramatic improvements in fuel conversion efficiencies were achieved in electricity generation during this century. The prevailing efficiency of electricity generation was about 5% around the turn of the century, whereas today, the average efficiency in OECD countries is about 36% and the best combined-cycle natural gas-fired power plants can achieve more than 50% efficiency.

Another way of measuring the overall efficiency of energy use is to determine the ratio of primary energy consumption divided by the GDP, usually called the energy intensity. On the average, the energy intensity of most developed countries has declined by about 1% per year, indicating that during the last 70 years the energy requirements for producing a unit value added have been halved. (Energy 1993).

In the second half of the 20<sup>th</sup> century there were two major clusters of innovation in the power generation system. The first consisted of the innovations around the introduction of nuclear power plants, with light water reactors diffusing in the 1970s. The second, appearing in the middle of the 1980s, was the use of gas turbines for electricity production. The latter now appears the more significant area of innovation for the following reasons:

- It permitted flexible (i.e. either baseload or peakload) electricity production;
- It opened the way for combine heat and power schemes to achieve dramatic increases in the overall energy conversion efficiency;
- It facilitated the downsizing of generation units without any loss of economies of scale, thereby counteracting the previous tendency for the power generating industry to become a natural monopoly; and
- As a consequence of its versatility, gas turbines may in future assist the penetration of renewable energy technologies since they are particularly well-suited for hybrid devices (IPTS, 1997).

## **The Supply of Fossil Energy**

Fossil energy dominates the world's energy supplies and is likely to do so for the foreseeable future. It provides about 90 per cent of the world's energy, with oil providing 41 per cent, natural gas 22 per cent and coal 27 per cent. Because OECD economies are so heavily reliant on each of these three fuels, it would take at least two decades of dedicated technical and infrastructure development to alter this fuel mix substantially (IEA 2000).

The long-term supply outlook depends critically on technology development and deployment. Technology will affect the choice and cost of future energy systems, but the pace and direction of change is highly uncertain. Oil production costs will be highly dependent on recovery rates and on the use of unconventional resources, which are likely to cost significantly more than conventional oil to exploit. The long-term supply outlook for natural gas depends largely on lowering the cost of long-distance transportation. The long-term coal supply outlook depends largely on whether ways can be found to use coal in an environmentally acceptable way. Beyond 2020, the role of renewable energy in global energy supply is likely to become much more important. The future of nuclear power is very uncertain.

There are ample energy resources to support consumption in the longer term, but which reserves can be economically produced will depend on production costs and on the price that the fuel can be sold for. The downward trend in production costs through technological advances is likely to continue. But fossil-fuel prices could increase as the lowest-cost reserves are depleted and a small number of increasingly dominant oil-exporters seeks higher prices.

The prospects for oil supply after 2020 will be influenced by technological, market and policy developments as well as by demand-side factors. Ultimate recoverable reserves have grown over time and are expected to continue to grow with improvements in upstream technology. The recovery factor depends on the cost of oil extraction. The earth contains enormous volumes of extra-heavy oil and bitumen. The technology exists to extract them, but the cost is high compared to that for conventional oil reserves. Technology currently exists to increase the effective volume of liquid hydrocarbon reserves through the conversion of solid hydrocarbons (coal) and gaseous hydrocarbons into liquid hydrocarbons. Recent developments have reduced the cost of these processes (IEA 2001c).

## **Energy Emissions**

What is the potential for reducing the greenhouse intensity of non-renewable energy supply? From the perspective of future carbon emissions associated with coal-fired power generation, the data suggest that a 20% cut from present emission levels is certainly within reach. This reduction would involve no carbon abatement measures and is a result of technological change and associated efficiency improvements.

To take one example, the current net efficiency of coal-fired electricity generation is about 33% efficient at the global level. State-of-the-art conventional coal has an

efficiency of 39%, but still holds quite a small market share in the world as a whole. Several clean coal technologies with efficiencies in the mid-40% range have already crossed the threshold to commercial maturity. Moreover, the favourable economics associated with Integrated Gasification Combined Cycle (IGCC) and Pulverised Fluidised Bed Combustion (PFBC) systems make these technologies very attractive as strategic components of utility supply planning. For IGCC systems, the higher energy efficiency reduces fuel use per kW and reduces total electricity generating cost even taking into account the slightly higher capital cost of introducing the new technology, while also reducing carbon emissions.

As bright as the prospects for coal seem to be, one should note that the greatest true carbon reduction potential can be realised with natural gas. Although the environmental performance of coal-fired electricity generation definitely benefits from 'Borrowing' combined-cycle technology and adopting, in part, natural gas properties, it is obvious that methane remains the superior fuel, with half the carbon emissions of coal at half the cost (Energy, 1993).

## **NATURAL GAS**

Natural gas has a fundamental advantage over oil and coal in terms of reducing carbon emissions because of its lower carbon-to-hydrogen ratio. Economical conversion of natural gas streams to liquid products such as fuels and commodity chemicals will allow full use of natural gas supplies while addressing the issue of greenhouse gas emissions. However, research and technology advances are needed to improve conversion processes for liquefied natural gas.

### **Power Generation Technologies**

Natural gas combined-cycle (NGCC) power-generation systems are highly promising for emissions reduction in the near term. These systems are revolutionising the power industry. They have two important advantages over other options: high efficiency and low levels of pollutant and greenhouse gas emissions. Combined-cycle gas turbines (CCGTs) can achieve system efficiencies in the range of 50 per cent or above. This high efficiency is achieved by combining a gas turbine with a heat recovery steam generator.

The conversion of existing coal-fired power plants to operate on natural gas can significantly increase the efficiency of power generation and reduce carbon emissions. The simplest approach is site repowering, where existing power plant site is reused with an entirely new NGCC system. This approach provides the highest cycle efficiency but requires a greater capital investment. In the more conventional approach of steam turbine repowering, a new gas turbine and heat recovery steam generator are used with the existing steam turbine and auxiliary equipment. Because of equipment age and the fact that the steam turbine was designed for linkage with a coal-fired boiler, this approach results in lower efficiency than site repowering and hence higher operating cost, but has a lower capital cost.

A gas turbine can also be coupled to the existing coal boiler, with 80 per cent of the coal firing being maintained. Such an approach could reduce CO<sub>2</sub> emissions by 35 to 40 per cent with only minor dislocation (IEA 2000).

## **Emissions**

Because of its highly competitive cost and its cleanliness and efficiency in conversion, and because the combustion turbine with or without combined-cycle technology is relatively inexpensive and can be put in place quickly, gas is the fuel of choice for new electricity capacity additions in the United States and Europe, enjoying a significant economic advantage over new coal plants. Efficiencies of NGCC systems are continuing to improve, with some achieving efficiencies of 52 to 55 per cent., and, in those recently built in the United Kingdom and Korea, conversion efficiencies approaching 60 per cent.

Carbon dioxide emissions from NGCC plants are approximately 50 per cent lower than emissions from conventional coal-fired plants. Switching from coal to gas in existing plants is limited primarily by natural gas availability and deliverability. Supply problems aside, if market and regulatory conditions favoured retirement of old coal plants and their replacement by NGCC plants, this option alone could meet the Kyoto targets within the electricity sectors of many countries, as the U.K. experience has indicated.

Limitations on the availability and deliverability of natural gas restrict the addition of new gas-fired capacity in specific areas. In addition, economic penalties associated with mandated replacement of existing coal plants with natural gas plants can be high. Overcapacity in power generation at present limits the rate of market penetration of new NGCC plants.

The potential for social dislocation is a local, regional and national barrier to large-scale shifts from coal-fired generation to generation based on natural gas. Concern over the need for diversity in fuels and in fuel supplies may also arise after 2010. Moreover, the price of gas could increase, which could shift the economics in favour of clean coal technologies (IEA 2000).

## **Gas Supply**

The long-term impact of technological advances on the way in which gas reserves are developed and transported could be very great. Estimates of conventional gas resources suggest that there will be ample resources to support the projected growth in supply until well beyond 2020. Nevertheless, the marginal cost of supply could increase sharply in the long run as the nearest-to-market and lowest-cost conventional resources, especially in large fields, are depleted. This may lead to greater emphasis on unconventional resources, such as coal-bed methane, tight gas, ultra-deepwater resources and arctic resources. There is undoubtedly a huge potential for supplying gas from these sources, although development costs could be high. Trends in development costs will depend largely on successful research and development.

Gas hydrates are another potential long-term source of natural gas. Natural gas hydrates are solid, crystalline ice-like substances composed of water, methane, and usually a small amount of other gases, with the gases trapped in the interstices of a water-ice lattice. They form under moderately high pressure and at temperatures near the freezing point of water. Hydrate deposits are found throughout the world on subsea continental shelves and slopes and in permafrost regions. Hydrates primarily occur at the base of the continental margins at depths exceeding 500 metres. They are generally located between 100 and 500 metres below the water-sediment interface. In Arctic areas, they occur at very shallow depths due to the low mean surface temperatures in these regions. Very large accumulations have been identified in the last twenty years, particularly off the coasts of Japan, the east coast of the United States, British Columbia, New Zealand and New Caledonia.

Gas hydrates are the world's largest hydrocarbon reservoirs. If the technology is developed to exploit them economically and in an environmentally acceptable way, hydrate resources could meet any conceivable level of gas demand for centuries to come and would transform the fossil-fuel supply outlook.

Little is known so far about gas hydrate reservoir conditions and possible production methods. One of the most appealing aspects of this potential new gas source is that large deposits are located near the centres of high demand. Another major motivation for seeking to produce gas from hydrates is their high concentration of energy, many times that of conventional gas deposits. Median estimates of the amount of methane in worldwide gas-hydrate accumulations is some 100 times greater than the generally accepted value for conventional methane reserves.

Methods for producing gas from hydrates on a commercial scale have yet to be developed. For this reason, gas hydrates must be considered a potential rather than a confirmed energy resource option. Production, if possible, is unlikely to be economic until well beyond 2020.

Further improvements and cost reductions in transporting gas to market are possible beyond 2020, although major technological breakthroughs appear unlikely given the mature state of pipeline and LNG technology. The biggest opportunity for reducing the costs of pipeline transportation is probably through economies of scale, with the development of higher-capacity pipes operating at higher pressures. It has been suggested that natural gas could be transported by ship like LNG, but in the form of hydrates. The energy density of hydrates is about 170 times that of conventional natural gas, but is only a quarter of that of LNG, so that much bigger carriers would be needed to transport the same amount of energy. However, hydrates can, in principle, be transported at atmospheric pressure and relatively mild temperatures compared to LNG, so that the overall capital and operating costs would probably be lower per Mbtu transported.

There may be greater scope in the long term for advances in gas-to-liquids technology, including the development of higher-yielding catalysts and improved thermal efficiency of the various processes involved in converting natural gas feedstocks. GTL and/or similar gas-conversion technologies could revolutionise the gas industry by facilitating the development of reserves currently considered to be "stranded" by their small size and remoteness from markets. Producers may consider

various means of exploiting reserves, including some combination of LNG, GTL or gas-to-chemicals. Such tailored packages could render the development of more associated oil-and-gas fields economically viable (IEA 2001c).

## **Natural Gas in Australia**

Significant demand growth for natural gas in Australia is forecast for the current decade, with an acceleration compared to the long-term trend in the first half of the decade. This means that gas will overtake coal to become the second largest primary energy input. The demand growth is expected essentially from the power generation and industrial sector. The share of natural gas of national gross power generation is expected to rise from 10.6 per cent in 1999 to 20 per cent in 2010. The industrial sector, especially minerals processing, is thought to have the second largest demand growth potential.

Australia's recoverable natural gas reserves were estimated by the government to amount to more than 91 times current annual production as of December 1998 (IEA Energy Policies in Australia, 2001). Gas transportation has historically developed largely within state boundaries. Only a small amount of interconnection exists at present. One reason for this is the huge distances involved, but low population density outside the south-eastern coastal region also plays a role. Both factors tend to constrain the economic viability of pipeline investment. However, in the past decade the total length of Australia's transmission pipeline system has doubled. A further major expansion in pipelines is anticipated in the coming decade.

Three policy strands – competition in the gas market, increasing interconnection and promotion of LNG exports – can be expected to bring substantial benefits to Australia in terms of extracting wealth from gas reserves, establishing an efficient gas supply system that minimises costs and ensures a high level of system security, and providing some diversity to the national energy market (IEA 2001b).

## **COAL**

### **The Market for Coal**

Coal resources are vast and widely distributed around the world. This gives coal a major advantage, from an energy-security perspective, over other fuels. However, only some of these resources are economically recoverable using current technology. Nonetheless, using estimates of proven coal reserves (coal that is both technologically and economically recoverable), today's world reserve base represents more than 200 years of current production. The outlook for coal production and supply costs is subject to less uncertainty than are those for oil and gas. Continued productivity gains should result in some further cost reductions. The biggest uncertainty for coal supply concerns demand, which in turn is heavily dependent on how coal-combustion technologies develop in response to environmental worries.

While breakthrough technologies in coal mining are unlikely, there is ongoing scope for significant productivity gains. Where conditions are economically attractive for new investment, there is no shortage of unexploited supply opportunities. The open



and competitive nature of the coal supply chain and the steady growth of international trade mean that these opportunities could be readily exploited. Prices could remain highly competitive, especially if oil and gas prices rise in the long term, although coal may be penalised by its high carbon content (IEA 2001c).

### **Energy Efficiency**

The average energy efficiency of a new coal-fired plant today is about 34 per cent but can be expected to reach 50 to 60 per cent in the medium-to-long-run (IPCC 1996). The majority of the coal used in electricity production is burned in pulverised fuel (PF) boilers heating water to drive steam turbines. However, these PF turbines are inefficient in conversion to energy and give rise to high levels of emissions. These disadvantages have encouraged research into efficiency improvements (better turbines, higher boiler temperatures), alternative methods of combusting coal (gasification, fluidised bed combustion), co-firing with other fuels, and even conversion of coal into alternative types of fuel (such as liquefaction or pyrolysis).

Coal's advantages from the point of view of cost and energy security over other energy sources may be eclipsed by the need for coal to satisfy new environmental standards. The long-term prospects for coal may well depend, in particular, on developments in coal-combustion technology that reduce or eliminate carbon emissions or in carbon-sequestration technologies. Coal currently emits twice as much CO<sub>2</sub> per kWh as natural gas in power generation. In addition, costly investments are needed to reduce SO<sub>x</sub>, NO<sub>x</sub> and particulate emissions. These disadvantages have contributed to a growing preference for natural gas by power companies that have to meet increasingly stringent environmental regulations.

### **Clean Coal Technologies**

Clean Coal Technologies (CCTs) will, therefore, play a vital role in the long-term prospects for coal supply. The current generation of CCTs does not achieve environmental performance that would allow coal to compete effectively in a carbon-constrained world. Not even the most cost-effective versions are commercially viable yet. One of the most promising CCT developments is Integrated Gasification Combined Cycle (IGCC) power generation, which is currently under development in Europe, the United States and Japan. IGCC systems may reach thermal efficiencies above 50%, compared with 33% to 40% achieved by conventional sub-critical plants. They also produce significantly lower emissions of SO<sub>x</sub>, NO<sub>x</sub> and particulates. Other advanced cycles are also under consideration, but are at a less advanced stage of development. Hybrid Combined Cycles, for example, combine the best features of coal gasification and combustion technologies in a two-stage process (IEA 2001c).

Most modern conventional coal-fired power plants that use the steam cycle are subcritical pulverised coal (PC) plants with steam drum boilers. Modern PC boilers which have increased efficiency and are equipped with emissions control technologies for SO<sub>x</sub>, NO<sub>x</sub> and particulates, are proven and effective, and are contributing substantially to the reduction of pollutants from existing fossil fuel units.

However as emission standards have become more rigorous, and national commitments to reduce CO<sub>2</sub> emissions have involved, there is a need for new clean

coal technologies – circulating fluidised bed combustors (CFBC), pressurised fluidised bed combustors (PFBC), integrated gasification combined cycle (IGCC), and supercritical pulverised coal (SC/USC) – aims to improve economic and environmental performance by attaining higher levels of energy efficiency, and by using advanced methods of pollution control (IEA 2001a).

Fluidised bed combustors have been in operation since the early 1900s. Their original applications were as early fuel gasifiers and catalytic crackers. Utilisation of the technology for coal combustion advanced in the 1960s and 1970s in Europe and North America. Crushed coal and limestone are injected into a bed which is “fluidised” by the primary and secondary combustion air.

CFBC technology offers several benefits. Emissions of  $\text{SO}_x$  and  $\text{NO}_x$  are significantly reduced without the addition of expensive flue gas control technology. The boilers are extremely flexible, allowing a wide range of fuel qualities and sizes to be consumed.

Disadvantages of the technology are that  $\text{NO}_x$  and  $\text{SO}_x$  emissions may exceed stringent current standards in some areas when the boilers are operated at less than full load. Further, the nature and impacts of CFBC residues (primarily ash) are not fully understood, resulting in some reluctance to approve low cost disposal.

Although CFBC boilers have achieved considerable success, the technology needs to be pushed to a larger scale. Most successful units are 150 MW or less. In addition, thermal efficiency remains at or below the level of conventional PC systems. Parasitic power demand for bed fluidisation and lack of commercially available supercritical models leave operating performance in a range well below the thermal efficiencies desired to mitigate  $\text{CO}_2$  emissions and reduce fuel consumption per unit of electricity produced. Major CFBC manufacturers are now offering to build large scale supercritical boilers as demonstration projects, but none are under construction at this time (IEA 2001a).

The design of pressurised fluidised bed systems integrates the emission reduction advantages of a conventional steam cycle fluidised bed with the added efficiency of a topping or expansion cycle. In a PFBC unit, hot, high-pressure gas leaving the combustor is exploited directly by using an expansion turbine.

The advantages of PFBC technology are that it offers significantly higher thermal efficiency, units are more physically compact –allowing greater on-site flexibility, sulphur capture is achieved with lower limestone injection and  $\text{NO}_x$  emissions are lower than experienced with traditional CFBC technology.

