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Chapter 4: Energy Supply

EXECUTIVE SUMMARY

Current situation
The energy sector currently accounts for around 80% of global greenhouse gas (GHG) emissions. There are regional differences in current energy demand, the greatest being in developed economies, with rapid growth now occurring in many developing countries. Energy access, equity, and sustainable development are compromised by increasing prices of oil and other fossil fuels, but these factors may increase incentives to deploy carbon-free or low-carbon energy sources.

Global dependence on fossil fuels has led to the release of over 300 GtC into the atmosphere since around 1850. To continue to extract and combust the world's rich endowment of oil, coal, peat, and natural gas at current or increasing rates without carbon capture and storage (CCS), hence release the stored carbon to the atmosphere, is no longer environmentally sustainable.

Since the TAR was published in 2001, in spite of the introduction of supporting government policies, a wide range of advanced technologies, and more recent higher energy prices, GHG emissions from the use of fossil fuels continue to increase. Mitigation has therefore become even more challenging.

There is an abundance of all forms of energy for the future and the technologies to use them effectively. However, enormous issues surround costs, security, and environmental impacts, including GHGs. Trends indicate that:

- Conventional oil will peak but it is uncertain exactly when and what will be the nature of the transition to alternative liquid fuels (coal to liquids, gas to liquids, unconventional oil, biofuels) reaching the market and resultant carbon emissions.
- Conventional natural gas is slightly more abundant than conventional oil but also not distributed evenly across all regions. Unconventional gas resources are also abundant but development of all of these resources is uncertain.
- Insecurity of future conventional oil and gas supplies and rising prices could cause a transition to more coal, nuclear and renewables (as well as unconventional oil and gaseous fuels).
- Coal is also not evenly distributed but is very abundant and can be converted to liquids, gases, heat and power but its utilization will demand viable CCS technologies if GHG emissions are to be limited.
- Nuclear energy, already at about 7% of total primary energy, could make an increasing contribution to carbon-free energy carriers in the future, although without recycling this could be severely restricted by utilizing a small fraction of the uranium resource. Other major issues relate to economics, proliferation, terrorism, safety, waste management, and public opinion.
- New renewables, particularly solar, wind, and modern biomass, although small overall contributors now, are the most rapidly increasing electricity supply technologies.
- Traditional biomass still accounts for more than 10% of global energy supply and could be replaced by modern biomass, renewable or nuclear heat and electricity systems, and fossil fuels.

Absent effective policy actions, GHG emissions from the combustion of fossil fuels are predicted to rise over 50% from around 24.6 $GtCO_2$ (6.6 GtC) in 2003 to between 37–39 $GtCO_2$ (10–10.5 GtC) by 2030.

Large-scale energy conversion technology plants, such as hydro-power or district power or heating plants, tend to have a life of 30–100 years, hence a rate of turnover around 1–3% per year. Thus, decisions taken today that support the deployment of carbon-emitting technologies, especially in the rapidly developing world, will have profound consequences on development paths for the next 40–60 years. Smaller-scale, distributed energy plants can be built more quickly, can utilize combined heat and power (CHP) as well as cooling and make use of 80–90% of the total fuel energy instead of wasting 50–70% as heat. CHP and distributed-electricity systems together can also reduce transmission losses and the high investment costs of distribution networks.

Effective policies supporting energy-supply technology development and deployment are crucial to the uptake of low-carbon emission systems, but must be regionally specific. In addition, no single policy instrument will enable the desired transition to occur in any one region.

Transition to low-carbon technologies

New energy-supply and conversion technologies resulting in decreased amounts of GHG emissions could be implemented more rapidly than at present. Supply-side technologies that aim to enhance access to clean energy, improve energy security, and promote environmental protection at local, regional and global levels include thermal power plant designs based on gasification, combined cycle and supercritical boilers; natural gas as a bridging fuel; and CCS used in the transition period until advanced renewable energy technologies and advanced nuclear fission become commercial. Energy-supply technologies are complemented by improved end-use efficiency technologies and a closer matching of energy supply with demand.

The energy systems of many nations are evolving from their historic dependence on fossil fuels in response to climate-change mitigation, market failure of the supply chain to meet the ever-growing demands for energy, and increasing reliance on global energy markets, thereby necessitating the wiser use of energy in all sectors. The transition from surplus fossil-fuel resources to constrained gas and oil carriers and hence to alternative, non-conventional, low carbon energy supplies has begun but faces regulatory and acceptance barriers. Fossil fuels in individual locations at densities of one-hundred-thousand W/m^2 land area have been discovered, extracted, and distributed downwards, whereas renewable energy is usually widely disbursed at densities of 1–5 W/m^2 and hence must either be used in a distributed manner or be concentrated to meet the intensive energy demands of cities and industries.

Energy-resource extraction and consumption should account for environmental costs. This requires long-term vision and leadership based on sound science in concert with policy initiatives. Sustainable energy systems will need to emerge as a result of government, business and private interactions. However, selection of energy-supply technologies should not be on cost and GHG mitigation potential alone but also include the many co-benefits.

Energy services are fundamental requirements needed to achieve sustainable development as outlined by the goals of the United Nations Millennium Declaration (UN, 2000). In many developing countries provision of affordable energy services has been insufficient to reduce poverty levels and improve standards of living. To provide energy services for everyone will require major investment in the energy-supply chain, conversion technologies, and particularly infrastructure in rural areas if adequate, affordable and reliable energy supplies are to be utilized in an environmentally sound way.

Mitigation opportunities, costs, and potentials

The total mitigation potential from the energy-supply sector by 2030 costing under USD 50/tCO_2eq has been shown to be around 4.5 GtCO_2 eq based mainly on the increased nuclear power (1.0 Gt), hydro and other renewable energy including wind, solar and geothermal (0.8 Gt), bioenergy (2.1 Gt), CCS with coal and also gas plants (0.1 Gt but with potential for rapid growth after 2030) and fuel switching (0.5 GtCO_2). In addition, biofuels and unconventional oil based transport fuels will grow by 2030, the carbon mitigation of biofuels of 0.25–0. 45 GtCO_2 possibly outweighed by the increased carbon emissions from oil shale, tar sands and coal to liquid processes. Still under development include advanced nuclear power, improved renewables, second-generation biofuels, commercial CCS demonstration, and possibly hydrogen in the longer term.

Future cost ranges vary from around USD -27 to 6/tCO_2eq avoided for nuclear power; fuel switching from USD 3 to 17/t; wind, hydro, geothermal and bioenergy around USD -17 to 70/t (with most solar PV, solar thermal and ocean energy probably remaining above USD 100/t); and coal and gas CCS varying from USD 35 to 170/t. Future selection of energy-supply systems should not be on costs, discount rates and GHG mitigation potentials alone, but also encompass the many co-benefits that society should internalize.

Policy issues

No single policy instrument will ensure the transition to a future secure and decarbonized world and policies will need to be regionally specific. A range of policies is already in place in OECD countries and in Brazil, Mexico, China and India, to encourage the development and deployment of low carbon emitting technologies. These include renewable energy systems, many of which also have proven benefits linked with energy access, distributed energy, health, equity and sustainable development. Nuclear energy is also receiving renewed attention. However, the use of cheap fossil fuels, at times heavily subsidized by governments, will remain dominant in all regions to meet ever increasing energy demands unless the full costs of environmental (including climate change) and health issues from their use are incorporated. Energy sector reform will be critical to energy development and should include reviewing subsidies, establishing credible legal and regulatory frameworks, developing policy environments through regulatory interventions and creating market-based approaches such as emissions trading. How to use all resources in an environmentally acceptable manner while providing for the needs of growing populations and economies is a great challenge.

The necessary transition will involve continued development of a wide range of technologies and their implementation. Many such technologies are at an early stage of development and require greater public and private investment in research, development, and demonstration if rapid deployment and diffusion are to result. Research investment in energy has varied greatly over time and from country to country, but has declined significantly since the levels achieved as a result of the oil shocks during the 1970s.

Energy security has recently become a more important policy driver. In developed countries lack of investment in plant and infrastructure from liberalization of the energy market and reliance on only a few suppliers, but also from threats of natural disasters, terrorist attacks, and future uncertainties of imported energy supplies add to the concern. For developing countries lack of security and higher world energy prices constrain their endeavours to accelerate access to modern energy services in order to decrease poverty, improve health, increase productivity, enhance competitiveness and thus improve their economies.

In summary

Energy access for all people will require basic and affordable energy services made available using a range of energy resources with innovative conversion technologies while minimizing GHGs, human health and other environmental damages. The optimum method and scale of integrating the provision of heating, cooling, electricity and transport fuels with increasing energy-supply system efficiency will vary with region, rate of growth of energy demand, existing infrastructure and identified co-benefits. To accomplish this will require collaboration of governments, the public and the global energy industry.

A transition toward new energy-supply systems with reduced carbon intensity needs to be managed to minimize economic, social and technological risks and to co-opt stakeholders who have strong interests in maintaining the status quo. Market competition alone will not lead to reduced carbon emissions. More sustained public and private research investment is essential to better understand our energy resources and develop cost effective and efficient low or zero carbon emitting technologies. Such actions will determine:

- future security of energy supplies;
- accessibility, availability, and affordability of desired energy services;
- attainment of sustainable development;
- free-market distribution of energy supplies to all countries;
- deployment of low-carbon energy carriers and conversion technologies;
- quantities of GHGs emitted for the rest of this century;
- achievement of Article 2 of the UNFCCC objectives to stabilize concentrations at a level that minimizes threats to the climate system.

4.1 Introduction

Chapter 4 addresses the energy-supply sector and analyses the costs and potentials of greenhouse gas (GHG) mitigation. It considers how far low- and zero-carbon-emitting technologies (including carbon capture and storage) might be able to contribute toward a sustainable GHG stabilization path over the course of the next few decades. Detailed descriptions of the various technologies have been kept to a minimum, especially for those that have changed little since the Third Assessment Report and are well covered elsewhere (for example IEA, 2006a).

The main goal of all energy transformations is to provide energy services that improve quality of life (e.g. health, life expectancy, and comfort) and productivity (Hall *et al.,* 2004). A supply of secure and sustainable energy is vital to future prosperity.

Globally, demand for all forms of energy continues to rise to meet expectations of growing world population and economies. Rising prices compromise these expectations. On the other hand, large investments in developing countries provide opportunities for a shift toward sustainable energy supply. Energy supply is intimately tied in with development in the broad sense. At present, the 1 billion people living in developed (OECD) countries consume around half of the 490 EJ annual global primary energy use, whereas the 1 billion *poorest* people in developing countries consume only around 4%, mainly in the form of traditional biomass used for cooking and heating. The United Nations has set goals to eradicate poverty, raise living standards, and encourage sustainable economic and social development in its Millennium Declaration (UN, 2000). To succeed will require improved access to modern energy services for everyone. Abundant and affordable energy, access to that energy, and how it is used determines how many humans achieve a decent standard of living in the future (section 4.5.4; SRES scenarios B1, A2, Chapter 3).

If demand continues to grow along the current trajectory and rate, by 2030 the global energy industry will need to provide much more energy, which entails improving energy carrier and conversion systems, requiring an investment of ~$US16 trillion or 1% of global GDP (IEA, 2004a). Total annual capital investment by the global energy industry is currently around US$280 billion (ibid).

Security of the energy supply has become a major consideration for many governments, linked with ensuring that future generations will be able to provide for their own well being without their needs for energy services being compromised.

Currently, fossil fuels provide almost 80% of world energy supply. A transition away from traditional fossil fuel use and inefficient traditional biomass to low- or zero-carbon-emitting modern energy systems would be a part solution to greenhouse gas emission reduction along with carbon capture and storage (IPCC special report 2005). It is yet to be determined which technologies will facilitate this transition and which policies will provide appropriate impetus.

A mix of options to lower the energy per unit of GDP and carbon intensity of energy systems (including lowering the energy intensity of end uses) will be needed to achieve a truly sustainable energy future in a decarbonised world. Energy-related GHG emissions are a function of several economic sectors:

the conversion and delivery sector (including extraction/refining, electricity generation, and direct transport of energy carriers in pipelines, wires, ships, as heat etc.), and
energy end use sectors (transport, buildings and industry, including agriculture, forestry and waste, as outlined in Chapters 5 to 10; Fig 4.1.1).

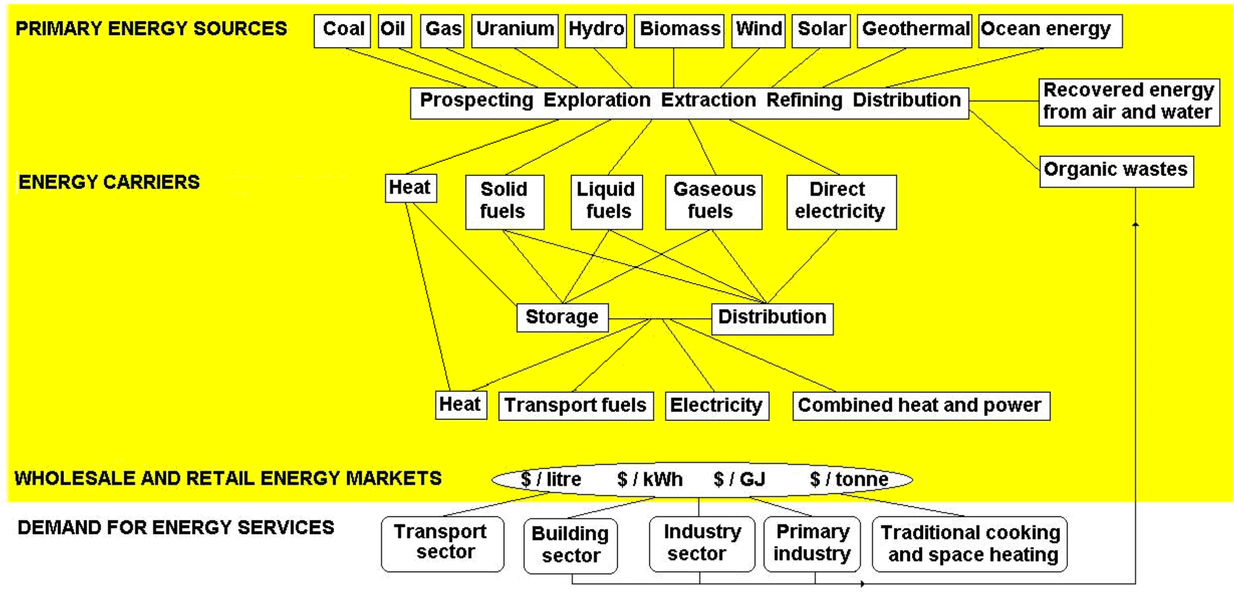

Figure 4.1.1*: Primary and secondary energy supplies meet societal needs for energy services. This Energy Supply chapter 4 (yellow box) links with the energy end-use sector chapters on transport (chapter 5), buildings (6), industry (7), agriculture (8), forestry (9) and waste (10)*

In all regions of the world energy demand has grown in recent years (Figure 4.1.2). A 52% global increase in primary energy demand since 2003 is anticipated by 2030 under business as usual (IEA, 2005a[1]). This will require investment in energy supply systems of around $550 billion / yr, mainly to provide an additional 3.5 TW of electricity generation plant and transmission networks. Over half the total investment will be needed in developing countries and as a result energy related carbon emissions will rise from 6.6 GtC (24.2 $GtCO_2$) in 2003[2] to around 11 GtC (40 $GtCO_2$) in 2030, assuming the technology mix of today. All means of reducing carbon emissions are therefore desired in order to slow down the rate of increase of atmospheric concentrations (WBCSD, 2004).

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1 Note this Second Order Draft of July 2006 has referenced IEA World Energy Outlook 2005 but may be able to up-date some data after publication of World Energy Outlook 2006.

2 The current atmospheric carbon dioxide concentration will increase by an additional 1ppm by releasing 3.8 GtC from fossil fuel burning of which around 2.1 GtC will accumulate in the atmosphere.

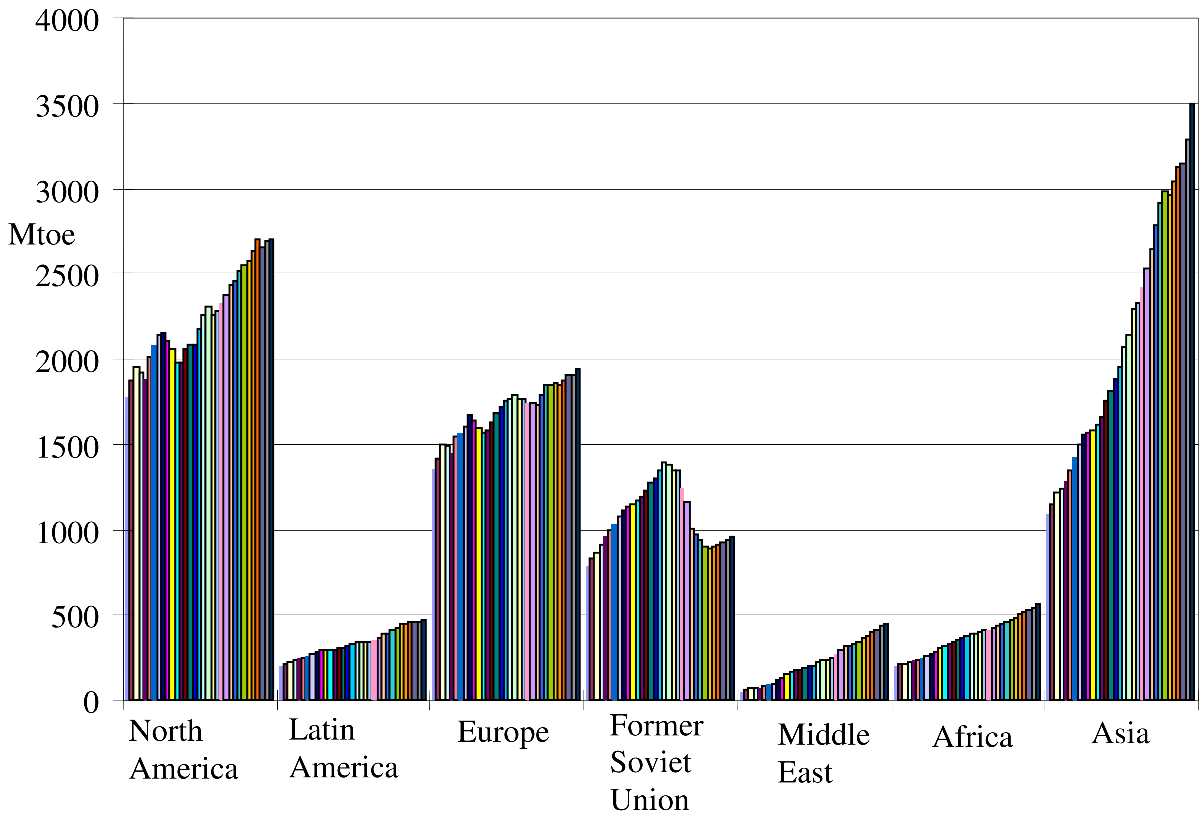


***Figure 4.1.2**: Global annual primary energy demand (Mtoe including biomass) from 1971 to 2003 by region (IEA, 2004a)*

Implementing any major energy transition will take time. The slow penetration rate of emerging energy technology uptake depends on the expected lifetime of capital stock and equipment and the relative cost. There is inertia to change and technology breakthroughs rarely happen.

Technology only diffuses rapidly once it can compete economically with existing alternatives or provide new value (for example, convenience). It took decades to provide the large-scale electricity and natural-gas infrastructures now common in many countries. Power stations, gas and electricity distribution networks, and buildings are usually replaced only at the end of their useful life. If stabilizing atmospheric greenhouse gases in a priority, then it is important to begin now as opposed to building "more of the same" today, especially in the developing world.

How best to meet future energy demand is uncertain. Possibilities (WEC, 2004a adapted from IIASA/WEC, 1998) include:

- High growth, with very large productivity increases and wealth being both technologically and resource intensive and technological changes yielding rapid stock turnover with consequent substantial improvements in energy intensity and efficiency;
- Business-as-usual, being a more cautious approach to economic growth, rate of technological change and energy availability, hence having a higher probability of occurrence;

- Reduced energy consumption, with a goal to reduce carbon emissions by 1% per year to 7.34 $GtCO_2$/yr by 2100. This is technologically challenging and assumes unprecedented progressive international cooperation focused explicitly on developing a low-carbon economy that is equitable and sustainable, and aggressive changes in lifestyle that emphasize resource conservation and dematerialization.