PFBC units suffer in that  $\text{NO}_x$  emissions can increase as boiler load is reduced. In addition, gases used in the expansion cycle are high alkali and contain a high concentration of particulate matter, which causes erosion in the passageways of the expansion turbine, and to the turbine blades. Some parts of the turbine equipment may

have to be regarded as expendable items subject to routine replacement. Although this does not necessarily affect unit availability, it can significantly increase maintenance costs.

The advancement of PFBC technology currently focuses on improving the efficiency of the conventional steam cycle and mitigating the erosion effects to boiler tubing and in the expansion cycle. Additionally, research is directed towards finding means to increase the PFBC gas exit temperature so that the efficiency of the expansion cycle can be improved (IEA 2001a).

Integrated gasification combined cycle technology is the combination of two established technologies: coal gasification for the production of synthesis gas; and gas combined cycle power generation. However, the combination of these two tested technologies, and achievement of necessary thermal efficiencies, presents some difficult problems.

IGCC offers the advantage of recovering potential pollutants like sulphur and particulates in concentrated form that reduces the cost of removal. The clean gas can be used in a combined cycle electricity plant to give high efficiency; and, the ash residue is produced in a benign form easy to dispose of.

Current development work on coal-fuelled IGCC feature entrained flow, medium pressure, oxygen blown slagging gasifiers. When coal is gasified for chemical production, hot ash laden gas is immediately cooled, the ash solidifies and is scrubbed out of the gas stream. In cases where the primary purpose of the system is to generate power, the heat from the gas stream has to be recovered in order to achieve acceptable thermal efficiency. This is generally accomplished by directing the hot, ash laden gas directly into a special boiler designed for its characteristics. The capital cost and complexity of these boilers significantly raise the price of electricity generated with IGCC.

Current research and demonstration is targeted at increasing the efficiency and reducing the cost of IGCC. This involves attention to the gas turbine/steam turbine combination, increasing unit size, increasing the turbine inlet temperature and improving the flexibility of gasifiers for taking a range of solid and liquid fuels – including ‘opportunity’ fuels which are produced by petrochemical refining. Currently, there are five IGCC plants commissioned or under construction in Europe which are designed for use of petroleum coke and residues (often very hazardous substances) as inputs to create a feed stock for lighter product refining and the generation of electricity (IEA 2001a).

Most subcritical boilers have a steam drum where a mixture of water and steam from the boiler is separated into water and steam. The water is recirculated to the boiler while steam passes to the superheater. Supercritical (SC) boilers are based on the ‘once through’ principle – an arrangement where the water flow matches the rate of evaporation, and allows steam pressure to be increased beyond the point where the

density of steam and water are equal. This allows steam conditions with much higher temperature and pressure. As the technology evolved, the development of new ferritic steels permitted boilers to be specified with steam conditions of even higher temperatures at a given steam pressure – ultrasupercritical (USC) boilers.

SC and USC boilers offer the advantage of significantly higher thermal efficiency than similar sized subcritical units. Efficiencies of 40% to 45% have been achieved with SC units while USC units have reached 47%. This represents an increase over typical PC subcritical units of 14% to 20% and permits electricity generation with less fuel input and lower emissions of greenhouse gases (IEA 2001a).

IGCC projects have received the highest level of support for research and demonstration, particularly in the United States and the European Union. PFBC projects have also received significant support in the above regions as well as in Japan. Research and demonstration of CFBC projects is most prevalent in the United States, while work on SC/USC projects is centred in the European Union.

### **Coal in Australia**

Australia has a very substantial coal resource. It is the world's sixth largest coal producer and, since 1984, the largest exporter of hard coal, responsible for between 35 and 40 per cent of world sea-borne trade. Exports are fairly evenly divided between thermal coal and coking coal. Brown coal is used domestically, mainly for power generation in plants sited close to mines. Hard coal and lignite together account for some 80 per cent of electricity generation.

Australia has economically recoverable hard coal reserves of more than 210 times current production. The Australian hard coal industry has the capacity to expand production substantially to meet possible future demand increases. Australian hard coal is generally of high quality with high calorific value, moderate ash content and low sulphur and heavy metal content. Over recent years industry productivity has increased by around 20 per cent per annum (IEA 2001b).

The activities of the CRC for Black Coal Utilisation are noteworthy. The research focus at this institution is on how Australian coals will perform in advanced technologies. There are five research programs:

1. The development of rapid and accurate analytical techniques for characterising Australian coal relevant to utilisation processes;
2. Improving our understanding of the reactivity of coal under the conditions of temperature and pressure used in the new clean coal technologies;
3. Studying the relationships between coal ash properties and the processing chain in power generation and metallurgical applications;
4. Environmentally-sensitive gaseous, liquid and solid waste concentrating on prediction of N and S species formation and understanding of behaviour; and
5. Bringing together these research programs and other information technology assessment in process simulation models of the major advanced coal processes.

The CRC for Clean Power from Lignite undertakes research to develop power generation technologies that are efficient and cost competitive. The techniques relate to both currently operating power stations and to the most advanced configurations of plant utilising Australia's vast reserves of low cost lignite. The Centre has a balanced program involving fundamental research, applied research, technology development and commercialisation. A coal drying, dewatering and characterisation program will address water removal which is one of the key issues in improving the efficiency of lignite utilisation in power generation. Research also focuses on thermal efficiency and operational improvements from existing power plant.

The Latrobe Valley Generators Group, comprising the valley's five power-station operators, has urged the creation and funding of a new power station to trial the Mechanical Thermal Expression Technology (MTE). It would develop this technology from its current testbed status to a full-scale demonstration plant and power station. MTE technology dries brown coal before it is burnt, thereby reducing the amount of carbon dioxide emitted per unit of power produced. The technology would result in substantial greenhouse savings on current technology while facilitating a longer-term use for Victoria's abundant brown coal deposits (Hopkins 2001). New exploration tenders let for Victorian brown coal envisage the use of geosequestration of carbon to cut down greenhouse gas emissions ((Dabkowski and Myer, 2002).

## **NUCLEAR ENERGY**

### **Global Uranium Supply Outlook**

The outlook for the global uranium market can be characterised in the following terms.

1. The needs of nuclear power generation are currently met by primary production of uranium and by stockpiles and inventories. Supply is secure for the next twenty years.
2. Future growth in nuclear power is likely to occur in Asia (mainly Japan, China and South Korea), but, although 30% of existing plants may be retired by 2020, there are signs of renewed interest in some OECD countries.
3. Uranium reserves are abundant and concentrated largely in OECD countries (notably Australia, the United States and Canada).
4. Primary uranium production is likely to rise in the medium term, while secondary sources (inventories, stockpiles and recycled materials) will play an increasing role in meeting reactor requirements.
5. There is much uncertainty about the amount of defence-related uranium that may eventually reach the commercial market.
6. Uranium prices will probably remain at modest levels in the medium term, but they may rise over the longer term as secondary supplies are depleted (IEA 2001c).

## **Demand for Nuclear Power Generation**

In 1997 nuclear power provided 17% of global electricity output. Nuclear power was introduced in the 1950s and gained momentum after the oil shocks of the 1970s. Annual capacity additions averaged around 12 GW in the 1970s and 18 GW in the 1980s, but slowed to just 2.5GW per year in the 1990s, primarily because lower fossil-fuel prices and lower up-front capital requirements made generation from coal and gas more attractive. Increasing public concern about nuclear safety was also a factor, particularly after the Chernobyl accident in 1986.

In the WEO 2000 Reference Scenario, new nuclear capacity to be built up to 2020 amounts to a little over 100 GW. Some 135 GW of existing nuclear capacity will be retired, and the projected share of nuclear power in the global electricity mix will drop to 9%. Expected output from nuclear power plants is set to decline more slowly than installed capacity because nuclear plants will operate at higher capacity factors. This trend is already confirmed in several OECD countries, where electricity-driven reforms have encouraged improved performance to reduce costs.

OECD countries currently account for more than four-fifths of nuclear electricity production. Nuclear provides nearly a quarter of the OECD's electricity output and is the second largest source of electricity after coal. Retirements expected from now to 2020 are about 30% of existing plants. Despite the fact that nuclear systems produce no new CO<sub>2</sub> emissions, new construction in the OECD will be limited for three reasons. First, because nuclear faces strong competition from fossil fuels, especially from combined-cycle gas turbines. High capital costs are the most important economic factor weakening the prospects for new nuclear power. Second, because a large number of countries have phased out, or plan to phase out, nuclear power. Belgium, the Netherlands, and Sweden have made political decisions to phase out the use of nuclear power. Third, most utilities are no longer willing to order new nuclear plants, principally because community opposition can lead to construction delays that result in unattractive economics and perceived financial risk.

Most of the future growth in nuclear power will occur in Asia – South Korea, Taiwan and India (IEA 2001c).

## **Technology and Production Costs**

Maximising the lives of existing nuclear plants is potentially a cost-effective route to providing considerable amounts of carbon-free energy in the near to mid-term.

Technological developments in the nuclear-energy sector focus on ways to reduce the use of uranium, either through increasing the efficiency of its use or through reprocessing. Technology also seeks ways to achieve economic competitiveness with other ways of generating electricity. Reprocessing is a currently available technology, which could supply large uranium requirements in the long term.

Relative to other energy sources, current nuclear power plant designs have very high capital costs per MW. Operating and maintenance costs are also higher. These costs are not fully offset by the relatively low fuel cost of nuclear power plants. No country

has a complete concept of the facilities and operations that will be necessary for decommissioning and waste disposal, thus there is considerable uncertainty in any cost estimate for future projects.

Specific goals of new plant designs are to reduce construction cost, construction time, operating and maintenance costs and fuel-cycle costs, while improving operating safety. Approaches to achieving these goals include:

- Reducing the number of components in the primary and secondary system, to lower capital and operating costs;

- Using factory assembly and modularisation, to reduce construction costs and schedules;

- Reducing the reactor size to 300 MW or less, to reduce the cost of the generation unit and shorten the construction schedule;

- Simplifying and reducing the cost of all safety systems and processes, ranging from hardware systems to inspection and testing;

- Achieving waste management goals, such as using thorium as a major component of the reactor fuel and reducing the specific volumes of low- and medium-level wastes.

One new reactor technology that is attracting a great deal of interest is the high-temperature gas-cooled reactor. Higher operating temperatures increase the amount of energy the system can convert to electricity. Proponents of this technology claim that it is safer and quicker to build than existing reactor designs. It also creates less spent fuel and can be built on a smaller scale.

Nuclear fusion, in which energy is produced from the reaction between isotopes of hydrogen deuterium and tritium, may be a longer-term option. Eventually, reactions involving deuterium only or deuterium and helium may be used. Deuterium is abundant, as it can be extracted from water. Tritium does not occur naturally but can be manufactured from lithium, which is plentiful in the earth's crust. Extensive R&D by several countries has so far yielded disappointing results and fusion technology is unlikely to be commercialised until 2050 at the earliest (IEA 2001c).

# Harnessing Renewable Energy

## Overview

The global renewable energy market will continue to grow. The WEO 2000 Reference Scenario projects that demand for RE will grow by 2.3% p.a. over the next two decades. Nonetheless, their share in the global energy mix will probably remain small in the absence of determined market intervention measures. In the OECD, most of the growth will be in the power sector, notably from increased use of wind and bioenergy. The share of non-hydro renewables in electricity generation increases from 2% in 1997 to 4% in 2020 under the Reference Scenario. However, the OECD Alternative Power Generation Case shows that if new policies and measures are introduced to support renewable energy, the projected share of non-hydro renewables in the OECD electricity generation mix could rise to nearly 9% in 2020. In developing countries, bioenergy will continue to play an important role in energy supply. However, increased urbanisation and rising per-capita incomes will cause the share of bioenergy in total developing country energy demand to decline from 24% now to 15% in 2020. Hydropower, an abundant indigenous resource in many of these countries will continue to expand, doubling over the next twenty years.

Renewable energy resources are plentiful. The study shows that renewable energy has the technical potential to meet large portions of the world's energy demand. Every region or country is endowed with renewable resources, but the potential varies among them. Sunny areas have the greatest potential for solar energy use, Coastal areas, plains and offshore locations have the greatest wind potential. Geothermal energy potential is abundant in areas with volcanic activity. Bioenergy is found in all countries with forests and a developed agricultural sector. Waste is most available where population densities are highest. Under current market conditions, the economic potential of renewables is much lower. Over the next twenty years economically recoverable resources will increase as a result of technological improvements that reduce costs and the economies resulting from expanding markets. New market valuations, however (e.g. of carbon emissions) may be just as important. Factors that may limit supply are competing land uses and non-dispatchability.

Substantial benefits arise from increased use of renewables, particularly environmental protection and increased security of supply. The WEO 2000 Alternative Power-Generation Case shows that CO<sub>2</sub> emissions from the OECD power-generation sector could be reduced by 6% compared to the Reference Scenario.

Developing renewable energy will require significant investment in infrastructure. In the OECD, investment in bioenergy, wind, geothermal and solar projects is expected to be in the order of US\$90 billion over the next twenty years in the Reference Scenario, amounting to 10% of total power sector investment over that period. In the Alternative Power Generation Case this investment is expected to rise to US\$228 billion or 23% of total OECD investment in new power generation capacity over the next two decades.

Substantial cost reductions will be required. Most forms of renewable energy are not competitive when their costs, as measured in today's markets, are compared with



conventional energy sources. Natural gas-fired CCGT plants are currently the preferred option for new power-generation projects. Such plants will continue to be attractive as long as natural-gas prices remain low. In many developing countries, coal is an abundant indigenous resource and the most economic option for power generation. The costs of RE technologies have already fallen but further reductions are needed for them to compete with the least costly fossil-fuel alternatives. The rate at which costs will decline in the future is uncertain. RE can be cost effective in specific applications. Costs are often highly site specific and the best sites used first.

Increasing the share of renewable energy sources in the energy mix of OECD countries will require continuous and large government support. R&D support has played an important role in the emergence of renewables. Maintaining this support could help accelerate the development of renewable energy. Strong support at the early phase of development can lower the cost of renewable technologies. As renewables gain market share, government involvement could be reduced (IEA 2001c).

## **Research and Development**

The success of current and planned R&D efforts will be among the key factors that determine whether advanced renewable-energy technologies capture a significantly higher share of global primary energy supply in the longer term. The principal goals of these R&D efforts include reducing the cost of energy production from renewable resources, increasing the quality of energy delivered and the reliability of renewable-energy supplies, and improving the matching of energy supply with end-user demand so as to reduce costs and losses in energy transport and distribution. Energy storage technologies are also important to greater use of renewable-energy technologies.

The following are some examples of R&D efforts that hold promise for the long term:

- The development of advanced power cycles using gasification technologies for the use of biomass for electricity supply;

- Improved wind turbine design for wind electric systems;

- The development of multi-junction, stabilised, thin-film solar cells using amorphous silicon or tertiary semiconductors in photovoltaic power systems;

- The thermochemical conversion of solar energy into chemical carriers (such as hydrogen, synthesis gas and metals);

- Fundamental research to demonstrate the technical feasibility of advanced solar photo-conversion technologies which use the energy of sunlight to produce fuels, materials, chemicals and electricity directly from renewable sources such as water, carbon dioxide and nitrogen;

- Improvements in the performance of parabolic trough and dish concentrator systems for the conversion of sunlight into electricity at large, grid-connected, central-station facilities;

- Advanced hydropower technologies that eliminate adverse environmental effects such as fish entrainment and the alteration of downstream water quality and quantity;

- The extraction of heat from geothermal “hot dry rock” (IEA 2000)

The main focus of current research on new supply technologies is on hydrogen production and use. Hydrogen technology holds out the prospect of large-scale energy supply with minimal environmental impact. The amount of carbon and other emissions from hydrogen-based energy will depend on how the hydrogen is produced. Fossil fuels may provide the initial source of energy for producing hydrogen for use in fuel cells. Much later, depending on how technology advances, hydrogen production may be based on electrolysis of water using nuclear or renewable energy. In that case, net carbon emissions could be negligible. Carbon sequestration – the separation of CO<sub>2</sub> from fuels and its storage in oceans or geological formations - could also have a profound impact on the long-term prospects for energy supply, if technologies are competitive.

### **Renewable Energy in Australia**

The objective is to achieve further development and commercialisation of renewable energy technologies and the growth of manufacturing in Australia. This would build on the existing growth of stand-alone power supply systems in rural and remote areas, solar hot water systems, and small hydro-electricity schemes. The Commonwealth Government is mandating a major expansion of renewable generation capacity by 2010.

Incentives for the development of renewable energy in Australia are offered through the Commonwealth's industry policy. Mandatory targets for the uptake of renewable energy in power supplies have been introduced, the objective being to lift the share of total electricity generated supplied from renewable sources from 2 per cent currently to 12.7 per cent in 2010. An innovative new e-commerce market for trading renewable energy has now started operating. A number of State governments in Australia have also encouraged the use of renewable energy.

Research and development into renewable energy is supported through Cooperative Research Centres and the provision of government funding for research. The Australian CRC for Renewable Energy is an important leader in renewable energy research in Australia. The areas of research expertise are power generation, storage and conditioning, energy efficiency, system integration. The Centre undertakes research in four clearly defined and linked programs. These are all essentially analyses of efficient and cost-effective renewable energy delivery systems. The research deals with a number of sources of energy including photovoltaics, solar-thermal and wind. These four research programs feed into a fifth and unifying program, Systems Optimisation and Integration. From this program a Demonstration Program with links to commercialisation and marketing, targeting the Asia/Pacific Region. The Education and Training program has an industry focus.

### **SOLAR ENERGY**

The solar energy resource is abundant. The amount of energy received at the surface of the earth is called "insolation". Solar power can be best exploited in areas with high annual insolation, where electricity demand is also greatest during daylight hours.

Electricity demand in some countries is higher in the summer when the sun shines longest. Countries with a summer peak include Italy, Greece, Japan, Korea, USA, Mexico and Australia. In Northern Europe, demand is higher in winter months, when sunlight is limited due to very short days and solar power may not be available towards the end of the day, when residential demand starts to peak.

## **Photovoltaics**

Photovoltaic (PV) technology transforms the energy of solar photons into direct electric current using semiconductor materials. The basic unit is a photovoltaic or solar cell. When photons enter the cell, electrons in the semiconductor material are freed, generating direct electric current (dc).