The trend over the past century has been the decline in the use of solids relative to liquids and gases, and in the future the use of gases are expected to increase even more (section 4.3.1). The share of liquids will probably remain but with a gradual transition from conventional oil toward liquids from coal, modern biomass, and unconventional oils (section 4.3.2.4) and biomass (section 4.3.4.3).

A robust mix of energy sources (fossil, renewable, and nuclear), combined with progressively improving end-use efficiencies, will almost certainly be required to meet the growing demand for energy services in developing countries. Primary energy demand could double before 2050 and potentially double the CO_2 concentrations. Technological development, decentralized non-grid networks, diversity of energy-supply systems, and affordable energy services are imperatives to meet this future demand together with improved energy efficiency. In OECD countries, the historical record shows a decrease in the amount of energy per capita and per unit of GDP to provide energy services and this is now becoming apparent with respect to electricity supplies in China (Larsen *et al.,* 2003) and elsewhere. A variety of co-benefits from utilizing new energy technologies can also result from economic policies aimed at sustainable development.

Future investment in state-of-the-art technologies in countries without embedded infrastructure may be possible by "leapfrogging" rather than following a similar historic course of development to that of the west. An analogy is the deployment of cellular mobile phone systems overcoming the cost barrier to developing costly landline telephone infrastructures. New financing facilities are being considered as a result of the G8 Gleneagles Communiqué on *Climate Change, Clean Energy and Sustainable Development* of July 2005 (World Bank, 2006).

4.1.1 Summary of Third Assessment Report (TAR)

Energy supply and end-use efficiency technology options (Table 3.36 of the TAR) showed special promise for reducing CO_2 emissions from the industrial and energy sectors. They included more efficient electrical power generation from fossil fuels, greater use of renewable technologies and nuclear power, utilization of transport biofuels, biological carbon sequestration and physical carbon capture and storage. It was estimated that a cost-effective reduction of 350–700 MtC was possible in the electric power sector (TAR Table 3.37) with opportunities divided equally between developed and developing countries. Improved end-use efficiency held greater potential for reductions by 2020.

Many barriers to implementing low-carbon technologies and measures identified in the TAR still remain, including a lack of human and institutional capacity; regulatory impediments and imperfect capital markets that discourage investment in small decentralized systems; uncertain rates of return on investment; high trade tariffs on emission lowering technologies; lack of market information; and issues of intellectual property rights. For renewable energy, high investment costs, lack of capital and/or subsidies, and policy impediments are constraints to their adoption.

The problem of "lock-in" by existing technologies and the economic, political, regulatory, and social systems that support them was seen as a major barrier to the introduction of low-emission technologies in all types of economies. This has not changed. Several technological innovations such as hybrid cars and wind farms have been recently introduced into the market as a result of multiple drivers including economic profit or productivity gains, non-energy related benefits, tax incentives, environmental benefits, performance efficiency and other regulations. Low GHG emissions were seldom a major factor in their adoption. Policy changes in development assistance (Renewables, 2004) and direct foreign investment provide opportunities to introduce low-emission technologies to developing countries more rapidly.

4.2 Status of the sector

Providing energy services from a range of sources to meet society's demands should provide security of supply, be affordable and have no impact on the environment. However these three government goals often compete. Recent liberalization of energy markets in many countries has led to cheaper energy services in the short term, but in the longer-term investments with longer amortization periods and often lower returns are not being made due to short-term shareholder value maximization. Energy supply security has improved in some countries but led to the contrary effect elsewhere due to increasing competition in turn leading to deferred investments in grid and plants due to uncertainties. Addressing environmental impacts, including climate change, usually depends on regulatory laws and tax incentives rather than market mechanisms.

Primary energy sources (Figure 4.2.1) come from fossil carbon fuels; geothermal heat and radioactive minerals; gravitational and rotational forces; and the solar flux. , The solar flux provides both intermittent energy forms including wind, waves, and sunlight, and energy stored in biomass, ocean thermal gradients and hydrologic supplies. To provide energy services, energy carriers such as heat, electricity, solid, liquid, and gaseous fuels are used. The efficiency of conversion of primary energy to carriers represents a cost of delivering them (Figure 4.2.2).

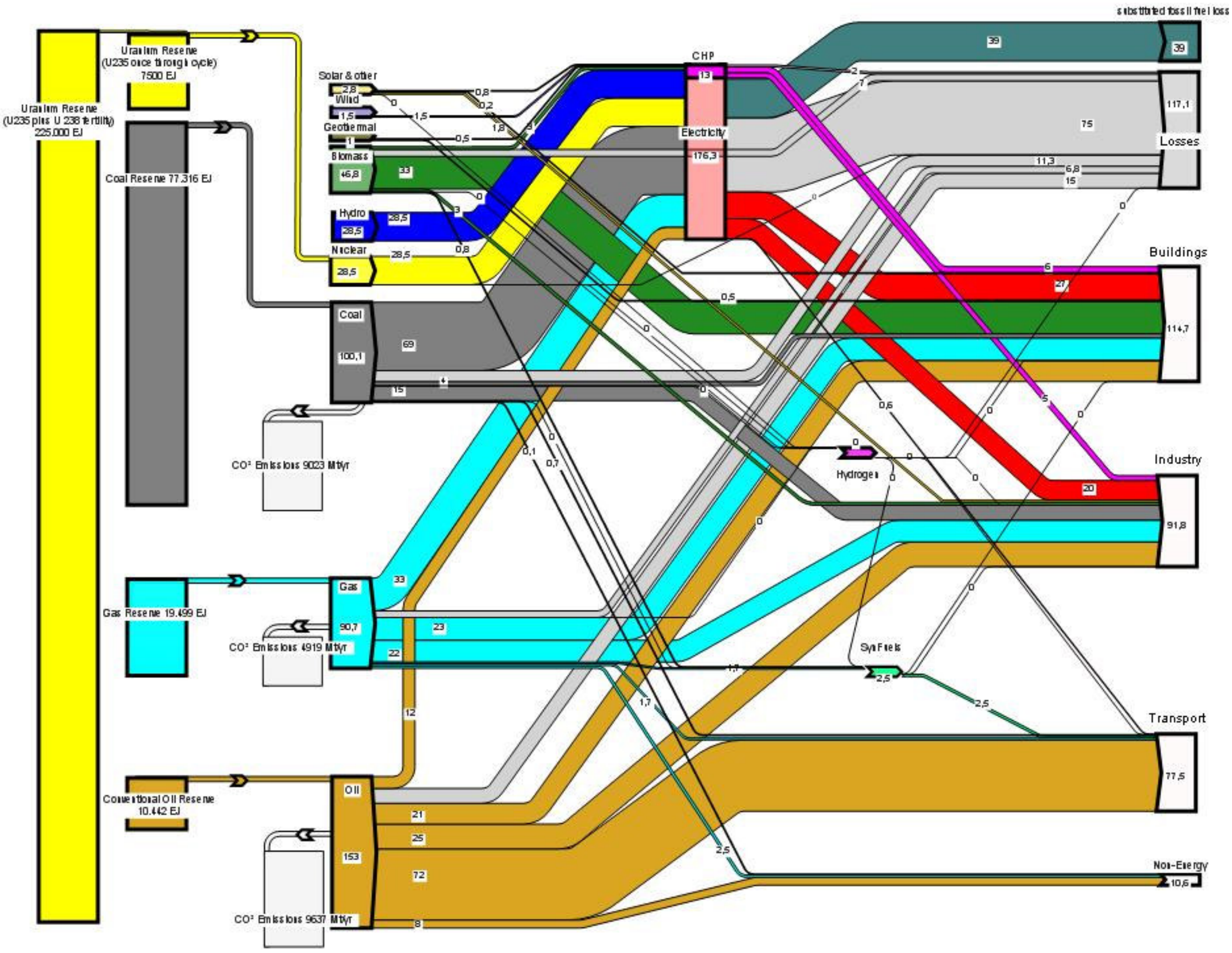


Figure 4.2.1 *Global 2003 energy flows from primary energy through carriers to end-uses. Carbon dioxide emissions are also shown*

Notes:

1) The current capacity of energy carriers is shown by the width of the lines.
2) Further energy conversion steps may take place in the end-use sectors, such as the conversion of natural gas into heat and/or electricity on-site at the individual consumer level.
3) Sources: IEA, 2004a.
4) Building and other sectors include residential, commercial, public services and agriculture.
5) Peat is included with coal.
6) Organic waste is included with biomass.

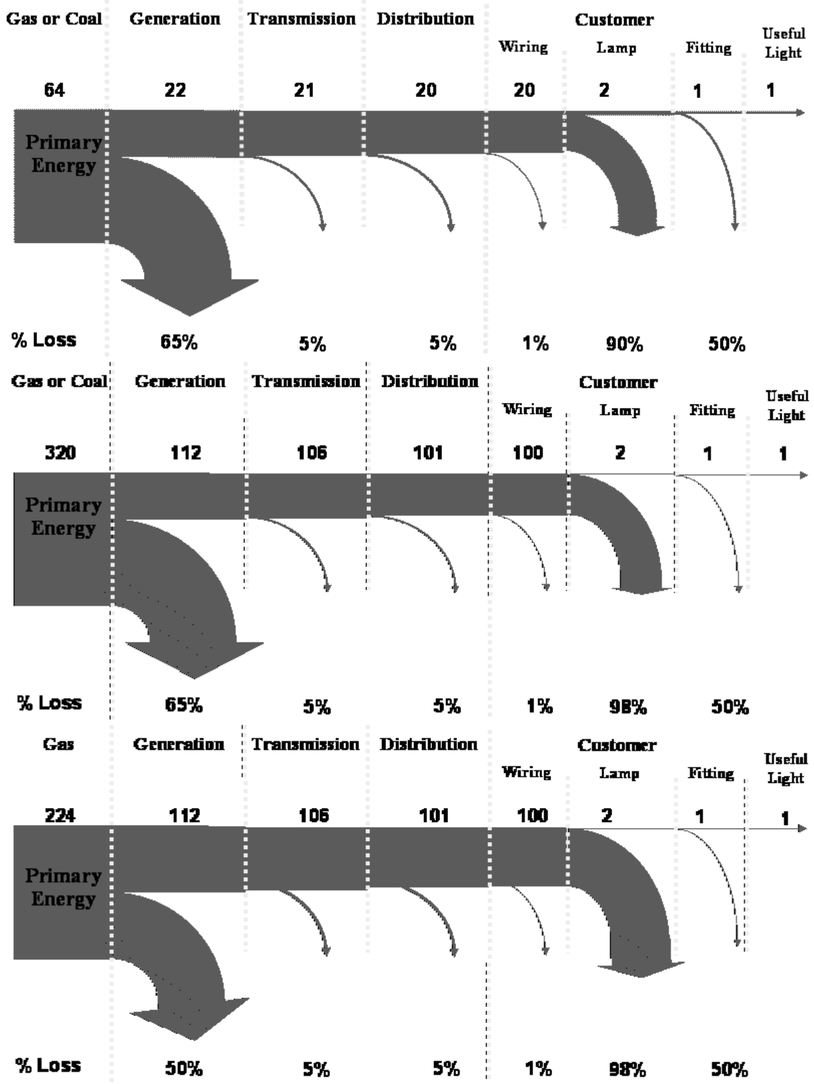


***Figure 4.2.2** Energy required for an electric lamp reduced using a combined-cycle gas turbine (CCGT) generation plant and a compact fluorescent light bulb (Cleland, 2005). This reduces the required energy by 80%*

Energy supply analysis should be integrated with energy demand since both these aspects of energy use are inextricably and reciprocally dependent. Energy efficiency improvements in the conversion of primary energy resources into energy carriers during mining, refining, generation etc. continue to occur. Reducing energy demand by the consumer using more efficient vehicles and appliances also reduces energy losses and carbon emissions along the supply chain and is usually cheaper and more efficient than increasing the supply (chapters 5, 6 and 7).

Primary energy consumption data of the major energy sources since 1971 show that oil and coal are still the most important with coal increasing its share since 2000 (Figure 4.2.3). The total share of fossil fuels dropped from 86% in 1971 to 80% in 2003 mainly due to the increase of the share of nuclear energy (BP, 2005a). Biomass (combustible renewables and wastes) contributed approximately 10% of primary energy consumption in 2003 with more than 80% used as traditional fuel for cooking and heating in developing countries.

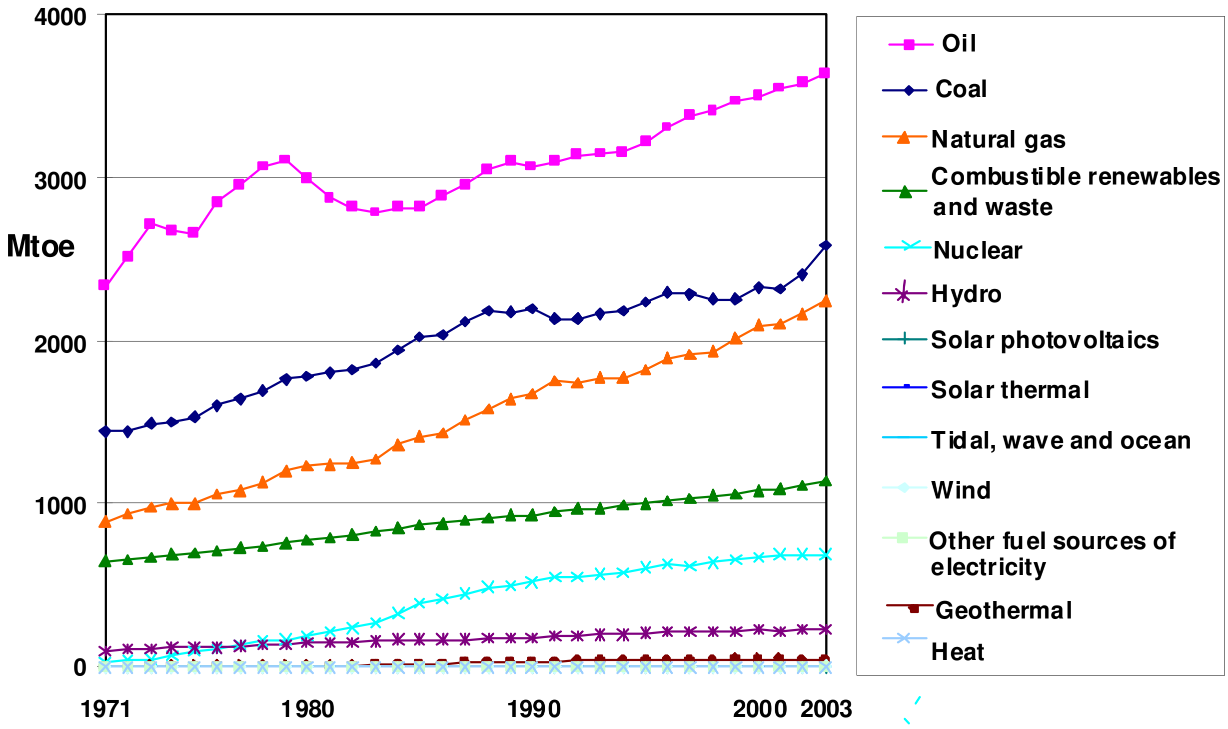


Figure 4.2.3 World primary energy consumption by fuel type (IEA, 2005a). (1000 Mtoe = 42 EJ).

In 2003, 38% of global primary energy was used as fuel by electricity generation plants. Electricity generation has had an average growth rate of 2.8%/yr since 1995 (see Figure 4.2.1) and is expected to continue growing at a rate between 2.5–3.1%/yr until 2030 depending on assumptions made (IEA, 2004a; Enerdata, 2004). In 2002, coal plus lignite fuels provided 32% of world electricity production with natural gas providing 19%, nuclear 17%, hydro 16%, and oil 7% (Enerdata, 2004). Non-hydro renewable energy power plants have expanded substantially in the past decade with wind turbine and photovoltaic installations growing by 30% annually and 10% for solar heating. However, they still supply only 1.8% of the electricity market (Enerdata, 2004).

Many consumers of petroleum and natural gas depend to varying but significant degrees on fuels imported from distant, often politically unstable regions of the world. For example, 16.5–17 Mb/d of oil was shipped through the Straits of Hormuz in the Persian Gulf in 2004 and 11.7 Mb/d through the Straits of Malacca in Asia (EIA/DOE, 2005). A disruption in supply at either of these points could have a severe impact on global oil markets. Political unrest in some oil and gas producing regions of Africa and Latin America have also sent prices higher and increased the vulnerability of supply. When in the foreseeable future international trade in oil and gas expand, the risks of supply disruption will increase (IEA, 2004b; CIEP, 2004).

For nuclear power, investment uncertainties exist due to financial markets commanding a higher interest rate to cover perceived risks, thus increasing the cost of capital and thereby generation costs. Increasing environmental concerns also raise the costs of obtaining permits. Conversely, surplus uranium supplies may possibly lower fuel prices, but this represents a relatively low fraction of generation costs compared with fossil-fuel power stations (Hagen *et al.*, 2005).

For renewable energy systems, price uncertainties result from dry years for hydro, poor crop yields for biomass, increased cloud cover and materials costs for solar, and variability in annual wind speeds. However, investing in price-stable sources, such as renewables , can avoid losses from fluctuating imported oil and power prices (Awerbuch, 2005). Higher world oil prices experienced in 2005 (and anticipated to continue) are significantly above what most pre-2006 scenario models predicted. This might lead to a reduction in transportation GHG emissions, but also encourage a shift to coal-fired power plants (China in 2005). Hence, high energy prices do not necessarily translate into lower GHG emissions.

4.2.1 Global development trends in the energy sector (production and consumption)

Global primary-energy consumption rose from 238 EJ in 1972 to 426 EJ in 2002 (see Chapter 1). During the period 1990-2002, the average annual growth was 1.4%/yr, lower than the 2.4% /yr for the period 1972-1990. This was due to the dramatic decrease in energy consumption in the former Soviet Union (FSU) (Fig 4.2.4) and to energy conservation and efficiency improvements in OECD countries. The highest growth rate in the last 12 years was in Asia (3.2%/yr) and North America was 1.5%/yr in the same period.

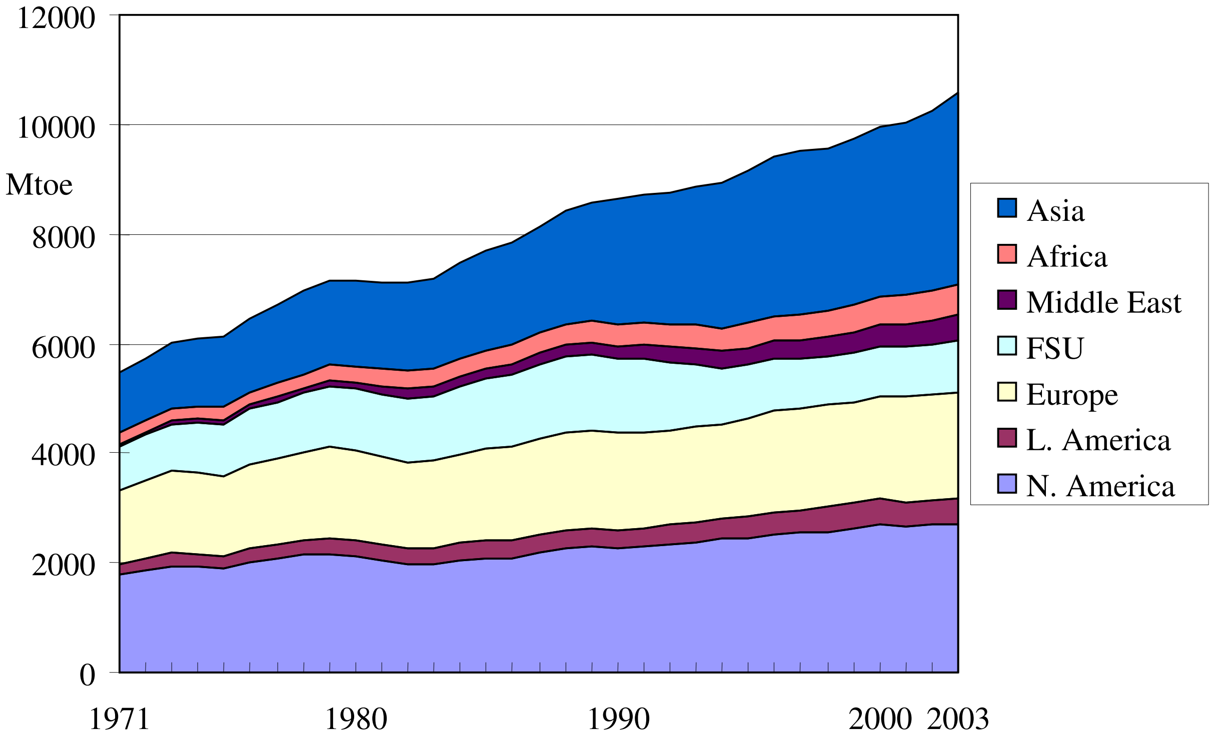


Figure 4.2.4: *Global primary energy consumption by region from 1971 to 2003 (IEA, 2005a) (1000 Mtoe = 42 EJ)*

The average electrification rates in the Middle East, North Africa, East Asia/China and Latin America have resulted in grid connection for over 85% of their populations whereas sub-Saharan Africa is 23% (but only 8% in rural regions) and South Asia is 41% (30% in rural regions) (IEA, 2005). Therefore, it appears that low electrification rates equate to slow socio-economic development.