Solar cells are made from a variety of materials and come in different designs. The most common semiconductor materials used in PV-cell manufacturing are single-crystal silicon, amorphous silicon, polycrystalline silicon, cadmium telluride, copper indium diselenide, and gallium arsenide. The most important PV cell technologies are crystalline silicon and thin films, including amorphous silicon.

PV cells connected together and sealed with an encapsulant form a PV module or panel. When greater amounts of electricity are required, a number of PV modules can be connected together to form an array. The components needed to transform the output of a PV module into useful electricity are called “balance of system” (BOS). BOS elements can include inverters (which convert direct current to alternate current), batteries and battery charge controllers, dc switchgear and array support structures depending on the use.

A PV cell converts only a portion of the sunlight it receives into electric energy. This fraction is the efficiency of the PV. Laboratory research has recently achieved efficiencies of 32%. In practice, efficiencies are lower.

The applications of photovoltaic technology directly linked with electricity production are outlined below.

1. Stand-alone (off-grid) systems. Using stand-alone photovoltaic systems can be less expensive than extending power lines and more cost-effective than other types of independent generation. Most of currently profitable applications are remote telecommunications systems, where reliability and low maintenance are the principal requirements. PVs also have wide application in developing countries, serving the substantial rural populations who do not otherwise have access to basic energy services. PVs can be used to provide electricity for a variety of applications in households, community lighting, small enterprises, agriculture, healthcare and water supply.
2. Grid-connected systems in buildings. When more electricity than the PV system is generating is required, the need is automatically met by power from the grid. The owner of a grid-connected PV system may sell excess electricity production. Net metering rules can promote this.
3. Utility-scale systems. Large-scale photovoltaic power plants consisting of many PV arrays installed together, can provide bulk electricity. Utilities can

build PV plants faster than conventional power plants and can expand the size of the plant as demand increases.

The cost of a PV system includes the cost of the photovoltaic module and the BOS costs. The installation cost of a typical, basic photovoltaic system ranges from US\$5000 to US\$7000 per kWp. The cost of the module is 40-70% of the total system cost depending on the application.

Because of its flexibility, modularity and simplicity, photovoltaic technology can be a cost-effective alternative option in many remote applications in both developing and OECD countries. The current cost of a 50 WPV system designed to meet the very basic needs of a rural household in a developing country is around US\$500. Additional expenses include maintenance costs and battery replacement every three to six years. PV systems are most likely to be competitive where fuel has to be transported a long way. Lack of financial resources for the initial investment is a major obstacle to widespread use of PV. Further reductions in the cost of PV systems are likely.

Buildings are a large potential market for grid-connected photovoltaic systems. Substantial reductions in capital costs will be necessary to make this technology commercially viable. The competitiveness of PV electricity in buildings depends, with technology given, on the price of electricity that the owner of the PV cell would otherwise have to pay to a local electricity supplier. Uncertainty over future electricity prices could be an important barrier to the development of PV markets, although it can also be a stimulus in regions that lack generating capacity. Over the past few years electricity prices to final consumers in the OECD area have tended to decline. If electricity prices increase in the future, PVs will become more competitive.

Recognition of the environmental benefits of renewable energy may encourage some consumers to invest in PVs, despite the higher costs. This is likely to be one of the main drivers of market growth over the next twenty years.

Only a small percentage of current PV capacity has been installed by utilities. It is unlikely that PV technology for utility-scale generation will become competitive over the next twenty years. Even if it did so, utilities are likely still to prefer to meet peak load with dispatchable devices with very low capital costs, such as gas turbines.

Installed PV capacity was 516MWp in 1999. Capacity has increased fivefold between 1992 and 1999. Nearly half the total PV capacity is used in off-grid application. This share is particularly high in Mexico, Australia and the United States. On-grid applications are mostly distributed (in buildings), while centralised PV production accounts for less than 7% of total PV capacity.

Japan has the highest PV capacity (205 MWp in 1999). This is a result of the “Residential PV System Dissemination Program” which provides investment subsidies to individuals, real estate developers and local organisations involved in

public housing projects. Japan aims to reach 5 GW of installed capacity by 2010, and increase by a factor of 25, requiring annual capacity additions of 436 MWp over the next ten years. This will represent a considerable challenge since the rate of installation in 1999 was only 72 MWp.

The United States had a PV capacity of 117 MWp in 1999. The most important initiative related to PV development is the Million Solar Roofs Program, which aims at installing solar energy systems on one million US buildings by 2010. This effort included two types of solar technology – photovoltaics that produce electricity from sunlight and solar thermal panels that produce heat for domestic hot water, space heating or swimming pools.

In Germany, there were 69.5 MWp of installed capacity in 1999. The 100,000 Roofs Solar Power Program provides low interest loans for 10 years. In addition to central government support, 10 of Germany's 16 federal states support PV through various incentives. The aim of the 100,000 roofs program is to reach a total installed capacity of 300 MWp in 2003. The "Renewable Energy Promotion Law" set an attractive buy-back tariff for PV-generated electricity.

The other main countries with significant installed PV capacity in 1999 were Australia (25MWp), Italy (18), Switzerland (13) and Mexico (13) (IEA 2001c).

Over the next twenty years, the use of PV technology is likely to expand, but its contribution to the global electricity mix will remain relatively small. On the other hand, PV may be the best technology to meet energy needs in remote areas and for building applications. Capital costs are expected to decline as demand for PV increases and larger quantities are produced. Most of the reductions are expected to be in PV module costs, rather than in the cost of BOS. The timing and rate of future cost reductions are uncertain.

Australia is an international leader in the field of photovoltaics. The Photovoltaics Special Research Centre at the UNSW has a number of world firsts to its credit. These include the buried contact solar cell and the breakthrough multilayer thin film technology. Australia also has several component makers designing and producing a wide range of associated products. The research team at UNSW has developed world-leading technology in solar cells to convert sunlight directly into clean and green electricity. New 'thin-film' photovoltaic cells developed at UNSW promise to cut the cost of solar power by two-thirds.

The PV industry in Australia has been growing at around 30 per cent per annum. A new market for photovoltaic cells – in the roofs of residential buildings – is being

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cultivated. Australian PV manufacturers currently have almost 8 per cent of the international market – a figure that could increase in the future as more state-of-the-art Australian technology enters the market place. The explosive demand for photovoltaics has caused a steady drop in the cost of PV panels, further encouraging demand. UNSW works with its commercial partner, Pacific Solar (Environment Technology Centre (2000) and Environment Australia (2000)).

Almost two-thirds of the total installed capacity of photovoltaic cells in Australia is dedicated to remote applications including telecommunications and navigational aids; about 25 per cent is in domestic off-grid applications, and about 10 per cent in water pumping. Grid connected photovoltaics currently comprise a very small segment but this is growing rapidly. Some electricity analysts see a trend away from construction of large generation units close to fuel sources toward smaller generation units located at critical points in the grid. The factors driving this trend are (i) the desire to avoid market risk associated with the construction of large plant; (ii) the availability of cost-effective smaller scale technologies, (iii) the desire of distribution utilities to diversify their sources of supply, and (iv) technical system management benefits of distributed generation. These smaller units may be gas turbines or gas engines but renewable generation technologies, particularly PV, are also expected to play a part. The final extension of this shift is to actually locate the system at individual customer sites as in the case of PV roof-top systems (Redding, 1999).

## **Solar Thermal**

Solar-thermal technologies concentrate solar radiation onto a receiver, where it is converted into thermal energy. This energy is then converted into electricity. There are a number of technology options available, although they are at different stages of deployment. The most important technologies are the parabolic trough, the central receiver and the parabolic dish. Parabolic trough is commercially available and is the least expensive solar-thermal technology. The other two technologies are at the demonstration stage. They have, however, the potential to achieve higher conversion efficiencies and lower capital costs than parabolic-trough technology.

Solar-thermal technologies can be combined with fossil-fuel or thermal-storage technologies to provide firm peaking to intermediate load power. They take up a lot of space, currently 20m<sup>2</sup>/kW. Their water requirements are similar to those of a fossil-fuel steam plant. Water availability could be an important issue in arid areas, which are otherwise best suited to solar thermal plants. Considerable interest is now developing in solar thermal electricity in a hybridised configuration, where use can be made of steam cycle equipment already in place, such as in existing thermal power stations. Hybridisation of up to 25 per cent in a coal-fired boiler facilitates reliability, enhanced conversion efficiency and increased capacity.

Solar thermal technologies have very high capital costs and are not yet competitive with conventional technologies. Although capital costs of solar thermal technologies are likely to fall over the next twenty years, the cost of generating electricity from them will remain high. The contribution of solar thermal is likely to remain a small fraction of total solar power (IEA 2001c).

Significant technological work has been taking place in Australia on solar collector technologies. The Australian National University has developed a paraboloidal dish technology, and a demonstration plant is to be built by a consortium in New South Wales.

The market for solar-thermal heating systems took off in the 1970s as a result of high oil prices. Low oil prices in the 1980s reversed the trend and many solar-thermal companies went bankrupt. Improvements, both in technology and in efficiency, have led to a recent resurgence of the industry in many countries.

Solar hot-water heaters use the sun to heat either water or a heat-transfer fluid in collectors. A typical system will reduce the need for conventional water heating by about two-thirds. Individual water heaters are the most common application for solar thermal energy. Other uses of solar thermal energy include space heating and solar cooking. These are of limited significance currently.

The main barrier to implementing solar thermal energy on a large scale is cost, particularly the high up-front cost of equipment to collect and store solar energy. As in the case with most forms of renewable energy, environmental benefits are not reflected in costs and so they appear more expensive than conventional fuels. Solar thermal heating, however, produces no emissions during operation, although small levels of emissions are associated with the manufacture and installation of components and systems. Other barriers include the need for large collecting areas for large amounts of energy and intermittence (IEA 2001c).

The Australian company Solahart produces leading edge solar water heating appliances.

## **Passive Solar**

Passive solar designs optimise the use of solar energy to provide heating, cooling and lighting for buildings with little or no mechanical assistance. When passive solar designs are used, buildings are oriented in a way that they can take full advantage of the available solar energy. The most common features of passive solar heating are direct solar gain, thermal mass, and sunspaces. Direct solar gain involves the use of large areas of south (north) facing windows. Thermal mass refers to materials such as masonry and water that can store heat energy for extended time and can prevent rapid temperature fluctuations. In sunspaces, glazing allows solar radiation to enter an accessible but isolated space on the south (north) side of the building.

The two most common methods of passive solar cooling are the use of vegetation and natural ventilation. Painting buildings a light colour to reflect sunlight and keep them cool is also considered to be a passive solar construction technique.

Daylighting is the use of sunlight to replace electric lighting in a building. Windows provide light for the perimeter of buildings while atria, light-shelves and light-pipes, can transmit daylight into the interior of a building.

Passive solar energy has the potential to supply a large proportion of the energy needs for a properly designed building. Recent advances in technology and building materials have greatly expanded the potential for passive solar energy (IEA 2001c).

## **WIND ENERGY**

### **Overview**

Wind resources are available globally. The technically available wind potential greatly exceeds current electricity demand worldwide. Most estimates of wind resources do not include offshore potential, which is also large. Estimates indicate that, where wind is available, up to 10 to 20 per cent of a region's electrical generation capacity could be supplied by wind without adverse economic or operational effects. Beyond this point, provisions would need to be made for storage, backup and load management (Energy Technology and Climate Change, 2001).

Wind technology converts the energy available in wind to electricity or mechanical power through the use of wind turbines. The most important components of wind turbines are:

- The drive train, which contains the gearbox and the generator.

- The rotor, which is an assembly of blades, hub and shaft. The blades transfer the wind's power into the hub. A low-speed shaft connects the hub to the gearbox. Power is then transferred to the high-speed shaft and drives the generator.

- The tower, which carries the nacelle and the rotor.

- The electronic control system, which monitors the functioning of the turbine.

- The support structures, electrical interconnections and service facilities (IEA 2001c).

While wind power sites are predominantly land-based, present pilot studies with offshore wind power generation are interesting. Offshore production allows for locations with much higher wind speeds, and avoids major visual impact if located sufficiently far from the coast. Nevertheless, at this stage the promised benefits do not compensate for the extra costs of installation, electric cables and maintenance. At present wind is the renewable energy that has the greatest potential in absolute terms to reduce emissions of carbon dioxide, as is reflected in the various scenarios for future emissions (IPTS, 1997).

### **Costs**

As discussed above, the resource base is not an inherent constraint to the development of wind power. The challenge lies in delivering this potential to the markets at competitive costs. The main factors that influence the cost of electricity from wind



power are capital cost, the influence of wind conditions on economics, and the influence of technology on economics.

The capital cost includes the cost of turbines, their installation and grid-connection costs. Turbine costs have declined as the size of wind turbines has increased and manufacturers have increased production volume. In addition to cost reductions, improved blade designs and control systems have enhanced turbine efficiencies, thus lowering the cost of producing a unit of power. The location of a wind farm may have a major impact on the investment cost. Wind farms located away from existing transmission lines, the need for grid-reinforcement in remote areas, and associated transmission losses are all important considerations. The issue of transmission costs may become more important in the future as the best locations near transmission lines are used first.

Locations with higher wind speeds and with winds available for longer periods produce more electricity. Wind speed increases higher above ground. Higher wind speeds can be obtained by building higher towers. Taller towers may increase capital costs, but they reduce generating costs.

The increase in turbine size has brought cost reductions per kW of installed capacity because of economies of scale. Large rotors have contributed to this trend (IEA 2001c).

### **Grid Integration**

Wind is an intermittent source of energy. Wind speeds vary on an hourly, daily, seasonal and annual basis. Wind is best suited for areas where there is a correlation between wind speed profiles and electricity demand profiles. For example, in Denmark and California wind patterns tend to match demand. But this is often not the case.

The value of wind-generated electricity to the local grid is closely tied to when it is available and how predictable this availability is. Electricity output from wind farms can increase or decrease rapidly, and such changes cannot generally be controlled by the producer. Thus, grid integration is likely to be a critical issue in the development of wind power. Intermittence and low overall capacity factors reduce wind's value in meeting peak demand. Hence, equivalent conventional capacity or energy-storage capacity may be required, which entails extra costs.

A relatively low proportion of wind power in power generation might be acceptable, without the need to add new conventional capacity. In the near term, therefore, this issue is not likely to be a barrier to the development of wind power. It could become more important, however, as the share of wind in total installed capacity increases. Should this occur, wind producers would have to find ways of mitigating the higher costs resulting from intermittence. The main way to do this is by aggregation with other generators, particularly those that can follow the variations in the wind farm's output. The intermittence is closely intertwined with network organisation. Decentralised forms of network organisation based on bilateral contracts may help to

exploit wind power by shifting the intermittance issue directly to users, who are in the best position to deal with it by various market mechanisms (IEA 2001c).

## **Land Use**

Although not much land is needed for the installation of each turbine, they must be spaced several rotor diameters apart, so wind farms have extensive land requirements. Assuming an average land use factor of 0.12-0.15 km<sup>2</sup>/GWh, 2% of Germany's total land area would be used by wind-farms if 10% of the country's current electricity demand were produced from wind turbines. Competing uses, such as agricultural crops, forestry, tourism or urban uses, may limit the sites available for wind-farm development. At the same time it should be noted that the "footprint" of a wind-tower is small so that other uses could be made of most of the wind farm area including grazing as in Denmark (IEA 2001c).

## **Environmental Issues**

Wind-power generation is free of pollutants but has a number of environmental effects that may limit its potential. The most important effects on the environment are:

1. Visual effects. This is perhaps the most important and most discussed issue. Wind turbines must be in exposed areas and are therefore highly visible. They are considered unsightly by some people.
2. Noise. Wind turbines produce two different types of noise – aerodynamic noise, from air passing over the blades; and mechanical noise, from the moving parts of the turbine, especially the gearbox. Better designs have reduced noise, and research on this issue continues.
3. Electromagnetic interference. Wind turbines may scatter electromagnetic signals causing interference to communication systems. Appropriate siting away from military zones and airports can minimise this impact.
4. Bird safety. Birds get killed when they collide with the rotating blades of a turbine. Migratory species are at higher risk than resident species. Siting the turbines away from migratory routes reduces the impact.

## **The Market**

Global wind generating capacity stood at 8 GW at the end of 1997 accounting for 0.2 per cent of the world's total installed electricity capacity (World Energy Outlook, 2001). Nearly 90 per cent of the capacity is installed in OECD countries, with 69 per cent in OECD Europe (Germany, Denmark and Spain being most important), 19 per cent in OECD North America, and 8 per cent in South Asia. The largest increase in capacity in recent years has taken place in Germany, which now accounts for one-third of the world's capacity, with wind providing 4% of total installed electricity capacity in 1999.

Electricity production from wind power received increased attention after the oil crises of the 1970s. In the 1980s almost all growth was concentrated in the United States and Denmark, but an increasing number of countries turned to wind power in the 1990s, as a result of strong government support and declining costs. Wind power

is now the fastest growing renewable energy resource, and perhaps the fastest growing of any energy resource (IEA 2001c).

In the United States, federal and state incentives encouraged the deployment of wind power in the early to mid-1980s. After an initial boom, the expiry of the incentives and a decline in fossil fuel prices slowed the trend. By the mid-1990s capacity was actually declining. However, since then, renewed interest in wind, supported by a number of incentives, has resulted in significant capacity increases. Wind capacity additions in 2001 could be of the order of 2 GW. This growth is due to a combination of state mandates and a production-tax credit.

In Denmark, growth in wind power was strongly encouraged by government since 1976. Denmark subsequently developed a large wind-turbine-manufacturing industry. Danish companies hold a large share of the global wind turbine market and Denmark has the highest share of wind (some 8 per cent) in its electricity mix of any country in the world.

Germany's spectacular increase in wind capacity in recent years can be almost entirely attributed to the supported grid purchase price. This support is now being very slowly phased down. In Spain, incentives to renewable-energy producers have also encouraged strong growth in wind capacity. The development of wind power in India has been encouraged by investment-related incentives.

## **Prospects**

Despite reductions in its production costs, electricity from wind power still costs more than production from the cheapest conventional technologies in almost all circumstances.