There is a large discrepancy between primary energy consumption per capita of 336 GJ/yr for North America to around 26 GJ/yr per capita for Africa (Enerdata, 2004). The region with the lowest per capita consumption has changed from Asian developing countries in 1972 to African countries today.

4.2.2 Emission trends-all gases

Global carbon emissions stabilized after the two oil crises in 1973 and 1979 and then growth continued (Figure 4.2.5), averaging 1.9% /yr during the period 1990-2003. Emission data can be found on the UNFCCC and European Environment Agency web sites. The European Union's carbon emissions almost stabilized in this period mainly due to reductions by Germany, Sweden, and UK offsetting increases by other members of the EU-15 (BP, 2004). Total carbon emissions had risen 6.5% by 2003. Other OECD country emissions increased by 25% during the same period, Brazil by 49%, and Asia and Pacific countries by 33%. Carbon emissions from Central and Eastern Europe and the former Soviet Union dropped by 38% between 1989 and 1999 and have started to increase. So, in spite of all the policies and and all the technologies available, energy demand continues to increase and global carbon emissions continue to accelerate.

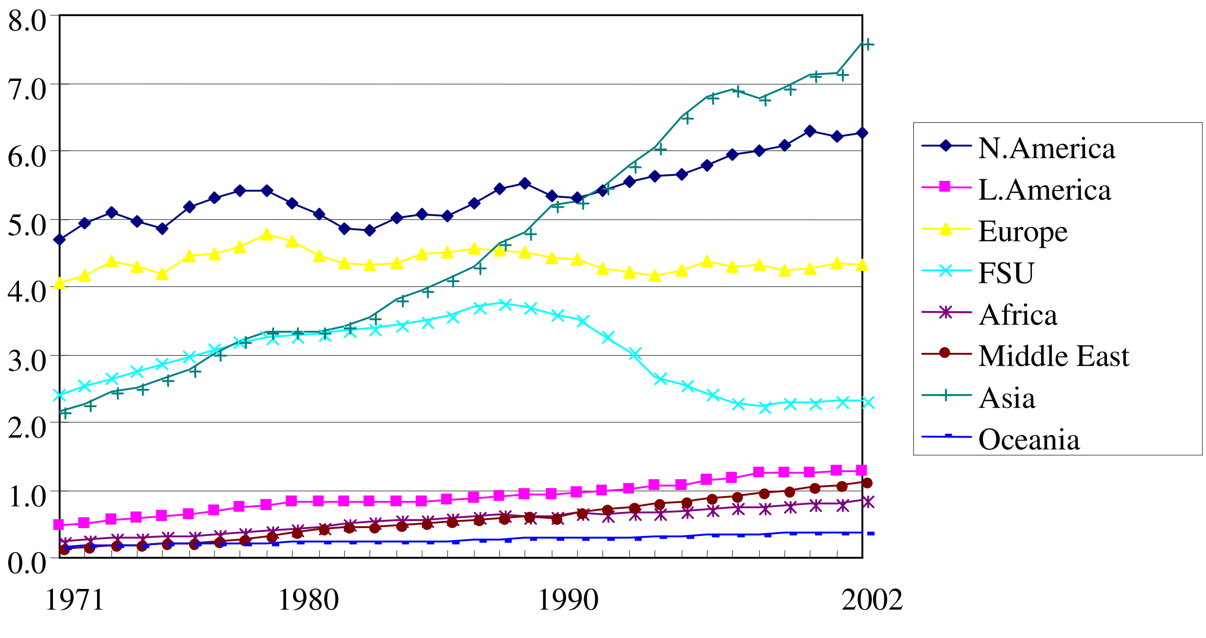


Figure 4.2.5: *Global carbon emission trends by region from 1972 to 2002 (IEEJ, 2005).*

In China, continuous technical progress toward energy efficiency improvement and renewable energy led to an annual decline in carbon intensity of around 5% during the period of 1980 to 2000 (Wang, 2004) with 3% expected out to 2050 (Chen, 2005). (Recent revision of China's GDP growth for 2004 up to 16.8% by government officials may affect these scenarios.) From 1990 to 2002, China's carbon dioxide emissions increased from 676 MtC/yr to 953 MtC/yr (second only to the United States) to become 14.5% of global carbon emissions (IEEJ, 2005).

Methane emissions from natural gas production, transmission, and distribution are uncertain (UNFCCC, 2004; Delahotel & Gallaher, 2005). Most of the emissions to the atmosphere reported to the UNFCCC in 2002 were in the range 0.3–1.6% of the natural gas consumed. For more than a decade, flaring, and venting of the gas associated with oil extraction has remained stable at a level of about 300 Mt CO_2eq. Developing countries account for more than 85% of this emission source (GGFR, 2004).

Coalbed methane (CBM, section 4.3.2.2) is naturally contained in coal seams and adjacent rock strata. Unless it is intentionally drained and captured from the coal and rock the process of coal extraction will continue to liberate methane into the atmosphere. Around 10% of total anthropogenic methane emissions in the USA are from this source (US EPA, 2003). The 13 major coal-producing countries together produce 85% of worldwide CBM estimated to be 237 MtCO_2eq in 2000. China was the largest emitter (102 MtCO_2eq) followed by the USA (36 MtCO_2eq), and Ukraine (30 MtCO_2eq). Total CBM emissions are expected to increase to 308 MtCO_2eq in 2020 (US EPA, 2003) unless mitigation projects are implemented.

Other greenhouse gases are produced by the energy sector but in relatively low volumes. SF_6 is widely used in high voltage gas insulated substations, switches and circuit breakers because of its high di-electric constant and electrical insulating properties. Its 100 year global warming potential (GW_p) is 23,900 times that of CO_2 and it has a natural lifetime in the atmosphere of 3200 years, making it among the most potent of heat trapping gases. Approximately 80% of SF_6 sales go to power utilities and electric power equipment manufacturers. The US government formed a partnership with 62 electric power generators and utilities (being about 35% of the USA power grid) to voluntarily reduce leakage of SF_6 from electrical equipment and the release rate dropped from 17% of stocks to 9% between 1999 and 2002. This represented a 10% reduction from the 1999 baseline to 14.2 MtCO_2eq (EPA, 2003). Australia and the Netherlands also have programmes to reduce SF_6 emissions and a voluntary agreement in Norway should lead to 13% reductions by 2005 and 30% by 2010 below their 2000 release rates. During low temperature combustion of fossil fuels and biomass, nitrous oxide, as well as methane, is produced. CFC-114 is used as a coolant in gaseous diffusion enrichment for nuclear power but its GHG contribution is small compared to CO_2 emissions (Dones *et al*. 2005).

4.2.3 Regional development trends

World primary energy demand is projected to reach 650–890EJ by 2030 based A1 and B2 SRES scenarios and IEA World Energy Outlook reference scenario (Price *et al*. 2006). All three scenarios show Asia could surpass North American energy demand around 2010 and be close to doubling it by 2030. Africa/Middle East and Latin America could double their energy demand by 2030, sub-Saharan Africa and the Former Soviet Union may both reach 60–70 EJ, and Pacific OECD, and Central and Eastern Europe will be less than 40 EJ each. Demand is more evenly distributed among regions in the B2 scenario, with Central and Eastern Europe and the Pacific OECD region reducing future demand. A similar pattern is evident for final consumer energy (Table 4.2.1).

Table 4.2.1:*Final energy consumption (EJ) and carbon emissions (Mt CO_2) for all sectors by region to 2030 based on assumptions from three scenarios (Price et al., 2006).*

	WEO 2004 Reference				**SRES A1 Marker**				**SRES B2 Marker**			
Region	2002	2010	2020	2030	2000	2010	2020	2030	2000	2010	2020	2030
Final energy (EJ)												
Pacific OECD	23.6	26.6	29.5	30.9	21.5	24.6	29.8	36.6	23.5	26.5	30.0	32.3
Canada/US	70.2	78.3	87.4	94.6	71.3	79.3	89.8	99.2	71.0	82.4	93.3	104.1
Europe	51.5	56.7	62.3	66.5	52.0	58.9	67.6	74.6	46.9	51.3	54.4	57.9
Economies in transition	27.0	31.0	35.9	40.5	38.4	42.6	50.1	58.8	32.0	37.5	44.8	52.7
Latin America	18.6	23.0	29.7	37.6	23.5	42.1	63.2	81.7	20.9	27.8	33.1	39.6
Africa / Middle East	28.4	35.4	44.8	54.3	36.4	57.2	87.6	123.7	25.6	32.6	40.2	53.1
Asia	66.8	83.1	105.3	128.3	71.5	100.6	143.9	194.6	69.4	92.5	122.0	157.5
World	**286.2**	**334.0**	**395.0**	**452.8**	**314.6**	**405.3**	**532.0**	**669.1**	**289.2**	**350.6**	**417.6**	**497.2**
Emissions (MtCO$_2$)												
Pacific OECD	2122	2318	2516	2534	2419	2620	2889	3123	2104	2332	2275	2098
Canada/US	6469	7244	7875	8317	5838	6082	6125	5967	6605	7631	8358	8432
Europe	4119	4454	4807	4897	4209	4533	4744	4725	3950	4035	4071	4134
Transition Economies	2393	2794	3208	3537	2968	3448	3706	3849	3234	3257	3657	4083
Latin America	1341	1677	2212	2868	1669	3385	4992	6160	1410	1988	2289	2694
Africa/Middle East	2013	2510	3398	4209	2498	4891	7551	10290	1979	2386	2851	3897
Asia	5522	7332	9913	12663	5816	9854	14319	18531	5579	7468	9651	12119
Internatl. marine bunkers	463	471	483	515								
World	**23979**	**28327**	**33930**	**39025**	**25416**	**34814**	**44328**	**52646**	**24862**	**29098**	**33152**	**37457**

The World Energy Council projected 2000 data out to 2050 for three selected scenarios with varying population estimates. The IEA (2003) and IPCC SRES scenarios (Chapter 3) did likewise. Implications of sustainable development were that primary energy demands are likely to lie between 600 and 1040 EJ (a 40 to 150% increase), with emissions between 18.35–55.05 $GtCO_2$/yr. This presents difficulties for the energy-supply side to meet energy resource growth. It requires technological progress and capital provision, and also provides challenges for minimizing the environmental consequences and sustainability of the dynamic system. Electricity is expected to grow even more rapidly than primary energy use by between 110 and 260% up to 2050 presenting even more challenges in needing to build power production and transmission facilities mostly in developing countries.

The Asia-Pacific region has almost 30% of proven coal resources but otherwise is highly dependent on imported energy, particularly oil, now the largest source of primary commercial energy consumption in the region. In 2003, 82% of imported oil came from the Middle East and the region will continue to depend on OPEC countries. A continuation of China's rapid annual economic growth of 9.67% from 1990 to 2003 (CSY, 2005) will result in continued new energy demand, primary energy consumption having increased steadily since the 1980s. Energy consumption in 2003 reached 49 EJ. High air pollution in China is directly related to energy consumption, particularly from coal combustion that produces 70% of national particulate emissions, 90% sulphur dioxide, 67% nitrogen oxide and 70% carbon dioxide (BP, 2004).

Increased use of natural gas has recently occurred throughout the Asian region, although its share of 12% of primary energy remains lower than the 26% and 23% shares in the United States and Europe respectively (BP, 2004). A liquefied natural gas (LNG) market has recently emerged in the region with about 75% of worldwide trade.

Primary energy consumption in the Asia–Pacific region due to continued overall economic growth and increasing transport fuel demands is estimated to increase by 1.0% annually over the period 2002-2030 in OECD Asia, 2.6% in China, 2.1% in India, and 2.7% in Indonesia (IEA, 2004a). This will then account for 42% of the increase in world primary energy demand. The region will be faced with both overall energy resource shortages in the coming decades (Komiyama *et al*. 2005). Energy security risks will likely increase and stricter environmental restrictions on fossil fuel consumption could be imposed. Nuclear (section 4.3.3) hydropower (section 4.3.4.1) and other renewables (section 4.3.4) may play a greater role in electricity generation to meet the ever-rising demand.

For economies in transition (EIT), the total primary energy consumption of Central and Eastern Europe as well as the former Soviet Union in 2000 was only 70% of the 1990 level (Enerdata, 2004). A sharp downturn in GHG emissions resulted and although increasing slightly in the 2000-2002 period, emissions remain some 30% below 1990 levels (IEA, 2003a). Despite the economic and political transformations, energy systems in EIT countries are still characterised by over-capacity in electricity production, high dependency on fossil fuel imports and inefficient use (IEA, 2003b) Market reforms have been accompanied with the opening of these economies, leading to their further integration into the European and global economies. [no para. break] Growth is likely to accelerate faster in those countries that have achieved EU membership (IEA, 2003b). The total primary energy consumption of EIT has increased by 2%/yr since 2000 and is expected to continue to increase steadily over the next couple of decades as income levels and economic output expand unless energy efficiency manages to stabilise demand.

Latin America and Africa and the Middle East are expected to double their energy demand over the next 2–3 decades but to retain their shares of global energy demand (IEA 2005a; Price *et al*. 2006).

Developing country policies aimed at energy-supply security, reducing environmental impacts and encouraging a free market economy may help in encouraging market efficiency, energy conservation, common oil storage, investment in resource exploration and international carbon emission trading. International cooperation will continue to play a role in energy resource development projects and industry productivity improvement.

4.2.4 Implications of sustainable development and energy access

Analysis from 125 countries indicated that well-being and level of development is correlated to the degree of modern energy services consumed in each country (Bailis *et al*, 2005) (Figure 4.2.6).

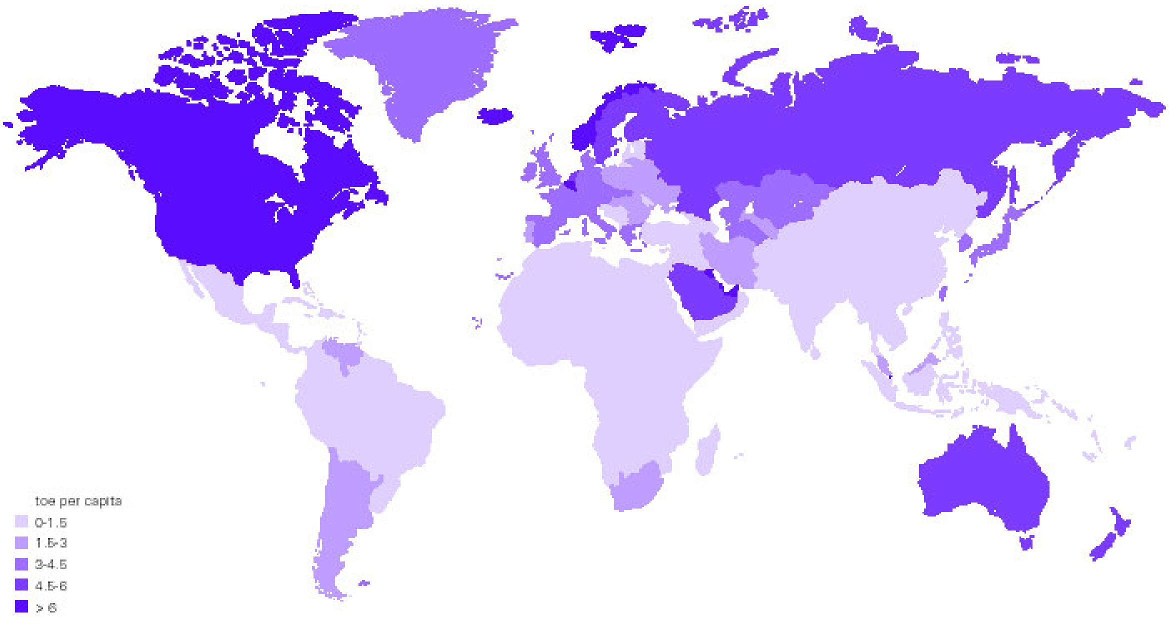


Figure 4.2.6 *Global energy consumption per capita by region (toe/capita) (BP, 2004).*

Lack of energy access frustrates the aspirations of many developing countries and, without improvement, the United Nations' Millennium Development Goals of halving the proportion of people living on less than a dollar a day by 2015 (UN, 2000) will not be met. Achieving this target implies a need for increased access to electricity and expansion of modern cooking and heating fuels for 600 million people in developing countries mainly in South Asia and sub-Saharan Africa (IEA, 2005a). Efforts will need to be greatly exceeded based on the historic electricity access rate of 40 million people per annum in the 1980s and 30 million in the 1990s. By 2030, around 2,400 GW of new power plant capacity will be needed in developing countries (100 GW per year), which, together with the necessary infrastructure, will require around $5 trillion investment. Access to modern and new technologies that employ renewable energy efficiently is the key to sustainable development in the long term because these sources will last indefinitely by human civilization scales.

Ecological implications of energy supply result from coal and uranium mining, oil extraction, oil transport, de-forestation erosion and riverflow disturbance. Certain synergetic effects can be reached between renewable energy generation and ecological values such as re-forestation and landscape structural improvements but these are relatively minor.

4.3 Primary energy resource potentials, supply chain, and conversion technologies

This section discusses primary supply and secondary energy (carrier) technologies. Many of these technologies have developed little since the TAR and are covered elsewhere (IEA, 2006a). Energy flows proceed from primary sources through carriers to provide services for end-users (see Figure 4.2.1). The status of energy sources and carriers is reviewed here along with their available resource potential and usage, conversion technologies, costs, and environmental impacts. For each resource, potential contribution and technological development, to meet the world's growing energy needs and reduce atmospheric greenhouse gas emissions are covered.

From 1900 to 2000, world primary energy increased more than ten-fold, while world population rose only four-fold during the twentieth century, from 1.6 billion to 6.1 billion. Most energy forecasts predict considerable growth in demand in the coming decades and due to increasing growth rates throughout the world but especially in developing countries. Assessments of global energy reserves, resources, and fluxes, together with cost ranges and sustainability issues, are summarized in Table 4.3.1.

Table 4.3.1: *Generalized data for global energy resources (including reserves), annual rate of use, cost ranges for good locations and comments on associated environmental impacts. (Data from BP, 2005a; WEC, 2004c; IEA, 2004c;IEA, 2005c,d; IAEA, 2005c; USGS, 2000; Johansson et al., 2004; Hall, 2003; Encyclopedia of Energy, 2004 and as noted).*

[a] Various sources contain ranges, some wider than others (e.g., those for conventional oil cluster much more closely than those for biomass). For the purposes of this assessment of mitigation potentials these generalized values are more than adequate to a first approximation.
[b] For example where a conversion plant is close to the coal or gas resource, or a site has high mean annual wind speeds, or with good solar radiation etc. Costs are for comparative purposes only. Fossil end-use costs ($/kWh shown in parentheses for current conversion to electricity) depend on conversion efficiencies as well as the capital and operating costs of the conversion process and discount rates used, and thus can vary greatly, as also for nuclear and renewables.
[c] See Glossary for definitions of conventional and unconventional fuels.
[d] Primary energy data can prove misleading due to definitions in terms of fossil fuel equivalents including waste heat from nuclear and geothermal power plants. Hydro and nuclear both produce a similar share of actual output generated (TWh/yr) (see www.iea.org/textbase/stats/questionnaire/faq.asp).