The World Energy Outlook 2000 expects in its Reference Scenario that electricity generation from wind power will increase by 12.6% per year, from 11 TWh in 1997 to 178 TWh in 2020 (World Energy Outlook, 2001). In this period, wind power technology is expected to go on improving and capital costs are likely to decline with larger volumes of turbines produced. The trend towards building larger machines with larger rotors and taller towers is expected to continue, improving performance and reducing the unit cost of electricity. The difference between the electricity generating costs of wind and fossil fuels is expected to narrow. At the best sites, wind will become competitive with the cheapest fossil fuel resources by 2010. However, wind market growth will continue to be constrained by the technology's intermittence and by site limitations. Since the best sites will tend to be developed first, later developments will have less favourable conditions, putting a brake on eventual growth.

## **Wind Power in Australia**

Australia is not an active participant in the current process of improvement and refinement of the technology and equipment for wind generation. This activity is dominated by Denmark, Germany and some other European countries. However, the Australian company Satec has developed a wind turbine that can be used to generate

electricity, pump water, run air compressors and be applied to sludge pumps, grain grinding or other mechanical operations. The technology is particularly suitable for remote locations (Environment Technology Centre, 2000).

Australian industry does have significant capability in the development and operation of wind generation projects. This is made up of a mix of leading foreign wind turbine manufacturers with a presence in Australia and a range of Australian companies with wind generation project development capability. Total capacity in main grids was 4 MW by 1999, with a further 4 MW in small remote grids and about 1 MW in domestic-scale remote area power supply systems. There are many excellent sites in Australia for wind power, many of them within the national electricity grid area (Redding, 1999).

## **GEOTHERMAL ENERGY**

### **Overview**

The technology for extracting electricity for hydrothermal resources is mature, and its use is expanding in both industrialised and developing countries. Geothermal sources all originate from thermal energy trapped beneath and within the solid crust of the Earth. Theoretically, the total accessible resource base of geothermal energy to a depth of 5 km is over 1 million TWyr, but only an infinitesimal fraction of this total could ever be captured even with advanced technology including hot dry rock concepts under development in the USA and elsewhere.

There are four types of geothermal sources, including hydrothermal sources (hot water and steam), hot dry rock (HDR), magma (molten rock reservoirs either very deep or in the vicinity of volcanoes) and geo-pressurised sources (hot brine usually associated with methane in pressurised water aquifers). Such occurrences within layers of the crust easily accessible by current or foreseeable drilling technology are limited.

### **Costs**

The investment in the development of a geothermal field, including exploration and drilling, can range from 15% to 50% of the capital cost of the system, with the cost being at the low end for very high temperature sites with high permeability. This stage of the project involves some investment risk since there is no guarantee that drilling will be successful. Drilling operations are similar to those used in the oil industry and therefore the development of geothermal projects could benefit from technological advances in the oil industry.

The most important factors influencing the cost of geothermal plants are;

- The temperature of the resource (a high-temperature resource produces more energy per unit of produced fluid);

- The depth of the resource (low-depth resources involve less drilling);

- The type of the resource (dry-steam resources are less expensive to develop because they do not require separators, reinjection pipelines and wells; dry

stem is found only at reservoirs that are partially dried out, and these have depleted rather rapidly);

The chemistry of the geothermal fluid (a resource with high concentrations of chemicals often creates technical problems that may incur extra costs; usually the worst chemistry problems occur in high temperature reservoirs where flash technology is used, rather than in low- to moderate-temperature reservoirs where binary technology is used);

The permeability of the resource (high permeability of the geothermal reservoir means higher well productivity and fewer wells needed to produce fluid for the power plant);

The location of the geothermal field (costs are higher in isolated areas because of higher infrastructure costs, while difficult terrain and earthquake conditions also add to the cost).

The technology of the plant also affects the cost. Binary plants are more expensive to build than plants using flash-steam technology. Geothermal technology is capital intensive and in most cases the development of geothermal power plants requires financial support from government.

Estimates of electricity generating costs of geothermal plants vary widely with location. The World Bank reports costs in the range of 2.5 US cents to 10.5 cents per kWh for projects in developing countries. The WEO estimates for good quality resources likely to be developed over the next twenty years are in the range of 3US cents to 4 cents per kWh.

## **Environmental Issues**

Geothermal plants may release gaseous emissions into the atmosphere during their operation. These gases are mainly carbon dioxide and hydrogen sulphide with traces of ammonia, hydrogen, nitrogen, methane, radon, and the volatile species of boron, arsenic and mercury. This characteristic could slow the future development of geothermal resources, although emission concerns have not been significant enough to stop the development of geothermal plants. The issue of emissions has been addressed, in many cases, through strict regulations and by control methods used by the geothermal industry to meet these regulatory requirements. Hydrogen sulphide abatement systems reduce environmental damage but they are costly to install.

## **The Market**

World electricity production from geothermal facilities in 1999 was 50 TWh, equivalent to 0.3% of total electricity generation. This places it third, behind hydro and bioenergy, as a source for renewable electricity. The USA is responsible for 17.4 TWh in geothermal production, but this represents only 0.4% of its total electricity generation. The statistics for the other major countries are Philippines (10.6; 25.6%); Mexico (5.6; 2.9%); Italy (4.4; 1.7%); Japan (3.5; 0.3%); Indonesia (2.7; 3.2%), New Zealand (2.5; 6.6%) and Iceland (1.1; 15.8%). In recent years the fastest growth in geothermal electricity capacity has come in Indonesia and the Philippines; within the

OECD, most incremental production was in Italy, where it is the most important source of renewable electricity.

## **Prospects**

Over the next twenty years, geothermal electricity is expected to increase almost three-fold (from 42 TWh in 1997 to 112 TWh in 2020). Most of the growth is likely to come in the Pacific region, notably East Asia (EA will rise from 9.8 to 38.1, and OECD Pacific from 5.8 to 23.6).

## **Geothermal Energy in Australia**

The two forms of geothermal energy, geothermal aquifer and geothermal hot dry rock, are covered separately.

The only geothermal power plants constructed in Australia to date are two small-scale units utilising low temperature hot water from the Great Artesian Basin to generate electricity for remote settlements. A small geothermal power station is operating as a demonstration in the small remote township of Birdsville in far outback Queensland.

Australia's best resources of conventional geothermal energy are located in the Great Artesian Basin region where many bores discharge water at high enough temperatures to operate heat engines. However, by world standards, Australia does not possess high grade geothermal aquifer resources./ As the resource is available only in central Australia it can supply only the very few towns located near the resource. The total demand for power at sites where the resource is available is estimated to be 20MW (Redding, 1999).

Geothermal Hot Dry Rock (HDR) technology is at the experimental stage; there are no commercial schemes anywhere in the world. Nevertheless the resource has potential in the very long term. Australia has a very large potential resource. An exploratory well is to be drilled in the Hunter Valley, New South Wales. A large area of the Cooper Basin in the south-west corner of Queensland and the north-east corner of South Australia has been identified as containing the largest and most promising HDR sites for creation of reservoirs that would make it possible to extract commercial quantities of energy.

Given the scale of the engineering required, this technology is likely to be most appropriate for grid connected applications. Further exploration is needed to delineate Australia's resources, as so far the best sites identified to date are located in central Australia, well away from significant sources of demand. Commercial production utilising the HDR technology appears unlikely before 2010 at least (Redding, 1999).

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## **OCEAN ENERGY**

The oceans offer a number of energy flows that could be tapped as sources of energy. They include ocean thermal energy, waves and tidal power, and the sea-freshwater interface as rivers flow into oceans.

### **Wave Energy**

The mechanical energy contained in waves is a function of the amount of water displaced from the mean sea level and the orbital velocity of the water particles in the waves. The energy transferred depends on the wind speed, the distance over which it interacts with the water and the duration of time for which it blows. It is estimated that the total power of waves breaking on the world's coastlines is on the order of 200 to 300 GW (IEA 2001c).

Several concepts to harness wave energy have been proposed, ranging from turbines that utilise oscillating water columns, combined water and air arrangements, to a design known as the Salter's duck. The latter consists of a series of wing-like, interconnected objects. It is not clear whether any of them will lead to a practical design. Cost estimates for wave energy are difficult to obtain, but appear to be relatively high (Energy, 1993). A commercial device for use on shorelines has been developed in Norway, while experimental prototypes exist in the United Kingdom, Japan and India. World installed capacity is a mere 650 kW (Redding, 1999).

The Australian company Energetech has a new system for extracting energy from ocean waves and converting it to electricity. The Energetech system can be deployed as a single device, or strung together in a series, similar in concept to wind farms. The potential customers for the system are power utilities, single industrial users in heavy and remote industry, and remote communities and islands. The technology can also be used in hybrid renewable projects in suitable locations, and combined with wind or solar. It can also be used as an integral component in the construction of coastal structures, such as harbour breakwaters. The Energetech Wave Energy System is a shoreline device suitable where there is fairly deep water on the coast, such as on harbour breakwaters and rocky headlands and cliffs.

Wave power worldwide is a potentially large resource but is still in the R&D stage. It appears to have a fairly low priority for commercialisation or for research. Nevertheless, if the technology were to develop faster than anticipated, Australia has suitable coastline conditions in its southern regions, and local technological expertise.

### **Tidal Energy**

Tides arise from the gravitational pull of the sun, the moon, and the earth's rotation. The energy of the tides is derived from the kinetic energy of water moving from a higher to a lower elevation. A dam is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator. Tidal power

utilises the oscillatory flow of water in and out of partly enclosed basins along coastlines with sufficient tidal flow. Water then flows back and forth through a number of reversible hydro turbines located in dams across the entrances of the tidal basins. The total resource is very limited. Assuming that tidal flows of more than 5 meters are required for a practical plant, the realisable global potential is some 64 GW<sub>e</sub>. In view of the relatively low aggregate potential, tidal power is not a globally important resource, but it has regional potential that has been reasonably well evaluated (Energy, 1993).

Tidal power plants are in operation in France, Canada and Russia. The main barrier to uptake of the technology remains the high capital cost of even the best schemes in relation to their energy output, which is consequently reflected in their generating costs.

Australia's best tidal energy resources are located in the north west of the continent. Given the high costs of transmitting the power to far-away metropolitan regions, the resource appears to be only suitable for local demand. There is a proposal before the Western Australian government for a 48 MW plant (Redding, 1999).

### **Ocean Thermal Energy**

Oceans cover more than 70% of the earth's surface making them the world's largest solar collectors. Ocean thermal energy conversion makes use of the naturally occurring temperature difference between warm water on the surface and cold water at depths of about 1000m. The minimum difference in temperature is usually about 20°C. Such differences are found in tropical and sub-tropical areas. This form of energy is costly and is not likely to be widely commercialised by 2020. However, it will remain a promising option for electricity generation in the long term (IEA 2001c).

Ocean thermal conversion (OTEC) systems utilise the relatively low temperature gradient in the oceans for electricity generation. The warm surface water of the oceans is used to boil a working fluid in a Rankine-cycle power plant. Temperature gradients of at most 20°C can be achieved, leading to very low efficiencies. This means that the systems would need to be large and would therefore be associated with high capital costs. Temperature gradients are relatively low in coastal regions and the commercial potential is very limited (Energy, 1993). While the principal of operation has been demonstrated, the technology is far from proven or reliable. Oil dependant tropical islands are potentially the most viable sites for this technology.

Optimum locations for OTEC systems in Australia would be within 20° of the equator (i.e. north of Townsville). There is no experience with OTEC in Australia (Redding, 1999).

### **Tapping the Salt Gradient**

The mixing of salt and fresh water in estuaries is another way to tap solar energy. Membranes separating the two fluids create different partial pressures that could be used for power generation. The low efficiency of the process may in part be offset by



the large resource potential. Differences in the salinity of water are an integral part of solar ponds. The salt gradient creates zones of different heat trapping potentials that can be utilised in analogy to the OTEC process (Energy, 1993).

There is no indication of commercialisation of this technology, either in Australia or internationally, in the foreseeable future.

## **HYDROPOWER**

### **Hydropower Resources**

The principles of operation of all hydroelectric schemes are essentially the same. A scheme consists of:

- A suitable catchment area;
- An hydraulic head;
- A water intake placed above a weir or behind a dam;
- A method of transporting the water from the head to a turbine;
- A flow control system;
- A turbine, a generator, associated buildings and grid connection;
- An outflow, where the exhaust water returns to the main flow.

Hydropower is at present the world's largest renewable energy resource. Its unexploited potential is still vast, particularly in the developing countries. In the OECD, the best sites have already been developed, although there is some room for upgrading existing capacity. Current world hydroelectricity production exploits 18 per cent of the technical potential. In developing regions, this share is 12 per cent. The largest regions for hydropower production in 1999 were OECD North America (14% of total electricity generated), Latin America (60%), and OECD Europe (17%).

Hydro is a capital-intensive option for electricity generation, but the cost per unit of electricity generated is low in good sites. High initial investment is an important issue. Developing countries may find it difficult to raise the funds to finance new projects (IEA 2001c).

### **Environmental Issues**

The environmental and social effects of large-dam construction are the subject of much controversy. Large-scale hydropower may disturb local ecosystems, reduce biological diversity or modify water quality. It may also cause socio-economic damage by displacing local populations. A number of projects in developing countries have been stalled or scaled down because of such problems. Although these ill effects can be managed and mitigated to some degree, they may affect the future of hydropower in general. Obtaining loans from international lending institutions and banks for major hydro projects has become more difficult. Mini- and micro-hydro systems have relatively modest and localised effects on the environment, but the kWh cost is generally higher in smaller systems.

Hydropower emits some greenhouse gases on a life-cycle basis, especially methane generated by decaying bioenergy in reservoirs, but emits far less than the burning of fossil fuels.

## **Prospects**

The World Economic Outlook 2000 projections indicate the likelihood that global electricity production from hydro plants will increase by 1.8% per year up to 2020.. Nonetheless, hydropower's share in electricity generation is expected to fall from 18% in 1999 to 15% by 2020. Most of the best sites in OECD countries have been exploited, and environmental concerns limit new construction. However, Canada, Turkey and Japan are expected to develop their hydro resources further. Hydro-electricity in the OECD is projected to grow by only 0.5% per year over the projection period.

Developing countries will account for 80% of the projected increase in hydroelectricity between now and 2020, three-quarters of that being in China and Latin America. Competing uses, such as for water supply, irrigation and flood control, are likely to influence the decision for the development of new hydropower projects.

## **Hydro Power in Australia**

Large hydro provides the vast majority of Australia's electricity at present generated from renewable energy sources. The current installed hydro capacity of electricity generating plant in Australia is about 7580 MW, of which approximately 50% is operated by the Snowy Mountains Hydro-Electric Authority and 30% by the Hydro-Electric Corporation of Tasmania. The remaining 20% is located at various sites in Queensland, Victoria, New South Wales and Western Australia.

When the Basslink interconnector between Tasmania and Victoria is built, there is potential for some of the older hydro stations in Tasmania to be decommissioned. In addition, changing requirements for river flows will lead to a significant loss of Snowy energy. Overall, reductions in energy production due to plant retirements and environmental flows could well outweigh the marginal increases in energy arising from the enhancement of existing plant.

On the other hand, the construction of new dams may provide additional new hydro capacity. The largest prospective development, the 500 MW Tully Millstream scheme, has been shelved due to potential inundation of World Heritage rainforest in its most economic configuration. Nevertheless, a smaller version of this scheme not involving such inundation of heritage areas might be viable, although, given the processes involved, such a scheme would not be available until towards 2010. The typical construction time for major hydro projects is four years, with significant time taken in the preparation of engineering plans and in environmental assessment processes (Redding 1999).

For the purpose of this analysis, small and medium hydro schemes are taken to be below 100 MW in capacity. The technology is generally mature but capital costs may be reduced by using newer materials and/or electrical and electronic developments for construction and transmission. Minimisation of civil engineering costs through selection of generating equipment and powerhouse sizing and siting may lead to greater savings.

While turbines and generators are generally sourced from overseas suppliers, Australian developments in technology and capability are notable in such areas as systems for control, switchgear, transmission, other mechanical and electrical requirements, and civil design and construction. There is now an established hydro project development industry, with developments taking place in new South Wales, Victoria and Western Australia.

However, the potential for further development of economically viable small hydro projects on large dams in Australia is limited as the most attractive projects have already been developed. In Queensland some half-dozen projects of 1-3 MS size are at the feasibility stage as well as the 50-80 MW Burdekin project. Construction time on these smaller projects is typically about one year. Research has identified more than 36 prospective sites in New South Wales, of which the 20 lowest-cost sites have a combined capacity of 62 MW.

The average costs of these prospective projects appear to be a little above the minimum threshold for commercial viability as things stand at present. The use of such hydro resources will probably depend more on energy prices than on further technology developments in the foreseeable future.

Two small Australian engineering companies – APACE and the Rainbow Power Company – are exporting micro hydro electric systems to the world. Microprocessor-based switching of the electrical load allows a stable system of operation, load management through priority load shedding, a reduced cost of civil engineering components through minimal surge and water hammer effects and optimal efficiency of operation. The technology has enabled the cost-effective application of hydroelectricity in remote areas at a scale that avoids the environmental and social difficulties faced by larger hydroelectricity schemes.

## **BIOENERGY**

### **Bioenergy Resources**

Bioenergy can be derived from a wide range of materials of different origin and with different properties. The most important bioenergy fuels are forest products, agricultural residues and wastes, energy crops, and municipal solid waste (MSW). Of these, energy crops is the largest resource globally, followed by wood, with animal waste, crop residues and MSW of lesser present significance.

The cost of bioenergy is likely to be reduced in the future because of (i) increased yields of biomass as a result of increased agricultural productivity and increased urban

waste, and (ii) the improved conversion efficiency of bioenergy combustion. The total economic potential of bioenergy in 1990 was 5393 Mtoe, and this could increase to between 6755 and 7569 Mtoe by 2020. At present, actual bioenergy consumption is only a fifth of its estimated potential (IEA 2001c).

## **Technology**

Currently, most bioenergy applications use direct-fired technology. Solid bioenergy is burned in a process similar to burning coal but with lower efficiencies ranging from 15% to 30%. With cogeneration of heat and electricity, total efficiency is in the order of 60%.

Bioenergy in a gaseous state can be burned in gas turbines (open or combined cycle). Most of it is landfill gas, a low- to medium-calorific value gas that is produced from MSW. The utilisation of landfill gas requires the development of a recovery system with wells or trenches to collect the gas.

Co-firing is the practice of using bioenergy as a supplementary energy source. Bioenergy can be burned along with another fuel, typically coal, but such a process requires modifications or additions to the power plant. Co-firing is a retrofit for existing coal plants to achieve a large scale introduction of bioenergy in the power sector. Direct addition of solid bioenergy limits the amount of solid bioenergy that can be burned with coal to about 10% to 15%. Solid bioenergy can be gasified and the gas co-fired with coal or with natural gas. If solid bioenergy is gasified prior to co-firing, the percentage that can be added is higher as compared to direct use of solids.

Advanced bioenergy technologies include gasification and pyrolysis. Advanced technologies can achieve high conversion efficiencies. Bioenergy gasification technology converts solid bioenergy into a combustible gas through a partial oxidation process. The resulting gas can be of low or medium calorific content depending on the conditions of the gasification. The gas can be burned in a turbine or a fuel cell. Gasification technology is at an early stage of commercialisation with some companies already offering gasification units for direct co-firing applications.

In pyrolysis, the fuel is heated in the absence of air to produce gas, oil and char. Fast pyrolysis techniques produce a higher proportion of the oil while slow pyrolysis makes char. The technology is moving from the R&D to the commercialisation phase (IEA 2001c).

## **Supply Costs**

The cost of producing electricity from bioenergy depends on the technology, the fuel cost and the quality of the fuel. Most bioenergy used for electricity production is in solid state. Bioenergy plants tend to be small in size. A typical plant size is 20 MW<sub>e</sub> or less. Bioenergy plants, therefore, have higher capital costs per unit of installed capacity and higher operating costs per unit of electricity produced than fossil-fuel plants.

Bioenergy fuel costs vary widely. The fuel cost can be zero in certain cases, especially if it is a by-product. The bioenergy fuel source must be abundant, reliable and low-cost. Factors that affect the cost of bioenergy supply are competition with other uses, variation in crops and seasonality, and distance from the source.

The electricity-generating costs of bioenergy are, on average, higher than those of fossil-fuel plants because of their higher capital costs, higher fuel costs and lower conversion efficiencies than conventional plants (IEA 2001c).

### **Environmental Issues**

The use of bioenergy can have many environmental benefits over fossil fuels if the resource is used in a sustainable way. If the land from which bioenergy is produced is replanted, bioenergy is used sustainably and the carbon released will be recycled into the next generation of growing plants. Substituting fossil fuels with bioenergy means the carbon from the displaced fossil fuels remains in the ground and is not discharged into the atmosphere. The extent to which bioenergy can displace net emissions of CO<sub>2</sub> will depend on the efficiency with which it can be produced and used.

Bioenergy plants have lower emissions of SO<sub>x</sub> than do coal and oil plants. They may produce, however, more particulate matter than oil- and gas-fired plants. These emissions are in general controllable but they increase generating costs (IEA 2001c).

### **The Market**

In 1999, global electricity generation from bioenergy was 160 TWh, a little more than 1 per cent of the total. Nearly all of it was in the OECD countries, where it accounted for 1.6% of total generation. The ten countries with the highest level of bioenergy electricity production in the world are the United States (63.5 TWh), Japan (16.2), Germany (9.4), Finland (8.7; it represents 12.5% of total electricity generated in this country), Brazil (8.5), the United Kingdom (7.7), Canada (7.1), the Netherlands (4.0), Australia (3.7), and Sweden (3.4).

More than half of bioenergy electricity is produced from solid products, such as forestry products and agricultural residues. Waste accounted for 35% of total bioenergy electricity production and its share has been increasing. Waste incineration is used to provide energy in several countries (IEA 2001c).

### **Prospects**

Bioenergy is a well established option for electricity and heat production and this is likely to continue in the future. Electricity generation from bioenergy is expected to double over the next two decades. Most of the increase is likely to be in OECD countries, where the share of bioenergy in electricity generation rises from 1.6% in 1997 to 2.1% in 2020.

However, bioenergy is likely to remain, on average, a fairly expensive option compared with fossil fuels. However, where there is demand for heat and where

bioenergy fuels are available at low or no cost, using bioenergy in Combined Heat and Power systems may be economical. Declines in generating costs are likely to occur over the next twenty years because of reductions in the capital costs of bioenergy plants and efficiency improvements. The evolution of the fuel-price component is more uncertain. Wider use of energy crops is likely to increase costs (IEA 2001c).

### **Biomass in Australia**

Australian technologies for the use of biomass in energy applications include small and large scale gasifiers and anaerobic digestors. Australian industry capabilities for handling biomass are in the main derived from those used in thermal electricity generation from coal, particularly brown coal with its high moisture content.

Redding (1999) estimates the annual electricity generated from biomass capacity in Australia is 530 GWh, made up of 400 GWh from bagasse, 90 GWh from black liquor at paper pulp plants, and 40 GWh from other sources, particularly sawmill waste and woodchips. The economics of biomass projects are highly site-specific.

The bagasse, the residual fibre waste from the processing of raw sugar, currently provides about 2% of Australia's total primary energy demand. Bagasse has the advantage over some other forms of biomass (such as forestry thinnings or woody weeds) that the sugar processing requires the bagasse to be brought to a central location at the mill, so there are no additional transport costs.

The steam raised from bagasse is used to work the machines that shred and crush the cane, for process heating and, increasingly, to produce co-generated electricity. Most mills feed excess electricity into the grid.

At present, cogeneration from bagasse uses conventional boilers and turbo-alternators, with adaptation of existing technology as required to use that fuel reliably and efficiently. Gasification of biomass, which has the potential for significantly higher thermal efficiency, is at the R&D and pre-commercial stage.

Bagasse is available for about half of each year (June to November) from the 25 sugar mills in Queensland, 3 in New South Wales and 1 in Western Australia. These mills have an installed electricity generating capacity of about 250 MW, fuelled almost entirely with bagasse. About 60-70 MW of current capacity is used to generate electricity for export to the grid.

The further development of bagasse in the Australian renewable energy industry depends on (i) the greater use of cane trash in addition to bagasse, (ii) the introduction of economically competitive gasification technology, and (iii) the sourcing of alternative fuel during the off season. Resource availability is unlikely to become a constraint, with capacity capable of increasing from the current 250 MW to 1000

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MW. Capacity increases of 95 MW are already underway. With the full conversion of the existing low pressure boilers to high pressure, high efficiency systems, the export capability of sugar mills could reach its ultimate capacity of 1000 MW. This could be extended even further if all cane biomass, instead of the current 50%, were utilised. And if bagasse gasification were developed, further substantial capacity increases would be possible, perhaps to 3000 MW.

Black liquor is produced as a by-product in some paper pulp processes. It contains the lignin after it has been separated from the cellulose in the wood and is combustible. The two plants in Australia that produce the black liquor by-product are Maryvale in Victoria (37.5 MW capacity) and Burnie in Tasmania (11.5 MW). Both plants use the resource for cogeneration. The currently available resource is now effectively utilised. The only possible addition is the construction of new paper pulp plant by Visy at Tumut in NSW. This plant is expected to utilise a black liquor by-product for cogeneration.

Wood biomass electricity generation capacity has increased significantly over recent years in some OECD countries, notably the United States. However, the current electricity production for forestry residues and wood waste in Australia is not significant. A number of sugar mills use woodchips and, in some cases, sawmill waste, in the cogeneration plant.

In Australian sawmills only 45% of the wood is utilised. The only current use for this is the horticultural industry. Many mills pay to have sawmill waste removed. Other sources of wood residues include the re-management of derelict woodlands, understory thinnings of native woodlands, and the pre-commercial thinnings of dedicated timber forests. The rapid expansion of commercial forestry plantations in Australia will provide increased fuelwood supplies for electricity generation.

It appears that wood residues could be delivered to industrial boilers at many sites at costs comparable to those for the delivery of coal to power stations. However, overall costs will still be higher than for bagasse.

There is widespread semi-commercial trialling of crops grown specifically for electricity production in Europe and the United States but Australia lags. The CSIRO has conducted trials on intensively managed, short rotation bioenergy plantations grown on effluent, saline water and sludge. However, energy crops are expected to be a more expensive resource again than forestry and wood wastes and are yet to be proven worldwide as a commercially viable resource.

This resource is not currently used commercially for electricity generation in Australia. However, preliminary investigations are under way. Case studies have been conducted in two areas, one using combustion of free rice hulls at a rice mill, the other using cotton gin waste. Some crop wastes may have higher moisture contents making them more suitable for an anaerobic digestion process.

Very detailed studies have been undertaken into the extent and availability of crop waste resources in Australia. Smaller resources will be available from the cotton and rice industries. Straw and stubble from broadacre cropping is theoretically a very large resource, but there are considerable doubts concerning its economic viability because of collection costs, the form of the resource, and the opportunity cost of using this resource in the field production cycle for cropping.

This resource includes wastes from intensive animal production, the possibility of collecting waste from field animal production, and waste streams from processing of fruit and vegetables, grains, meat and meat products, beverages, and milk products.

The potential resource from field animal production is theoretically large but it is doubtful that the field collection of the resource is practically viable. In practice the animal production waste is likely to be limited to that from intensive animal husbandry. In Australia intensive animal production is generally limited to pigs and poultry although a small fraction of beef production also comes from intensive feedlots. There is also a potential resource in the wash-down water from dairy farms.

These wet wastes may be suitable for production of biogas using an anaerobic digestion process. Anaerobic digestion is a well established waste treatment process in its own right with the production of a useful fuel providing an added benefit. These processes are established in Australia to produce gas for thermal applications at some food processing plants and also in the treatment of municipal wastewater. However, the use of the gas for electricity production is currently very limited.

Electricity from biogas produced from animal waste at piggeries is currently utilised at only one piggery in Australia, at Ballarat. In total there are 28 large piggeries located in Australia. The outer boundary of the potential for this resource for electricity production would be in the order of 50 MW of generating capacity. In the food processing industries in Victoria, anaerobic digestion is used for the treatment of waste streams at Weston Bioproducts, Mars Confectionary, McCain Foods, Warrnambool Milk Products, and Bunge Industries. This resource could contribute a 100 MW of generating capacity in Australia. A further 50 MW could come from other animal husbandry.

Costs for this resource using anaerobic digestion technology are relatively high. However, the process also has waste treatment benefits and potentially valuable by-products are also produced.



## **Municipal Solid Waste and Municipal Wastewater in Australia**

These resources are predominantly biomass but may also contain a fossil-fuel derived organic component. In Australia municipal solid waste (MSW) is currently used for electricity production only in the form of landfill gas from garbage tips. Landfill gas projects may either mine gas from existing tips or may be designed in to new landfills.

In other countries combustion of MSW is widely used on a commercial basis as an alternative to landfilling. Combustion of MSW is also potentially a source of electricity generation in Australia.

Municipal wastewater is established as a resource for energy production in Australia in the form of sewage gas at waste treatment plants. The gas is routinely used for heating purposes in the treatment process itself in larger treatment plants but electricity production from the gas has not always proved to be economic.

Under the anaerobic (oxygen free) conditions of landfill sites, organic waste is broken down by micro-organisms, leading to the formation of landfill gas. Landfill gas is predominantly a mixture of carbon dioxide and methane in roughly equal quantities. Landfill gas is collected through a series of gas wells on which small suction pressure is applied. A wide variety of gas wells and collection systems are available. Gas collection for energy recovery can often complement environmental protection. There is a potential risk to the local and global environment from the escape of landfill gas. It is estimated that 1% of Australia's greenhouse gas emissions can be attributed to escape of gases to the atmosphere from landfill sites.

The use of landfill gas as a fuel for electricity generation began in the mid 1980s. For most applications, landfill gas is used without extensive purification, other than the removal of moisture and particulate matter. Landfill gas is used as a commercial fuel in many countries. However, uncertainties over its future development still remain and a number of technical, commercial and institutional issues stand in the way of its full commercial exploitation.

The suitability of a tip for biogas generation in commercial quantities depends principally on the size of the tip, its waste composition and the way the tip has been filled. In Australia, tips above about 0.5 million cubic metres are considered viable, with an optimum production period of 1-2 years. Present installed capacity for landfill gas in Australia was about 80 MW at then of 1997, with 39 MW of that in Victoria. In 1999, capacity was reported to have increased to 97 MW. It could reach its peak level of about 250 MW by 2010.

More advanced approaches to utilisation are becoming available in NSW. The SWERF process being trialled at Wollongong is notable. This facility will recover reusable and recyclable resources prior to the conversion of organic components into gas and then electricity.

Municipal solid waste combustion (MSW) is commercial and well established in other OECD countries, notably Switzerland, Denmark, Germany, the UK and more recently in the USA, but is not currently used in Australia. In Europe a strong driver is the critical and increasing scarcity of landfill sites. Siemens has developed sophisticated integrated technology for this application.

Detailed assessment has been undertaken for a project for the City of Banyule (Victoria) using MSW combustion. It was found to be potentially economic but is sensitive to the avoided cost of landfill and the price chargeable for steam. The maximum potential of the resource is assessed at around 200 MW for 2010. Construction times will be in the range 2-3 years.

There has been a steady increase in the use of sewage gas for energy purposes in recent years. At present, sewage gas is used to generate electricity in Adelaide, Melbourne and Brisbane. Total capacity in 1997 was estimated at 7.45 MW, of which 3.2 MW was in Brisbane, 1.3 MW in Melbourne, and 2.95 MW in Adelaide.

By 2010 it is projected that 100 GWh will be generated from sewage gas, although this could be an under-estimate. Currently both Environment Australia and state EPAs are pursuing initiatives to encourage methane capture and use at smaller regional wastewater treatment plants in order to achieve the associated greenhouse gas abatement benefits.

## **RENEWABLE ENERGY SCENARIOS**

A number of scenarios for the development of renewable energy are analysed. The first represents two scenarios for 2030 in IPTS (1997): business as Usual, and a Future of Renewable energy Technologies. The second is contained in the World Energy Outlook (2001), with a scenario up to 2020, and some comments on the longer term. The third set of scenarios is forecasts for renewable energy in Australia by the year 2010 in Redding (1999).

### **IPTS (1997)**

In the Business as Usual Scenario (IPTS, 1997), renewable energy (excluding large hydro) penetration rises from 3.6% of primary energy in 1993 to 8.4% in 2030. This increase is largely accounted for by greater utilisation of industrial solid waste, wood energy crops, agricultural waste, municipal solid waste, landfill gas and geothermal and wind. This trend can be attributed to the rise in fossil fuel prices increasingly making renewable energy technologies cost competitive. In the case of the biomass technologies 70-100% of their increased penetration comes in decentralised heat markets rather than centralised electricity markets. Overall, the split between electricity and heat provided by renewable energy by 2030 is approximately 50/50.

The most cost effective renewable energy technologies for reducing carbon dioxide emissions are biomass based, such as energy crops and forest residues. However, because of its large penetration, wind is the renewable technology that has the greatest potential in absolute terms to reduce the emissions of carbon dioxide.

In this Scenario one could devise a situation in which, either due to supply-side shocks from the fossil fuel market, to a dramatic decrease of renewable energy technology (RET) costs, or to both reasons, RET would reach a commercial status. For long-distance, baseload electricity hydro resources that may be put in exploitation if the adequate conditions in transmission technology apply (super conductor lines, etc.). Secondly, home-produced electricity or heat (via photovoltaics, or low temperature solar thermal devices, whose market penetration may be induced by using the appropriate building regulation) may be introduced.

The fundamental issue that would characterise this scenario is the necessity to find appropriate technological solutions to provide a sufficient degree of flexibility in the system to accommodate to a significant share of intermittent power generation. The key technologies would therefore concern energy storage. This may take place at the power source, by accumulation of energy under several forms: thermal (molten salt reservoirs), mechanical (pump storage), chemical (synthetic fuels) or electrical (batteries), to be delivered to the grid when the original source is not available. The energy storage can also take place at the final consumption level. In addition, demand side management technologies would have a key role in achieving and maintaining the above-mentioned system flexibility.

Renewable energy penetration rises to 12.3% by 2030. Wastes, energy crops, wind and geothermal technologies benefit in particular. The extra market penetration over the Business as Usual scenario is 65% due to increased penetration of the decentralised heat market by biomass technologies. The remaining penetration is in both the centralised and decentralised electricity markets.

The main technologies affected in this scenario are the following;

Biomass gasification for electricity production on a small scale (less than 25 MW) combined cycle plants. There is a near seven fold increase in contribution between the present, and 2030, albeit with an inflexion of growth towards the end of the period due to increasing costs of the biomass itself as the cheaper sources are gradually exhausted.

Photovoltaics in buildings, involving mostly cells incorporated in window panels, allows for the development of niche markets and leads to a contribution of around 32 Twh world-wide by 2030.

Molten Salt Tower Solar plant with storage was the main solar thermal power technology retained in the reference case it achieved a contribution of 31 Twh world-wide. In the technology scenario its contribution reaches 114 Twh world-wide. It is worth noting that though this latter figure is relatively modest it does not represent the full potential impact of the scenario as by 2030 this technology is still in the stage of vertical take off in industrialised countries and has not even entered that stage in the developing countries where most of the physical potential exists.

Small hydro, assumed to be a mature technology in the reference case, sees its capital cost halved for the scenario and hence its contribution doubled from 250 Twh to 505 Twh by 2030. However, by the end of the period the technology displays clear signs of saturation as the best available sites are gradually exhausted.

On shore wind turbine (over 500 kW capacity) offers the highest contrast between reference and scenario. The technology scenario implies a reduction of capital costs to one-third of their present level and further significant increases (+33%) in capacity factors. These developments render wind power highly competitive, its intermittent character notwithstanding, and lead to massive development world-wide (nearly 1600 Twh by 2030). This development is furthermore fairly evenly distributed, with about half occurring in industrialised countries.

### **World Energy Outlook (IEA 2001c)**

Renewable energy excluding hydro rises from 3% of OECD electricity generated in 1999 to 4% by 2020 in the Reference Case and 8% in the Alternative Power Generation Case. The table below indicates the possible trend in particular forms of renewables in the Reference Case Scenario. Note the exceptional growth of wind-power, the slow growth of hydropower, and the solid growth of bioenergy and geothermal.