Energy Class	Specific type of energy source	Estimated available resource[a] (EJ)	Rate of use in 2003 (EJ/yr)	Share (%)	Cost when located on a good site[b] USD	Comments on environmental impacts	Other references used than in Table title
Fossil energy	Coal (conventional[c])	100,000	100	22.0	$3/GJ (4-6¢/kWh)	~25gC/MJ	
	Coal (unconventional)	32,000	Very small	0	?		
	Natural gas (conventional)	18,000	100	22.0	$11 /GJ (4-6¢/kWh)	14.3gC/MJ Cost @$360 /Mm^3	
	Gas shales	18,000	Small	0	?		
	Coal bed methane	>9,000?	1.5	0.3			
	Tight gas sands	8000	3.3	0.6		Extraction high.	
	Hydrates	60,000	0	0		Very uncertain.	
	Oil (conventional)	16,000	150	33.0	$7-12/GJ	20.8gC/MJ	
	Oil (unconvent'l)	35,000	3	0.6	$4 - ?/GJ	gC/MJ varies	
Nuclear[d]	Uranium U235 fuel	7400 (@$130/kg)	25	5.5	3-7¢/kWh 1-12¢/kWh	Treatment/disposal of spent fuel	Majority of refs. IAEA Redbook2005
	U238 and thorium	213,000	Very small	0	?		IEA, 2006a
	Fusion	5,000,000,000?	0	0	Very uncertain	Waste disposal issues unknown	Evans, 1978
Renewable electricity[d], heat and biofuels.	Hydro (>10 MW)	60/yr	25	5.5	2-10¢/kWh	Land use & social	Martinot *et al.*2005
	Hydro (<10 MW)	2/yr	2.4	0.4	2-12¢/kWh	"	
	Wind	600/yr	0.95	0.2	4-8¢/kWh	Aesthetic on-shore	"
	Biomass	250/yr	~ 46 ~37traditional	7.9	8-25$/GJ 1-12¢/kWh	Monocultures. Local transport.	"
	Geothermal	5000/yr	0.8	1.9	2-10¢/kWh	Resource limited?	"
	Solar PV	1600/yr	~0.01	0	25-160¢/kWh		"
	Solar thermal	50/yr	0.5	0.1	12-34¢/kWh		"
	Ocean (current	7/yr	Very small	0	8-40¢/kWh	Recreational use	"
	tidal, waves, etc.)	exploitable				conflicts	

Natural gas and nuclear gained an increased market share after the oil crises in the 1970s and continue to play a role in lowering greenhouse gas emissions, along with renewable energy. The carbon intensity of primary energy use declined from 20 gC/MJ in 1973 to 17 gC/MJ in 2000 (BP, 2005a) due to diversification of energy supply away from oil.

4.3.1 Fossil Fuels

Fossil energy resources remain abundant but contain significant amounts of carbon that are normally released during combustion. The proven and probable reserves of oil and gas are enough to last for decades and in the case of coal, centuries (see Table. 4.3.1). Possible undiscovered resources extend these projections even further.

Fossil fuels supplied 79.8% of world primary energy demand in 2002 (IEA, 2005). Oil was the largest constituent at 37%, coal 27%, and gas 24% (BP, 2005a). If only modern energy supplies were considered (by excluding traditional biomass), the fossil fuel share approaches 90% and there is every reason to expect it to grow over the next 20-30 years. World oil consumption increased 3.4% in the year to 2004, gas 3.3%, and coal 6.3% (WEC, 2004a). Oil accounted for 95% of the land, water and air transport sector demand (IEA, 2005d) and is projected to grow (IEA, 2003c) as there is no evidence of saturation in the market for transportation services (WEC, 2004). Oil and gas will continue to dominate world energy supply until at least 2030 assuming current energy policies remain in place. IEA (2005b) projected that oil demand will grow by 44% between 2002 and 2030, gas demand will almost double, and CO_2 emissions will increase by 62% (which lies between the SRES A1 and B2 scenario estimates of +101% and +55%, respectively, see Table 4.2.1).

Fossil energy use is responsible for about 87% of the anthropogenic CO_2 emissions produced annually (IEA, 2003d). Natural gas is the fossil fuel that produces the lowest amount of GHG per unit of energy consumed and therefore favored in mitigation potential strategies. Fossil fuels have large economic advantages that other technologies may not be able to overcome, although there has been a recent trend for fossil fuel prices to increase and renewables to decrease as a result of continued improvement. All fossil fuel options will plausibly continue to be used if matters are left solely to the market place to decide choice of energy conversion technologies. If GHGs are to be reduced significantly, either current uses of fossil energy will have to shift to non-carbon sources, or technologies will have to be adopted that capture and store the CO_2 emissions. Alternative transport fuels manufactured and consumed without GHG release are also a possible future option. Making these changes necessitates major investments in the development and implementation of new technologies.

4.3.1.1 Coal and peat

Resources

Coal is the world's most abundant fossil fuel and continues to be a vital fuel resource in many countries (IEA, 2003e). Coal consumption in 2004 accounted for 27% of total world energy consumption of modern energy, primarily in the electricity and industrial sectors (BP, 2005a; US EIA, 2005; Enerdata, 2004). Global proven recoverable reserves of coal are about 22,000 EJ (BP, 2004; WEC, 2004b) with another 11,000 EJ of probable reserves and an estimated additional possible resource of 100,000 EJ for all types. Although coal deposits are widely distributed, over half of the world's recoverable reserves are located the United States (27%), Russia (17%), and

China (13%). India, Australia, South Africa, Ukraine, Kazakhstan, and Yugoslavia account for an additional 33% (US DOE EIA, 2005). Two-thirds of the proven reserves are hard coal (anthracite and bituminous) and the remainder are sub-bituminous and lignite. Together these resources represent stores of almost 12,845 $GtCO_2$. Consumption is currently around 100 EJ/yr which introduces approximately 9.175 $GtCO_2$/yr into the atmosphere.

Peat (partially decayed plant matter together with minerals) has been used as a fuel for thousands of years, particularly in Northern Europe. In Finland, it provides 7% of electricity and 19% of district heating.

Technologies

The implementation of modern high-efficiency and clean utilization coal technologies is key to the development of economies, to minimize effects on society and environment (section 4.7.4). The demand for coal is expected to more than double by 2030 and the IEA has estimated that more than 4500GW of new power plants will be required in this period (IEA, 2004a).

A CSIRO (2005) project is being undertaken to investigate the production of ultra-clean coal (UCC) that reduces ash below 0.25% and sulphur to very low levels. The use of UCC with combined cycle direct-fired turbines for power generation can reduce greenhouse gas emissions by 24% per kWh of electricity compared with conventional coal power stations and reduce greenhouse gas emissions by up to 10%.

Gasifying coal prior to conversion to electricity reduces the emissions of sulphur, nitrogen oxides, and mercury, resulting in a much cleaner fuel while reducing the cost of capturing and sequestering CO_2 emissions from the flue gas where that is conducted. Continued development of integrated gasification combined cycle (IGCC) systems is expected to further reduce conventional coal combustion emissions. Fuel to electricity conversion efficiencies have increased from around 35% in typical steam plants to higher than 55% in the best integrated gasification combined cycle (IGCC) designs but at a greater cost of power generated (Equitech, 2005). This has significantly reduced the amount of waste heat and carbon that would otherwise have been emitted per unit of electricity generation (Sims *et al.*, 2003; NEA/IEA 2005). The development of new materials will allow higher steam temperature and pressures to be used in “supercritical” plant designs. The best plants currently commercially available have efficiencies of 48.5% (IPCC, 2001; Danish Energy Authority, 2005).

CTL is well understood and regaining interest. Coal liquefaction can be by direct solvent extraction and hydrogenation of the resulting liquid at up to 67% efficiency (DTI, 1999) or indirect by gasification then producing liquids by Fischer-Tropsch catalytic synthesis as in the three SASOL plants in South Africa. These produce 0.15 Mbbl/day of synthetic diesel fuel (80%) plus naphtha (20%) at 37-50% thermal efficiency or up to 67% efficiency by lower quality coals would reduce the thermal efficiency whereas co-production with electricity and heat (at a 1:8 ratio) could increase it and reduce the liquid fuel costs by around 10%.

Production costs of CTL compete when crude oil is around USD30-$45 /bbl, assuming a coal price of USD1/GJ. Converting lignite at USD0.50/GJ close to the mine would compete with a production cost of about USD30/bbl. The CTL process is less sensitive to feedstock prices than is the GTL process, but the capital costs of the coal-based process are much higher (IEA, 2005d). An 80,000 barrel per day CTL installation would cost about USD5 billion and would need at least 2 -4 Gt of coal reserves available to be viable.

4.3.1.2 Methane fuels

Conventional natural gas

World-proven reserves of natural gas are estimated to be 6500 EJ (BP, 2005a, WEC, 2004c, USGS, 2004b). Almost three-quarters are located in just the Middle East and the transitional economies of the FSU and Eastern Europe. Russia, Iran, and Qatar together account for about 56% of gas reserves, whereas the remaining reserves are fairly evenly distributed on a regional basis (BP, 2005a). Probable reserves and possible undiscovered resources expected to be added over the next 25 years account for 2500 EJ and 4500 EJ, respectively (USGS, 2004a), although other estimates are less optimistic. More than half of the probable natural gas reserve estimates are thought to be concentrated in the FSU, Middle East, and North Africa.

Natural gas production has been increasing in the Middle East and Asia-Oceania regions since the 1980s. Globally from 1994-2004 it showed an annual growth rate of 2.6%. During 2004 30% of natural gas was produced in the Middle East, while Europe and Eurasia produced 22%, and North America 17% (BP, 2005a). Natural gas presently accounts for 24% of global consumption of modern energy at around 100 EJ/yr contributing around 5.138 $GtCO_2$ annually to the atmosphere.

Despite rising prices, natural gas is forecast to continue to be the fastest growing primary fossil fuel energy source worldwide (US EIA, 2005), maintaining average growth of 2.3% annually and rising to 165 EJ consumption in 2025. The industrial sector is projected to account for nearly 36% of global natural gas demand during the period out to 2025 and nearly 50% for new and replacement electric power generation in the future. Its share of total energy used to generate electricity worldwide is projected to increase from 18% in 2002 to 24% in 2025 (US EIA, 2005).

Natural gas-fired power generation has grown rapidly since the 1980s because it is relatively superior to other technologies in terms of installation costs, fuel efficiency, operating flexibility, rapid deployment, and environmental benefits, especially when fuel costs were relatively low. CCGT plants produce less carbon dioxide per unit energy output than other fossil fuel technologies because of the high hydrogen-carbon ratio of methane and the relatively high thermal efficiency of the technology. A large number of CCGT plants currently being planned, built, or operating are in the 10–500 MW_e size range. A typical existing single cycle small scale plant is around 30% efficient, a 50–100 MW_e medium CCGT investment costing around €570–830/MW is around 50% efficiency, and a larger 100-500 MW_e plant costing €350–700/MW has an efficiency around 58% (DEAT, 2004). Advanced gas turbines currently under development, such as so-called “G” designs, will have efficiencies approaching 60% through the use of high combustion temperatures, steam-cooled turbine blades, and more complex steam cycles.