#### **OECD Renewable Electricity Generation, 1999 and 2020 (TWh)**

<b>Energy Source</b>	<b>1999</b>	<b>2020</b>
Hydro	1280	1441
Bioenergy	147	250
Geothermal	29	56
Wind	15	154
Solar		19

Beyond 2020, renewable energy is likely to play an increasingly important role in global energy supply. The resource base is vast, and the environmental impact of renewables' production and use will favour their market development in certain cases. Demand for electricity will continue to rise in the long run and the rate of retirement of existing capacity will be significant in the coming decades. These two factors will create significant opportunities for renewable energy to penetrate the power sector. How rapidly it does so will depend on its cost relative to other energy resources. Technological innovation and government policies, especially in relation to carbon emissions, will be the critical factors in this respect.

It is likely that the promotion of renewable energy will remain a key component of government strategies to achieve sustainable-development objectives. Policies to reduce greenhouse-gas emissions, in particular, will continue to encourage and

promote the use of renewable energy. The role of renewable energy in enhancing security of supply may also grow in importance.

Renewable energy will probably remain a relatively costly supply option for power generation up to 2020 in the absence of a sizeable carbon penalty. Costs are expected to decline over this period, but not enough to make renewable energy competitive generally with other sources. It is likely that improvements in cost performance will continue for many existing renewable-energy technologies beyond 2020. The timing and the amount of these cost reductions are, however, highly uncertain.

The long-term use of renewable energy will depend on technological advances that will bring cost reductions and allow better integration of these sources into the energy system. Up to 2020, the supply of renewable energy will remain concentrated in OECD countries. In the longer-term, renewables use is likely to become more widespread in developing countries, especially if they establish their own manufacturing capacity.

With increased productivity, energy crops could provide a low-cost fuel for producing **bioenergy**. However, their long-term development will depend on the availability of land and water, and competition from other uses, especially for producing food. Advanced technologies, such as biomass gasification and pyrolysis, could boost the use of bioenergy in heat and electricity production. Bioenergy could also power fuel cells. If these technologies become cost-effective, bioenergy could emerge as a significant energy source, especially when fuel is cheap.

**Wind-power** production holds promise for continuous growth beyond 2020. Growth in the next two decades is likely to be concentrated in a few regions. Beyond 2020, growth is likely to spread to more countries, notably in the developing world. China, for example, has a wind-energy potential of about 250 GW, which could meet a large share of the country's rising electricity demand. Lower capital costs, reduced maintenance requirements, and improved corrosion resistance could boost the development of offshore wind farms. Integrating larger amounts of wind-turbine capacity into networks may require the development of cost-effective **energy storage** technologies.

**Hydropower** resources will also continue to be used. Although hydroelectricity technology is mature, further advances are possible, particularly for small facilities. Advances in turbine technology such as the use of variable-speed turbines and submersible-turbo generators would bring further cost reductions. Innovative turbine designs could also reduce the environmental impact of hydropower on fish populations.

Further research in the area of hot dry rock **geothermal** technology could lead to further development of the world's geothermal resources. Hot dry rock resources are more widespread than hydrothermal resources and offer the greatest potential for geothermal energy. Increasing well production is the key to reducing costs. In the very long term, the exploitation of the geothermal energy contained in the magma may be possible. Magma chambers contain large amounts of energy, but the technical and commercial feasibility of exploiting them has not yet been demonstrated.

**Solar** energy could become an attractive option for heat and power production in buildings, if the cost of producing energy through solar power continues to fall substantially. The use of PV in buildings is likely to continue to expand, both in grid-connected applications and in rural electrification projects. The integration of PV cells directly into the shell of buildings could reduce overall costs substantially. Cost improvements in concentrating solar heat could offer opportunities for larger-scale development of these technologies. Passive solar designs can provide heating and cooling in buildings.

The cost-competitiveness of **ocean energy** has yet to be demonstrated. Continuous research involving the performance and reliability of ocean technology could eventually bring cost reductions. This form of renewable energy could provide energy for many developing countries, since much of the potential is located in tropical regions.

### **The Prospects in Australia – Redding (1999)**

Research on new technologies for renewable energy in Australia is flourishing. At the same time, a number of companies are commercialising research in developing new sources of supply using solar, fuel cell, wind and landfill gas. Other companies are assembling portfolios of renewable energy to supply electricity grids. Mandatory targets for the uptake of renewable energy in power supplies will give the necessary demand-side impetus to the development of renewable energy capacity in Australia.

Solar hot water 450-1150.

PV grid negligible up to 100, with 800 as an outside possibility.

Solar thermal small, with an outside possibility of up to 400.

PV and PV-hybrid in Remote Area Power Supply 20-150.

From 30 up to 1100.

From negligible up to 160.

From negligible up to 190.

Large hydro from 100 to 300.

Small hydro up to 700.

Bagasse 1500-6800.

Wood waste 700-1400.

Energy crops negligible up to 300.

Crop wastes negligible up to 700.

Wet wastes from agriculture and food up to 100.

Landfill gas 500-800.

MSW combustion negligible up to 400.

Sewage gas 100 to 400.



# Cross-Cutting Technologies

## INTRODUCTION

Cross-cutting technologies hold out the prospect of an environmentally benign energy supply. Hydrogen-based fuel cells are the main focus of current research and development on cross-cutting technologies. Fossil fuels may provide the initial source of energy for hydrogen production for use in fuel cells. Much later, depending on how technology advances, hydrogen production may be based on electrolysis of water using nuclear or renewable energy. In that case, net carbon emissions could be negligible. Carbon sequestration could also have a profound impact on the long-term prospects for energy supply (IEA 2001c).

Ultimately, ultra high-efficiency, zero-carbon-emissions systems can be envisioned that would take advantage of synergies between energy generation, fuels production and chemicals production by integrating these processes into a single entity, an “energyplex”. An energyplex would incorporate a series of modular plants capable of co-producing power and chemicals or fuels that can be integrated to use local sources of carbon (coal, biomass, municipal solid waste) as fuel and feedstocks. With the incorporation of modules for capture and sequestration of CO<sub>2</sub>, energyplexes would have essentially no carbon emissions.

These complexes would optimise the entire cycle of carbon use by incorporating co-processing concepts, the integral capture of CO<sub>2</sub> and the incorporation of carbon into useful products or carbon sequestration. This is a long-term, futuristic concept that challenges the R&D community to make significant breakthroughs in areas such as novel industrial process configurations, novel power cycles and co-production of heat and power, with suitable energy-efficient reuse or storage options for carbon and CO<sub>2</sub>. Representative technologies include IGCC systems, coal liquefaction, fuel cell/gas turbine bottoming cycle combinations with efficiencies of more than 70 per cent and integral capture of CO<sub>2</sub>, power systems with alternative working fluids, high-temperature oxygen separation membranes, and advanced oxygen production techniques (IEA 2000).

## COMBINED HEAT AND POWER

Combined heat and power (CHP) is one of the most promising technologies for the near-term reduction of greenhouse gas emissions. It involves the joint production of heat (steam) and electricity. Both the heat and the electricity can be used on site, or surplus electricity can be sold back to the grid and surplus heat can be used in district heating (DH) and community energy systems.

There are substantial thermodynamic advantages to the joint production of heat and power that could greatly reduce generation losses from traditional power production and would reduce carbon emissions system-wide. Little additional fuel is required for electricity production over that required for simple steam production, so overall efficiency is higher than with separate electricity generation and steam production. The most attractive use of CHP is where existing by-products and waste can be burned



(for example, wood chips, paper mill wastes, refinery gas), substituting for purchased fuel.

Highly efficient lower-temperature CHP is well-developed technology for the commercial sector, but high-temperature CHP is still in its infancy. Industrial processes where direct heat is needed in the range of 200°C to 800°C, such as those in bakeries, ceramics manufacturing, brick making and dairies, can make use of high-temperature CHP, although using it on a retrofit basis would require major plant changes such as replacement of existing furnaces. Currently, industrial CHP is used particularly widely in countries with major energy-intensive industries and town centres with an extremely dense heating and cooling load, as in the United States and Japan. It is also used widely in Europe; the most technologically developed direct heat/CHP systems are to be found in the Nordic countries and Germany. In a number of European countries, the CHP share of direct heat production has increased markedly over the past 20 years, reaching 79 per cent in Sweden.

Recent advances in the efficiency and cost-effectiveness of electricity generating technologies have allowed for the development of new CHP configurations that reduce size yet increase output.

In a CHP or DH/CHP system, the overall conversion efficiency of fuel energy to useful heat or power can be as high as 85 to 92 per cent. It thus has the potential to reduce CO<sub>2</sub> emissions significantly compared with producing the heat and power separately from the same fuel. This is a technology that is widely seen as offering a major short-to-medium-term contribution to energy efficiency and thus CO<sub>2</sub> emissions, particularly in Western Europe, North America and Japan. The European Commission estimates that the maximum electricity potential of CHP in the European Union may be four times the amount generated in 1994, giving rise to a reduction of 9 per cent in CO<sub>2</sub> emissions compared with what they otherwise would have been.

One of the largest barriers to CHP use is the difficulty of matching heat and electricity loads. In addition, the high initial costs of these systems could deter investment in the power-generation sector under deregulated markets as well as in industry. Operational problems, such as the effect of direct heating on product quality, could also deter industrial investment. Lack of experience with CHP in a given industrial sector could do the same. Depending on the locality, four additional barriers may be environmental permitting, which is often complex, time-consuming and uncertain; regulations that do not recognise CHP's overall energy efficiency or credit emissions avoided from displaced electricity generation; discriminatory backup rates and interconnection fees charged by utilities; and unfavourable tax treatment and depreciation requirements (IEA 2000).

## **ADVANCED GAS TURBINES**

Advanced turbine systems (ATs) are a promising, crosscutting technology for the near and longer terms. The turbines are high-efficiency, next-generation, gas-fired turbines that will produce less carbon per kWh than technologies used in conventional power markets. They are being developed in two size classes: industrial gas turbines (approximately 5 MW and 15 MW) and turbines for utility combined-cycle systems

(approximately 400 MW). These ATSs are one of the major low-carbon technologies for the industrial sector between now and 2010 because of their high efficiencies (greater than 40 per cent) and their capability to cogenerate electricity and steam. These turbines are able to run on a variety of fuels and can be adapted for biomass and landfill gas fuels.

Advanced turbine systems are poised to enter the market in 2000-2001. Some ATS manufacturers already have significant orders for their engines. Currently, most manufacturers are engaged in component and full system demonstration activities. Additional technology under development included ceramic materials and coatings, low emission technology, and alloys. Some of these technologies will be commercially available in the ATS and spin-off engines by 2003.

When introduced in 2000-2001, ATSs will have CO<sub>2</sub> emissions 21 to 61 per cent lower than conventional turbines. Efficiencies of industrial ATSs will exceed 40 per cent and reach 60 per cent for utility combined-cycle systems.

With restructuring of electricity markets, many customers may delay decisions on investment in power generation and cogeneration until the regulatory situation is more settled. The low availability of capital in several end-user industries discourages investment in new technology. In addition, slow rates of capital stock turnover in industry will affect the rate of adoption of this technology (IEA 2000).

## **AUXILIARY EQUIPMENT**

### **Sensors And Controls**

Sensors and controls are a promising crosscutting technology for energy end-use and power generation applications. Sensors and controls do not themselves save energy, but they increase the efficiencies of equipment and processes, thus reducing energy use and related emissions. Sensors and controls have applications in industry, whereas precise industrial process control is often limited by the lack of advanced sensor technology. They are also used in fossil energy extraction systems, building energy systems, advanced vehicle engines and other systems.

Industrial process control and energy management are continuously evolving with new and improved sensors and advances in information processing technologies. Use of advanced sensing and signal processing capabilities allows a progressive transition from localised control of a production process to full factory floor automation. The speed of this transition has been sharply accelerating over the past five years, aided by significant advances in fibreoptic, semiconductor, microfabrication and microprocessor technologies. With new devices becoming more reliable and cost-effective, the use of "smart" sensors in factory automation will become more widespread.

The use of sensors for industrial process control has already improved productivity substantially and has reduced energy consumption and CO<sub>2</sub> emissions. It is estimated that energy management systems using sensors and controls could save about 5 to 10 per cent of process energy use in industry. Combustion control through closed-loop

feedback has improved passenger-vehicle efficiency by an estimated 15 per cent and fossil-fuel-burner efficiency by about 3 per cent, with commensurate reductions in CO<sub>2</sub> emissions.

The primary barrier to wide use of sensors and controls is technical: the lack of low-cost, robust and reliable sensors that are resistant to corrosive conditions and able to withstand high temperatures. The integration of sensors into control systems is also needed. High capital costs for new systems using sensors and controls is another barrier to wide use, as is the lack of readily available and accessible information on their potential economic and environmental benefits (IEA 2000)

## **Power Electronics**

Power electronics serve to upgrade power from distributed and intermittent sources to grid quality and to iron out disturbances to the grid that could result from end-use electro-technologies such as variable speed drives. Power electronics are therefore important to renewables-based electricity generation, distributed generation and end-use electro-technologies. They themselves do not reduce CO<sub>2</sub> emissions but permit technologies to be used that can do so. For example, motors achieve variable speed capability, which results in increased efficiency, via power electronics. “Inverter” circuitry converts power generated using a number of alternative technologies – such as photovoltaics, wind energy systems and fuel cells – into alternating-current (AC) power.

There are many commercial technologies, though improvements are still needed. Inverter technologies have recently been developed with improved efficiency, reliability and performance and reduced size and cost. A multi-level inverter has been developed that will allow 26 per cent more energy to be extracted from photovoltaic or other renewable-energy sources.

The use of improved electronics leads to reduced carbon emissions in virtually all electricity generating technologies and energy end-use technologies and can improve electricity grid operation and management.

Cost and technical barriers stand in the way of wider use of power electronics. Smaller, lighter, more efficient, lower-cost inverters are required, and reliability, cost and electromagnetic compatibility must be improved (IEA 2000).

## **TRANSMISSION AND DISTRIBUTION**

Electrical transmission and distribution system improvements are essential to enable deployment of alternative electrical generating technologies, particularly for large-scale development of remote resources such as renewables. Power system component development to reduce losses from transmission and distribution systems also offers significant opportunities to reduce greenhouse gas emissions.

Advances are needed to better use existing systems. Advances are also needed in new systems and components, such as those required for distributed utility and generation

concepts. R&D is needed on automated system control technologies and high-strength overhead line conductors to increase the capacity of existing systems. Developments in power electronics – including wide-band semiconductors for high-power switching devices and advanced converter designs – are needed to improve power management on existing systems and to enable high-voltage direct-current (DC) transmission for long-distance power transfers. Improvements in superconducting materials and associated refrigeration technologies will lead to the development of superconducting cables and power transformers that offer half the energy losses and many times the capacity of conventional devices while taking up less space and reducing environmental impact. Further development of superconducting generators, motors and transmission cables, and of low-cost methods of manufacturing amorphous metal materials for high-efficiency distribution transformers, is needed (IEA, 2000).

## **FUEL CELLS**

Fuel cells store chemical energy which is converted directly into direct current electricity. They operate with a continuous external supply of fuel. Fuel cells for stationary generation are promising technologies for reducing greenhouse gas emissions in the decade beyond 2010. Fuel cells have been developed for cogeneration (combined heat and power) applications and are being developed for residential and distributed power-generation applications. Hybrid fuel-cell/turbine systems are being developed for large distributed generation, industrial and utility applications.

Phosphoric acid fuel cells (PAFCs) represent the first generation of commercial fuel cells (200 kW). The development of this technology has enabled subsequent development of other fuel cells and of the needed infrastructure for fuel-cell technology.

The proton-exchange membrane fuel cell (PEMFC) is a low-temperature fuel cell with possible applications in transport, CHP systems, and distributed power generation. It offers the potential of low cost in mass production and power densities high enough for even demanding applications such as the automobile.

Developers of the molten carbonate fuel cell (MCFC) and the solid-oxide fuel cell (SOFC) seek 50 to 60 per cent stand-alone efficiencies for distributed or centralised power-generation applications. These fuel cells may also be used with turbines in a combined-cycle arrangement. Both MCFCs and SOFCs have important potential in properly managed biomass systems (IEA 2000).

Fuel cell technologies are yet to benefit from the long history of commercialisation associated with many other energy technologies. PAFCs are the only fuel-cell systems commercially available today. There are currently more than 200 PAFC systems installed worldwide, with a total generating capacity of about 50 MW. The main industrial firms developing and selling fuel cells are based in North America, Western Europe and Japan. Gas and electricity companies are the major buyers of fuel cells.

Other fuel cells are still in the development or demonstration phase, and there are still technical barriers to surmount. The first commercial PEMFC, SOFC and MCFC systems are expected within the next four to six years.

Low-temperature fuel cells have wide market opportunities in both transport and stationary CHP applications.. Currently, the most promising low-temperature fuel cell is the PEMFC. Hydrogen is the natural fuel for low-temperature fuel cells. But PEMFCs might be launched on the market first with conventional hydrocarbon fuels and point-of-use fuel processors. For CHP applications, PEMFCs will be fuelled initially with natural gas that is reformed on site to a hydrogen-rich gaseous mixture that the fuel cell can use; fuel processors for such applications are commercially available (IEA 2000).

The technology of fuels cells, by directly converting chemical energy into electric energy, can attain higher yields than is the case for thermally-generated electricity. They also have other advantages – silent functioning, small emissions of pollutants, a great variety of usable fuels (natural gas, propane, butane, naphtha, methanol, carbonic oxide gas, hydrogen, gasified coal, biomass or landfill gas), relatively small size, good performance in partial charging, modular construction, short manufacturing time, quick replacement, and economic maintenance (due to the small number of moveable parts).

The use of fuel cells for centralised electricity generation is unlikely within the next ten years, although by 2015 Europe, Japan and the United States could all have significant installed capacity. There is potential for significant CO<sub>2</sub> savings because fuel cells are much more efficient than competing technologies in most applications. In power generation, for example, an advanced SOFC/gas turbine system is expected to operate at more than 70 per cent electrical efficiency, producing only 50 to 70 per cent of the CO<sub>2</sub> emitted from an equivalent CCGT plant (IEA 2000).

Cost is likely to be the major barrier to wide use of fuel cells for stationary generation. Production costs, even for fuel cells approaching market readiness, are high, making them less competitive with established technologies. There are also technical barriers associated with individual fuel cells. For example, the sensitivity of fuel-cell performance to impurities in the fuel stream is an important research topic for applications with coal, biomass or waste as their primary fuel. In addition, a lack of awareness of the technology on the part of potential users is a barrier to wider use (IEA 2000).

The Southern Hemisphere's only commercial fuel cell is operating at the Australian Technology Park in Sydney. It supplies electricity to a major bio-medical research centre in the technology park run by Johnson & Johnson, and will also power the planned new Australian centre for Advanced Computing and Communications. The park's fuel cell has been backed by a range of corporate sponsors, a loan from the

NSW Sustainable Energy Development Authority, and a grant from the U.S. Government's Climate Change Program. An American company called ONSI Corporation is the manufacturer of the cell (Environment Australia, 2000).

## HYDROGEN

Hydrogen is a carbon-free energy carrier that has potential uses in many applications. For example, it can fuel vehicles, provide process heat for industrial processes, supply domestic heating needs through cogeneration or heat recovery systems, and fuel power plants for centralised or distributed generation.

Some analysts believe that hydrogen will be the basic form of energy that will provide power to future societies, replacing natural gas, oil, coal and electricity. Such a vision is for the very long-term. However, the commercial deployment of some hydrogen technologies, such as fuel cells, is likely to begin soon, although significant market penetration is not expected before 2015-2020.

Hydrogen can, in principal, be obtained from fossil fuels, biomass and water. To produce hydrogen from fossil fuels, the fuel reacts with oxygen or air to produce mainly carbon monoxide and hydrogen. The former (CO) then reacts with steam in a catalytic reactor to give carbon dioxide and more hydrogen. The CO<sub>2</sub> is separated out and stored, and the hydrogen is used as a fuel.

How much carbon is emitted by hydrogen-based systems depends on the fuel input and the production process. Biomass gasification or pyrolysis can produce a fuel gas that is subsequently used to produce hydrogen. Hydrogen can also be produced from water through electrochemical and photochemical processes. If nuclear power or renewable energy is used in these processes, the life cycle CO<sub>2</sub> emissions are close to zero.

Hydrogen as an energy carrier can be used to power fuel cells. These cells are a promising technology as a source of electricity and heat for buildings, and as a power source for electric vehicles. The fuel-cell units currently in operation are generally natural gas-fired, but research efforts are also being directed at the integration of other fuel sources, such as gasified coal, with fuel-cell plant (IEA 2001c).

The source flexibility of hydrogen and electricity on the one hand, and the storability of hydrogen and the synergism between the electron and proton carriers on the other, make hydrogen the ideal load-balancing fuel for primary energy sources with intermittent availability. It appears that the development of a hydrogen supply infrastructure will be an inevitable prerequisite for the large-scale utilisation of many renewable forms of electricity. For example, the prospects for a rapid market penetration of photovoltaic electricity beyond the level of local or incremental importance hinge on the removal of the electricity storage barrier. Hydrogen represents an immediate solution to electricity storage (Energy, 1993).

A big increase in R&D is needed on biological, thermochemical and electrochemical processes for producing hydrogen. Research is also needed on hydrogen storage

technologies such as this based on innovative materials – for example, carbon fibres and structures and metal hydrides (IEA 2000).

## **CARBON SEQUESTRATION**

There appear to be no serious technical barriers to the sequestration of CO<sub>2</sub>, although high costs for CO<sub>2</sub> capture and uncertainties about environmental impacts and the long-term integrity of storage schemes remain as issues to be resolved. Technologies for CO<sub>2</sub> capture and sequestration are being demonstrated currently. One example is that of Statoil, the Norwegian oil and gas company, which is using state-of-the-art technology to capture CO<sub>2</sub> from the production of natural gas and sequester it in saline aquifers under the North Sea.

### **Carbon Dioxide Separation Technologies**

The efficient separation of CO<sub>2</sub> from flue gases is essential for any sequestration scheme. There are many techniques potentially usable for separation of CO<sub>2</sub> – examples include gas-separation membranes, solvent scrubbing (usually using either potassium carbonate or amines), adsorption and cryogenics.

Currently, various separation techniques using membranes are being tested in different parts of the world, and ongoing R&D is aimed at developing more cost-effective separation methods. Chemical and physical solvents are already used commercially for this purpose.

Carbon dioxide capture is applicable to large flue gas streams in energy-intensive industries and in power generation. It is able to deliver deep reductions in emissions while enabling continued use of fossil fuels. It is primarily applicable to new plants, as replacing existing coal plants with renewable-based or more efficient fossil-based technology would be cheaper than retrofitting existing plants with CO<sub>2</sub> capture systems. In the case of coal plants, the obvious route to incorporating CO<sub>2</sub> capture into plant design is through coal gasification, which can be adapted to produce a pure CO<sub>2</sub> stream.

The cost of separating CO<sub>2</sub> is a major obstacle to the wide use of available methods for CO<sub>2</sub> capture, as it largely exceeds the cost of transporting it, even over long distances. The need for appropriate storage sites could constrain the emissions reduction potential over the longer term (IEA 2000).

### **Geological Storage of Carbon Dioxide**

Geological storage of CO<sub>2</sub> is the most promising sequestration technology for the near term. It involves capturing the gas and injecting it into subsurface repositories such as deep coal beds; depleted oil and gas reservoirs; and deep, confined saline aquifers.

Other options aside from geological storage are also being investigated, including deep ocean storage and use of fertilisation to enhance the ocean carbon sink.

The technology for subsurface injection is readily available from the petroleum industry. That industry uses technologies for drilling and completion of injection wells, compression and long-distance transport of gases, and characterisation of subsurface reservoirs. It has experience with CO<sub>2</sub> injection for enhanced oil recovery. Natural gas is routinely transported and stored in subsurface reservoirs and aquifers.

Amine absorption, in combination with CO<sub>2</sub> storage in saline aquifers is used in the Sleipner Gas field, located in the Norwegian part of the North Sea. In this case, CO<sub>2</sub> is separated directly from the well stream before the gas is further processed and exported. Injection of CO<sub>2</sub> into partially depleted oil reservoirs is being used for enhanced oil recovery at about 70 sites worldwide. Injection into deep, unmineable coal beds to recover coalbed methane is under active investigation in a number of countries.

Long-term storage in geological repositories will reduce greenhouse emissions by sequestering them from the atmosphere. Injection into depleted oil and gas reservoirs and deep coal beds could store CO<sub>2</sub> and also yield commercially valuable hydrocarbons. In a study carried out for the European Commission, underground aquifer storage capacity in the North Sea alone was estimated to be adequate to store up to 200 to 250 years of CO<sub>2</sub> emissions from OECD-Europe, at 1990 emissions rates (IEA 2000).

The main practical barrier to wider use of geological storage is the cost of separating CO<sub>2</sub> from dilute flue gas streams. The costs of carbon capture and disposal are very uncertain. All the options for capturing CO<sub>2</sub> require extra energy, thus reducing the overall efficiency of combustion, typically by ten percentage points (IEA 2001c).

### **Advanced Carbon Sequestration**

Research and development is needed on several advanced approaches to carbon sequestration.

Augmented **ocean fertilisation** would enhance the capability of the ocean to sequester CO<sub>2</sub> by enriching nutrient-poor regions of the ocean floor with iron or nitrogen. This enrichment is a first step toward stimulating phytoplankton growth, enabling carbon deposition on the ocean floor and CO<sub>2</sub> drawdown.

Advanced **chemical and biological sequestration**, which is aimed at permanent stable sequestration and recycling of carbon into new fuels and chemical feedstocks.

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Emissions are reduced through converting CO<sub>2</sub> into an environmentally benign product while generating liquid fuels, generating hydrogen fuel and converting into organic compounds. Representative technologies include chemical sequestration as mineral carbonate, direct solar conversion of CO<sub>2</sub> to methanol, advanced conversion of coal to hydrogen and conversion of CO<sub>2</sub> into reusable biomass using microalgae.

**Elemental carbon sequestration**, which is based on production of hydrogen from fossil fuel and carbonaceous fuels (for example, by thermal decomposition of natural gas) followed by sequestration of the particulate carbon formed in the reaction. This process is an alternative to conventional steam reforming and subsequent sequestration of CO<sub>2</sub>. Thermal decomposition of methane to produce carbon black is conventional technology. Production of hydrogen for methane decomposition has been demonstrated in a catalysed fluidised bed, and plasma decomposition has been performed in a pilot plant. But these are relatively inefficient processes and development of reactors that can produce hydrogen continuously at an efficiency of about 70 per cent is needed. Research is also needed on using large amounts of carbon as a material commodity – for example, in construction applications.

**Carbon sequestration in soils**, which involves implementation of appropriate soil management practices that also increase agricultural productivity. These include minimum tillage agriculture, increased return of crop residues to the soil, use of irrigation and fertilisers at levels that maximise crop and root biomass, return of agricultural lands to forests and grasslands, and plant breeding and genetics to increase below-ground carbon storage. These techniques are available now, but research is needed to evaluate their effectiveness in sequestering carbon.

**Deep ocean sequestration** of CO<sub>2</sub> in gas hydrates, which could be a stable form of sequestration. The CO<sub>2</sub> sequestered in the deep ocean can also be stored in a liquid form or as a solution. R&D is needed in performance assessment, deep ocean science and engineering, fate and transport chemistry, and three-dimensional characterisation and monitoring.

## **ADVANCED ENERGY STORAGE**

Advanced energy storage technologies include mechanical processes (flywheels, pneumatic systems), electrochemical technologies (advanced batteries, reversible fuel cells, hydrogen) and purely electrical technologies (ultracapacitors, superconducting magnetic storage). Their greatest value for electricity systems is that they can enable better use of intermittent renewable-energy sources, such as solar energy and wind, that produce no direct CO<sub>2</sub> emissions.

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The major challenge for all storage technologies is cost reduction. The major needs in R&D are developing new electro-catalysts, new electrode materials and new structural materials for electrochemical systems; magnetic bearings, better fail-safe designs and lightweight containment, and composite rotors with higher specific-energy for flywheels; better corrosion-resistant materials for batteries with higher power density; commercial high-temperature superconductors (operating at liquid nitrogen temperatures) for superconducting magnetic energy systems; higher energy-density ultracapacitors for light-duty vehicles; and improved power conditioning systems (IEA 2000).

# Improving End-Use Efficiency

## OVERVIEW

The actual efficiency of individual conversion and end-use devices and systems varies widely. There is also a considerable difference between the best performance and average performance of most conversion devices. Conversion efficiencies range from less than 5 per cent for the ordinary incandescent lamp to 99 per cent for large electric generators. Overall, the primary to final energy conversion processes are quite efficient; the global average is about 74 per cent. In comparison, the final to useful energy conversion efficiency is very low, being 46% at the global level.

Energy end use is the least efficient part of all energy systems, and it is in this area that improvements would bring the greatest benefits. The applications of efficiencies prevailing today in the market economies of the OECD to provide useful energy for the rest of the world would reduce the global primary energy requirements by 17 per cent and would lead to a similar reduction in CO<sub>2</sub> emissions (Energy, 1993). This is of course a very simplistic exercise that does not take into account the many structural changes that would take place as a result of such an improvement in energy efficiency, which would tend to be associated with higher overall growth and hence energy demand.

Large efficiency differences in energy use also exist within the advanced market economies as well. If we again assume the structure of the energy system to be fixed and the level of economic activity unchanged, we can estimate the hypothetical energy reduction potential that would result from a worldwide diffusion of best available technologies. Total primary energy requirements and also CO<sub>2</sub> emissions would be reduced by 40 per cent. In practice, it would take time to achieve such a result. As previously indicated, the average global energy intensity (the energy-GDP ratio) has declined at a rate of about 1% per year. At this rate, it would take more than 70 years to reduce the average energy intensity to one-half (Energy 1993). Of course, the stimulus given by the oil shocks of the 1970s saw an acceleration in this rate of reduction in energy intensity, but this has been difficult to sustain.

Improved end-use energy efficiency should be sought through a number of means, particularly in relation to buildings, domestic appliances, commercial and industrial equipment, electric motors, hot water, recycling, fuel switching, benchmarking best practice, life cycle analysis, and energy information programs. Current best-practice technologies and possible new technological change offer the possibilities of major improvements in end-use energy efficiency.

Before taking note of some of these possibilities for increased efficiency and lower emissions, we need to be aware that there are a number of significant barriers that may delay or inhibit the achievement of efficiency potential in the near future. One of them is the cost of these measures and the associated capital requirements. The other class of barriers is related to the inherently long process of innovation diffusion and technology transfer. The introduction of new energy technologies takes anywhere from 10 to 50 years in the case of investment in basic infrastructure. This the vintage structure of the capital stock and the dynamics of its replacement also determine the

likely rates of future efficiency improvements. This is particularly the case with buildings. One implication of this is that the realisation of some efficiency improvement potentials will therefore need to be associated with retrofitting some of the older vintages. However, in most industrialised countries almost 80% of the capital stock is replaced over a period of 20 years, meaning that substantial efficiency gains could be achieved over the next two decades in most energy end uses (Energy, 1993). Moreover, the frenetic pace of the information revolution, particularly in the United States, indicates that the rate of transformation associated with technical change is tending to accelerate.

## **BUILDINGS**

Improvements to the design of commercial and residential buildings have the potential to make an important contribution to limiting Australia's greenhouse gas emissions. Building design has to be considered in its broadest sense – relating both to the architectural design of the building itself and to the wider building envelope and aspects of subdivision design which impact on energy efficiency.

Building stock turns over only very slowly, but the equipment used in residential and commercial buildings has a much shorter lifetime. There is a significant opportunity to replace it with more efficient equipment and systems by 2010 and shortly beyond. Building retrofits also provide opportunity to improve building shell components such as windows and insulation.

Among the more promising areas for reducing greenhouse gas emissions are:

- Efficient heating, ventilation and air-conditioning equipment through the use of heat pumps or condensing gas furnaces;
- New technologies in energy-efficient lighting;
- Further improvements in the energy efficiency of domestic appliances;
- Retrofits in windows (with low-emissivity coatings or gas-filled windows) and insulation (using new materials);
- Building energy management systems designed to improve the efficiency with which buildings operate and at the same time conserve energy);
- District heating and cooling systems; and
- Technologies that reduce losses through the use of electricity by appliances on standby.

In the very long term, further technological advances could result in “best practice” buildings incorporating features such as:

- Computer-based building design and optimisation;
- Manufactured wall systems with integrated super-insulation and electrochromic windows;
- “Superwindows” optimised for orientation (to take advantage of natural lighting) external temperature and internal needs;
- Integrated natural and electric lighting systems (for commercial buildings, highly-efficient centralised electric light sources combined with tracking daylight collectors connected to “piped” light-distribution systems);

Photovoltaic roof shingles, reflective roofing and strategic positioning of trees to reduce cooling costs;  
Fuel cells for power generation and space conditioning;  
Sensor-controlled ventilation systems with air filtration and heat exchange;  
Advanced building control systems incorporating “smart” technology to closely match energy and water supply for efficient, multi-functional and integrated appliances and to match ambient conditions with need;  
Energy storage systems; and  
Advanced district heating and cooling systems.

Future buildings can be completely self-powered through the use of fuel cells, small turbines, photovoltaic building components (panels, shingles etc.) and energy storage systems. Excess electricity can be generated for sale to the grid.

A future sustainable building can be envisioned that would have a minimal impact on the indoor, local, regional and global environment. It would use recyclable materials, would consume a minimum of non-renewable heat and electricity, and would employ heat recovery and heat cascading. It would be connected to wastewater cleaning/recycling and to waste management/recycling, would have high energy efficiency, and would provide good thermal comfort, indoor air quality and lighting throughout the year.

In the long term, if greenhouse emissions attributable to the building sector are to be significantly reduced, incorporation of features such as those described above must be the norm, not the exception. To make this happen, work is needed to integrate energy-efficiency practices and principles into broader building-sector policies (codes, standards and so forth). Because the lifetimes of buildings are so long, actions to influence building design, construction and refurbishment are high-leverage activities for the long term. In addition, long-term R&D is required to provide the advanced appliances, equipment, components, systems and design tools needed to create advanced buildings. Examples of areas in which such R&D is needed are on-site power generation, system optimisation, advanced sensors and smart controls, energy design and diagnostic tools, automated diagnostics, super-insulations, adaptive building materials and envelope systems, innovative thermal distribution networks, recycled materials, integrated multifunction appliances, innovative lighting and new materials for appliances (IEA 2000).

## INDUSTRY

Numerous efficient technologies could reduce energy intensity and emissions in industry. Many of them are specific to individual industries, such as pulp and paper manufacturing, chemical processing or glassmaking. Others are common to several industries. Some examples of the latter are given below.

**Process integration** is the term used for a collection of strategies, methods and tools that focus on the efficient use of resources (energy, raw materials, water and capital) on a systems level. The best-known and most widely applied process integration method is pinch analysis. It was originally developed to facilitate optimal heat recovery between heat sources and heat sinks. Process integration applies to most

sectors in the process industries, including petroleum refining, chemical manufacturing, food and beverage production. The scope of process integration methods has broadened considerably since the early 1980s when the emphasis was on heat recovery. Today, process integration can be also be used for heat and power systems, utility systems, distillation systems, reactor systems, and even water management and wastewater treatment systems. Process integration is also expected to move into batch processing of such products as pharmaceuticals, resins and dyes.

**High-Efficiency Motors, Drives and Motor-Driven Systems** hold significant potential for reducing emissions in the near term. Energy-efficiency opportunities in these systems derive not so much from the replacement of older motors with high-efficiency models as from energy-conscious design throughout the system. The system includes power supply lines, controls, motor feed cables, the electric motor, the drive and transmission system, and the driven load. Each of these system elements may present an opportunity to conserve energy. Efficient technologies are available on the market. Power electronic switching devices and micro-electronics have made electronic adjustable speed drives increasingly popular and have brought down their price. Adjustable speed drives are available in a large variety of designs.

**High-Efficiency Separation Processes** such as membrane processes, freeze crystallisation and better system controls, have significant potential to reduce emissions attributable to industry in the near term. Industrial separations recover, isolate and purify products of virtually every industrial process. Today's separation processes include distillation, extraction, drying, absorption, adsorption, crystallisation, membrane-based technologies and stripping. Such processes account for a large share of energy consumption in industry. Improvements in this area are applicable across a wide range of industries.

Recovery of materials for **recycling** into new products can contribute to a reduction in greenhouse gas emissions by the energy savings involved in using used materials instead of virgin materials. The major materials that can be recycled include metals, paper, high density polyethylene (HDPE), milk cartons and glass bottles. Whilst recycling can reduce emissions of greenhouse gases, there are costs involved, and further analysis is needed before general conclusions can be drawn.

**Advanced End-Use Electro-technologies** for industrial end-use applications hold promise for near-term emissions reduction. These technologies can replace many fossil-fuel-based combustion processes in industry. Examples include infrared heating, drying and paint curing; ultra-violet curing; radio-frequency and microwave heating and drying; electron beam processing for metal welding and hardening; induction heating; laser-based technologies; and industrial heat pumps. Electro-technologies in general promise less energy use, less material waste, less pollution and better product quality. They can also provide greater compatibility with advanced sensors and controls, computer controls, and decentralised manufacturing operations. Many electro-technologies are available today and in use in the process industries.

In the longer term, the opportunity to influence new plant design, and R&D to develop advanced technologies for specific processes and crosscutting needs, can result in even greater reductions. Novel concepts such as integration of industrial

facilities with other plants and with facilities for power supply and waste management could lead to “zero-emission” systems.

The efficiency of energy conversion processes in industry can be improved by incorporating the best available technologies in a systems approach, particularly for new plants. In the longer term, fuel cells and gasification of biomass and in-plant residues (such as black liquor in the forest products industry) are likely to have a large impact.

In addition to the energy conversion improvements mentioned above, developing new, more efficient processes can also substantially reduce emissions from energy use in industrial processes. Such processes can encourage new, higher-quality products while generating less waste and fewer undesirable by-products. Opportunities exist to improve process efficiency via advances such as more selective catalysts, further developments in advanced separations, improved materials and improved electric motor systems. A particularly attractive longer-term opportunity is the use of biotechnology and bio-derived chemicals and materials.

Increased fundamental understanding in enabling sciences such as chemistry, metallurgy and biotechnology will allow the development of novel manufacturing processes. This knowledge, along with enabling technologies such as advanced modelling and simulation, improved industrial materials, and advanced sensors and intelligent control systems, can result in major incremental improvements and lead to fundamental breakthroughs. Likewise, developing and demonstrating micro-manufacturing systems (such as mini-mills and micro-chemical reactors) for flexible process configuration can reduce emissions in the long term.

Resource recovery and utilisation offer further savings. An advanced concept is an industrial ecology, in which a community of producers and consumers performs in a closed system. Fossil energy is conserved or energy is obtained from sources that do not give rise to greenhouse gas emissions; materials are used or recycled. Through technological advances, the raw materials and resources needed for manufacturing can be obtained by designing products for ease of disassembly and reuse, using more recycled materials in finished goods, and selecting raw materials to eliminate waste discharge or undesirable by-products. Examples of developments that could facilitate this approach are new polymers, composites, and fibres and advanced ceramics engineering techniques. Another approach is to substitute materials such as biomass feedstocks for producing chemicals. Some longer-term technological approaches could use CO<sub>2</sub> as a feedstock and reductants that do not lead to greenhouse gas emissions as substitutes for carbon. These approaches represent fundamental changes in the way raw materials are obtained, the properties they exhibit and the way they are used in the design process (IEA 2000).

## **HOT WATER**

The manufacture and marketing of low-emission water heaters is important. There is a need to increase the production and market penetration of low greenhouse gas emission hot water systems, including solar water heaters, high efficiency natural gas water heaters, heat pump water heating systems and hybrid systems. In addition,

attention should be given to improving the design and efficiency of smaller hot water systems.

The installation of energy efficient water heaters and the more efficient use of hot water will be promoted by encouraging consumers and, where appropriate, builders and tradespeople to purchase energy efficient dishwashers, washing machines and hot water systems, improve the insulation of hot water storage systems and pipework, adjust thermostats to optimal levels and use low flow shower heads and low faucet aerators (Ecologically Sustainable Working Groups, 1991).

## **BENCHMARKING BEST PRACTICE**

Databases are being developed for benchmarking Australian performance in energy efficiency in the residential, commercial and industrial sectors against available international data. Australia is also participating in international comparative data. This work will be complemented by analyses, in specific sectors, of the technical and economic options for improvement of Australian performance against these benchmarks. As a priority under this initiative, governments will work with industry to improve energy efficiency in the wholesale and retail sector, which has become the largest and fastest growing component of commercial sector energy use (Ecologically Sustainable Working Groups, 1991).

## **LIFE CYCLE ANALYSIS**

In Australia a database and nationally accepted methodology for life cycle energy analysis is being developed. This analysis has concentrated initially on materials and products identified as contributing to high energy use over whole product life cycles, or significant life cycle stages, including sourcing of materials, manufacture or construction, product use and product disposal. This analysis will be undertaken to determine cost-effective opportunities for achieving net greenhouse gas emission reductions involving substitution of materials or manufacturing processes, design or product operation considerations, disposal of product (including recycling and recovery of energies), and whole-of-life-cycle approaches that lead to net energy reductions over the whole life cycle of the product.

Based on these life cycle analyses, policies will be developed and implemented to encourage producer responsibility for sourcing of materials, product design and manufacture, product operating efficiencies and product disposal, as a means of improving greenhouse outcomes. This is to be pursued by actions such as cooperative agreements with industry, information/education, best practice guidelines, codes of practice, promotion through award schemes, legislation, regulation and standards (Ecologically Sustainable Working Groups, 1991).

## **ENERGY INFORMATION PROGRAMS**

Energy information programs in a number of jurisdictions provide information and advice with the aim of encouraging the adoption of cost-effective energy efficiency



and renewable energy technologies in the residential, business and government sectors. Programs include provision of information, raising awareness of the benefits of energy efficiency coupled with initiatives to encourage and facilitate actions that lead to improved energy efficiency.

## **OTHER FACTORS**

Demand management initiatives by electricity utilities are an integral part of reforms in the electricity sector and are leading to the growth of energy service companies. Non-technical measures that conserve energy include behavioural change, redirection of investment decisions towards more energy-efficient requirements and using alternative means to achieve the same goal, such as telecommunications to reduce the need for transport.

## **IMPACTS**

Several recent Australian studies have attempted to aggregate the above potential emission reductions from the energy sector. Although they are all in agreement as to the direction that must be taken, there are differences of opinion as to what can be achieved. Despite the differences in methodologies and assumptions, these studies identify a broad range of possible savings which could be achieved by 2005. They show a range of 107 to 194 million tonnes of CO<sub>2</sub> that could be saved annually by 2005, equivalent to reductions 16 to 39 per cent below ABARE's business-as-usual scenario (Ecologically Sustainable Working Groups, 1991).

## Emissions

Energy has a critical role in generating global warming emissions. Emissions are associated with overall demand for energy use and with the actual production of primary energy. The key parameters for overall energy demand, and hence for energy emissions, are GDP (energy demand is boosted by GDP growth), relative energy prices (higher energy prices relative to general prices will tend to reduce energy demand), and technology (some new technologies may generate additional demand for energy or additional emissions while others will have a role in saving energy or energy emissions).

The income (or GDP) elasticity of demand for energy is very high for developing economies as the structure of their economies moves from low energy consumption to a more energy-intensive industrialised structure, but then tends to decline below unity as the structure of the economy reaches an advanced status. The price elasticity of demand for energy is low in the short run, given the fixed nature of technologies in the short run, but higher in the medium term, when substitution is more feasible, and still higher in the very long term (15-20 years) when considerable changes can occur in infrastructure). Technological change in the past was energy using (note the role of electricity and energy-intensive transportation), but contemporary technological developments are tending to reduce energy use.

The introduction of new technologies in one type of energy production can have the following impacts:

1. Increasing energy efficiency and reducing energy production costs in that area;
2. Reducing emissions when compared with the existing technologies employed in that area of energy production (eg clean coal technologies compared with conventional coal-based energy technologies);
3. Increasing the competitiveness of that form of energy against other energy forms (because of the first effect); and
4. Stimulating the overall demand for energy (again, because of the first effect).

Because of the varied nature of the impacts of technological change on energy markets, new energy-efficient technologies introduced in one part of the energy sector can be expected to have mixed effects on total global warming emissions. For example, in IPTS (1997) a scenario based on accelerated development of clean coal technologies showed that, while clean coal plants are more efficient and produce considerable less global warming emissions per KWH of electricity generated, they also become more cost attractive and are often chosen in preference to nuclear and gas-fired plants which produce even less carbon dioxide per KWH. The upshot is that global CO<sub>2</sub> emissions actually increase slightly in this scenario.

It should be noted that one energy form is not perfectly substitutable for another. In particular, some forms of energy are particularly appropriate to providing baseload capacity for an energy system because of their economies of scale – coal and nuclear energy are prime examples. Other forms of energy can be utilised to provide peakload capacity because of their flexibility (e.g. gas, large hydro). Still others provide intermittent supplementary power (such as wind energy), while others are appropriate for remote areas (e.g. solar). In addition, in specific geographic areas, the choice of energy forms can be limited by the nature of local resources, the local infrastructure,

and financial constraints. In this context, specific technological breakthroughs may lead to significant net emission reductions in regions where they provide a unique opportunity for emissions savings, while having zero effects on other regions where the technology cannot be adopted.

Scenarios involving major technical and economic improvements in fossil fuel technologies produce weakened impacts on CO<sub>2</sub> emissions because at the same time as they reduce specific emissions they make these technologies economically attractive, not only with respect to more polluting technologies but also less polluting ones. Choices are therefore influenced in a far from ambiguous manner as far as CO<sub>2</sub> emissions are concerned. In this context it is worth noting that all supply side technological improvements result one way or another in a reduction in the cost of consuming energy and hence potentially cause consumption to increase.

The IPTS analysis suggests that increased gas availability produces surprisingly weak results so far as CO<sub>2</sub> emissions are concerned. This is due partly to the uneven geographical distribution of the enhanced resources resulting in the gas not being available at sufficiently cheap prices where it could have made the biggest impact (the big Asian coal users in China and India) but also due to a series of secondary market effects which brought fuel prices down and caused demand firmness especially in electricity and gas. All this, notwithstanding the indisputable fact that these scenarios represent a more comfortable energy market situation with all its concomitant virtues of security and a propitious environment for economic development (IPTS, 1997).

There is a clear need for energy saving technology breakthroughs as these are likely to suffer less from the ambiguities and secondary effects associated with supply technologies. It is, however, very difficult to identify a cluster of technologies which would be homogenous enough to be convincing as an identifiable alternative while at the same time addressing a wide spectrum of energy demand. The discussion on energy use indicates a wide range of technologies pertinent to energy use. The unifying characteristics of such necessary technological change lie not so much in the technology per se, but the market characteristics – building construction and operation, the characteristics of state-of-the-art manufacturing production systems, sustainable household consumption, etc.

Finally, the complexity of the relationship between innovation in energy emissions-reducing technologies and economic growth needs to be considered. Improvements in energy technology stimulate broader energy efficiency and reduce one of the constraints on economic growth which is particularly important in some developing countries. In such circumstances there is an additional negative feedback on global emissions, implying the need for significantly greater gross emissions-savings in new technologies to compensate for the stimulus given to economic growth.

On the other hand, the conditions favourable to innovation in emissions-saving technologies would be greatly assisted by a general framework conducive to strong innovation in general. This would be the case where strong economic growth encourages a high rate of innovation.

# Policy Issues

## Targets

The essential tasks for a strategy to reduce carbon emissions from the energy sector are fourfold:

1. In the short-to-medium-term, reducing the carbon-intensity of non-renewable primary energy through the introduction of a wide range of new technologies.
2. In the medium-to-long-term, reducing the share of fossil-based energy in primary energy production by increasing the use of renewable energy, both in terms of its direct use and, in the long term, through synthetic fuels derived from renewables.
3. Increasing the efficiency of both non-renewable and renewable primary energy production through the introduction of improved cross-cutting technologies.
4. Improving the energy conversion efficiency system as a whole in order to obtain more useful final energy with the same amount of primary energy. Efficiency improvements may be seen in the electricity transformation system, electric power transmission, the refining industry, and other economic sectors.
5. Reducing the energy intensity of GDP i.e. the final energy consumption required to produce a unit of output.

But in a world with poverty, social deprivations of other kinds, and a range of environmental problems other than that of global warming, a sustainable energy strategy must be interpreted more broadly. The broader objectives of policy should be to:

1. Reduce global warming emissions from energy production and use;
2. Reduce other harmful environmental effects associated with energy production and use (principally, but not exclusively, local and regional air pollution);
3. Provide for a satisfactory rate of economic growth, particularly in the poorer areas of the world by ensuring an adequate supply of energy.

While there is a broad complementarity between the two environmental goals in the fact that cleaner technologies and reduced CO<sub>2</sub> emissions often go hand-in-hand, there are areas of conflict, such as with some forms of renewable energy (such as large hydro schemes and geothermal energy, depending on specific circumstances). Hence some forms of energy innovation will be more suited to particular environments and regions than others. More importantly, the relationship between the environmental goals and that of economic growth is very complex. A pre-condition for emissions savings may be higher prices for energy inputs, but this may have a negative impact on economic growth. It is important to have that moves to more environmentally-compatible energy pricing are accompanied by an acceleration in the rate of innovation in the energy sector, since this would facilitate the attainment of the twin goal for the environment and the economy.

Finally, there is a compelling case for providing a stimulus to innovation across a broad range of technologies:

Given the uneven global distribution of resources, it provides the maximum global reach for energy sector improvements;

The principal driver of competition between energy forms would rest on innovation, thus ensuring a broader stimulus to increased energy efficiency and reduced emissions;

It would enable more sustainable energy pricing to improve energy efficiency without unnecessary sacrifices to economic growth;

It would reduce a key element of uncertainty in energy markets by providing a clearer picture of the future paths of technology in the energy sector, thus enhancing the capacity of the market to provide rational outcomes for the energy sector.

## **Impediments**

A number of impediments exist to changes in energy use, including impediments to investment, price effects, the operation of public utilities and information impediments.

1. A number of factors inhibit the investment by firms or individuals in more energy efficient systems, including access to capital, the view of energy efficient investments as risky, and the unavailability of appropriate equipment.
2. If prices of fuels were based on their full economic, social and environmental costs they would play a more effective role in leading towards sustainable energy use; this is prevented by the distortion in the relative pricing between fuels in Australia due to taxation, royalty and service charge policies of the Commonwealth and State Governments.
3. The practice of structuring electricity and gas tariffs with a higher cost for the initial block of energy followed by a lower cost for subsequent energy use is seen by some as being a form of misplaced incentive that works against efficient energy use.
4. The absence of simple, credible information can prevent consumers from making wise decisions about purchasing energy efficient and conservation technologies; additional information is required to enable firms or consumers to calculate the trade-off between higher purchase cost of an energy efficient appliance, and the operating cost savings over a cheaper but less efficient purchase (Commonwealth of Australia, 1998).

The development of innovative new technologies is providing the technological means for reducing the greenhouse intensity of conventional sources of energy supply. The main constraint on the take-up of these technologies is the limited incentives currently existing in Australia for capital investment in new energy supply.

## **Available Policy Instruments**

Broad criteria for efficiency, equity, environmental impact and administrative simplicity will be fundamental in making choices of instruments to achieve the objectives of ecologically sustainable development. New measures should provide incentives for research, flexibility for modification and choice, and consistency with tax policy, and should take into account the possibility of side effects.

Instruments available include regulations, tradeable rights, pricing strategies, least-cost energy planning, demand management, subsidies, research, and information and education.

Regulation can cover a spectrum of prescriptiveness from outright bans to monitoring requirements. Standards should cover performance, environmental quality, design, behaviour and information. Regulations and standards need to be both practical and enforceable, and have broad community support.

Tradeable emission rights work within a framework of agreed environmental standards. Once overall limits on the total emission of a pollutant have been agreed, tradeable rights provide a mechanism for the allocation of rights to emit certain amounts of that pollutant. This creates a market which places a value on the right to emit, and an incentive is created for those who can most economically reduce emissions to do so, as they can sell the rights they no longer need at a profit.

The main focus of pricing strategies is to ensure that prices reflect full costs, including physical, social and environmental costs. Several types of taxes on energy use may be used. A carbon tax is a fuel tax levied in proportion to the carbon content of fuels. In practice, carbon taxes that have been considered in a number of countries are in the form of a relatively low unit rate of tax grafted onto existing fuel excise. Although such taxes may raise revenue effectively, and help to dampen demand, they are unlikely to provide a driving force for fuel switching unless they are very large in circumstances when the entire fuel tax is purely carbon related. A decision to impose a carbon tax in Australia would be influenced by international considerations. The revenue raised by a carbon or energy tax may be allocated to subsidise new energy efficient technologies, energy conservation strategies, research, development, and education programs.

Least cost planning refers to the approach which would allow additional demand for energy services to be met either by energy end use efficiency measures or by installing new supply capacity, whichever could be supplied at the lower cost. This approach meets the goals of economic and energy use efficiency and improved environmental protection. Demand management involves active strategies to reshape demand to improve capacity use or to avoid having to install new capacity, through measures such as peak reduction, conservation, valley filling and load growth.

Types of financial incentives include accelerated depreciation of equipment, tax deductibility, tax rebates, direct transfer payments to targeted groups or activities, export credits, subsidies, and the 150 per cent tax deductibility for research and development.

Continuing research and development will be required to improve the attractiveness of energy efficiency options, and reduce technological uncertainty. Government can provide tax concessions, research grants, cooperative arrangements for public/private sector cooperation in R&D, and direct funding of research institutions.

Education and information programs are important to overcome a primary impediment to action. Information programs are most effective when targeted at decision makers at various levels.

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