LNG

Future increases in global natural gas demand for direct use by the industrial and commercial sectors as well as for power production will require development and scale-up of liquefied natural gas (LNG) as an energy carrier. LNG is being traded and accounted for 26% of total international natural gas trade in 2002 or about 6% of world natural gas consumption.

The Pacific Basin is the largest LNG-producing region in the world, supplying 49% of all global exports in 2002 (US EIA, 2005). LNG transportation is expected to increase substantially and play a prominent role in the future. The share of total U.S. natural gas consumption met by net imports of LNG is expected to grow from about 1% in 2002 to 15% (4.5 EJ) in 2015 and 21% (6.8 EJ) in 2025. Energy loss during the LNG liquefaction process is estimated at 7 to 13% of withdrawn natural gas, a larger loss than typical of pipeline transportation over 2,000 km. This has consequent effects on the amount of methane released to the atmosphere.

LPG

Liquefied petroleum gas (LPG) is a mixture of methane, butane, and other hydrocarbons produced as a by-product of natural gas processing and crude oil refining. Total global consumption of LPG amounted to over 10 EJ in 2004 (MCH/WLPGA, 2005), equivalent to 10% of global natural gas consumption (Venn, 2005).

Unconventional natural gas

Methane stored in a variety of geologically complex, unconventional reservoirs, such as tight gas sands, fractured shales, coal beds and hydrates is more abundant than conventional gas (Table 4.3.2). Development and distribution of these unconventional gas resources remain limited worldwide, but there is growing interest in coal bed methane (CBM) and selected tight gas sands in the U.S.

Table 4.3.2 Global unconventional methane gas resources and US resources (Encyclopaedia of Energy, 2004)

	Worldwide probable resource (EJ)	**U.S. resource and production (EJ)**		
		Proven resource	**Remaining, recoverable**	**2001 production**
Coal bed methane	9,990	741	96	1.6
Tight gas sands	8,160	942	297	3.3
Gas shale	17,750	593	45	0.5
Methane hydrates	800,000	-	-	-

Probable CBM resources in the US alone are estimated to be almost 800 EJ but less than 110 EJ are believed to be economically recoverable today (USGS, 2004b). Worldwide resources may be larger than 9,000 EJ (Table 4.3.2) but a scarcity of basic information on the gas content of coal resources makes this number highly speculative.

Large quantities of tight gas are known to exist in geologically complex formations with low permeability, particularly in the US where most exploration and production has been undertaken. Early resource estimates varied between 450 and 1000 EJ (Surdam, 1995; NPC, 1980). However, only a small percentage is economically viable with existing technology and current US annual production stabilized between 2.7 and 3.8 EJ.

Methane gas hydrates occur abundantly in nature all over the world and are stable as deep marine sediments on the ocean floor at depths greater than 300 m and in polar permafrost regions at shallower depths. The amount of carbon bound in hydrates is not well understood, but is estimated to be twice as large as in all other known fossil fuels (USGSa, 2004). Hydrates may provide an enormous resource with estimates varying from 60,000 EJ (USGSa, 2004) to 800,000 EJ

(Encyclopedia of Energy, 2004). However, recovering the methane is difficult and represents a significant environmental problem if unintentionally released to the atmosphere during extraction. Safe and economic extraction technologies are yet to be developed (USGSa, 2004). Hydrates also have high levels of CO_2 that may have to be captured to produce pipeline quality gas (Encyclopedia of Energy, 2004).

GTL is gaining renewed interest due to higher oil prices, particularly for developing uneconomic natural gas reserves such as those associated with oil extraction or isolated gas fields which lie far from markets. The natural gas is turned into synthesis gas which is converted by the Fischer-Tropsch process to synthetic fuels. At present, at least nine commercial GTL projects are progressing through various development stages in gas-rich countries such as Qatar, Iran, Russia, Nigeria, Australia, and Algeria. Worldwide GTL production is estimated at 0.58 Mbbl/day and Qatar is set to produce about 0.39 Mbbl /day by 2011 (FACTS, 2005). GTL conversion technologies can help bring some of the estimated 6000 EJ of stranded gas resources to market and can compete with diesel fuel when world oil prices are above $20 per barrel (Annual Energy Outlook, 2005).

4.3.1.3 Petroleum fuels

Conventional oil refers to crude oil produced from well bores by primary, secondary, or tertiary methods. Oil represents about 34% of total world energy consumption (see Fig 4.2.1) with major resources concentrated by natural processes in relatively few countries. Two-thirds of proven crude oil reserves are located in the Middle East and North Africa (IEA, 2005a).

Known or proven reserves are those extractable at today's prices and technologies. Additional probable and possible resources are based on historical experience in geologic basins. New discoveries have lagged behind production for more than 20 years (IEA, 2005).

As conventional oil supplies become scarce and extraction costs increase, unconventional liquid fuels will become more economically attractive, but perhaps offset by greater environmental impact costs (Section 4.3.2.4).

Various studies and models have been used to forecast future oil production. Geological models take into consideration the volume and quality of hydrocarbons but do not include economic effects on price which in turn has a direct effect on supply and the overall rate of recovery. Mathematical models generally use the historical as well as the observed patterns of production to estimate a peak (or several peaks) when half the reserves are consumed.

Assessing the amount of oil consumed, the amount remaining for extraction and whether the "peak oil" tipping point is close or not, have been very controversial. Estimates of the ultimate extractable resource (proven + probable + possible reserves) with which the world was endowed have varied from less than 5730 EJ to 34000 EJ (1000 to 6000 Gbbl), though the more recent predictions have all ranged between 11500-17000 EJ (2000 – 3000 Gbbl) (Figure 4.3.1). Over time the prediction trend showed resource estimates increasing in the 1940s and 1950s as more fields were discovered. However the very optimistic estimates of the 1970s were later discredited and a relatively constant trend has been observed thereafter.

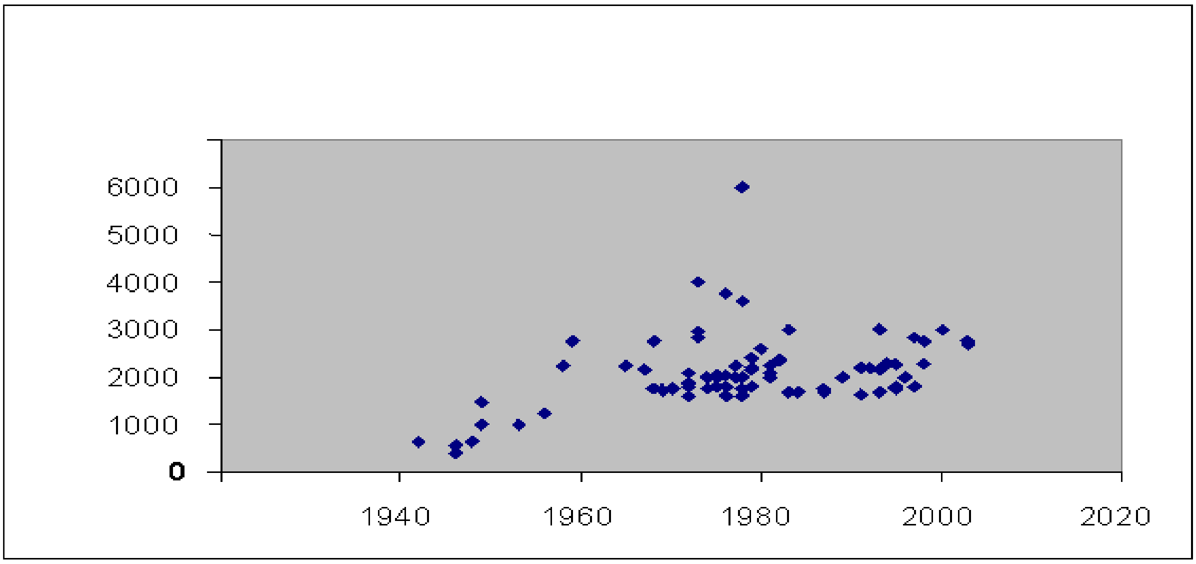


Figure 4.3.1: *Estimates of the ultimate extractable conventional oil resource from evaluations over the past few decades (based on Bentley, 2002a; Andrews and Udal, 2003)*

The US Geological Survey (USGS, 2000), the World Petroleum Congress, and the IFP agreed that approximately 4580 EJ (800 Gbbl) have been consumed in the past 150 years and 5730 EJ (1000 Gbbl) of proven reserves remain. Other detailed analyses (e.g Bentley, 2002) concluded 4870 EJ were consumed by 1998 and that 6300 EJ will have been extracted by 2008. The USGS also estimated there are 4150 EJ of probable and possible resources still available for extraction. Thus the total available potential of proven reserves plus resources is around 10,000 EJ (BP, 2004; WEC, 2004b). This should be sufficient for about 70 years supply at present rates of consumption, however rates will continue to rise and 40 years supply is therefore a more reasonable estimate. Burning this amount of petroleum resources would release approximately 700 $GtCO_2$ (200 GtC) into the atmosphere, about two-thirds the amount released to date from all fossil fuel consumption since the Industrial Revolution.

Opportunities for energy efficiency improvements in oil refineries and associated chemical plants are covered in Chapter 7.

4.3.1.4 Unconventional oil

Oil that requires extra processing such as oil from shales, heavy oils, and oil (tar) sands, are classified as unconventional. Converting gas and coal to liquid fuels (GTL and CTL) are additional sources. These sources together contributed around 3% of world oil production in 2005 (2.8 EJ) and could reach 4.6 EJ by 2020 (USGS, 2000) and up to 6 EJ by 2030 (IEA, 2005a). Because of higher energy inputs for extraction and processing, the total carbon dioxide emitted per litre of liquid fuel produced may be greater. The oil industry has the potential to diversify the product mix thereby adding to fuel supply security, but higher environmental impacts may result and new infrastructure could be needed.

Heavy oil reserves are greater than 6870 EJ (1200Gbbl) of oil equivalent with around 1550 EJ recoverable. The Orinoco Delta, Venezuela has a resource of 1500 EJ with current production of

1.2 EJ/yr (WEC, 2004c) and plans for 2009 are to apply deep-conversion, delayed coking technology to produce 0.6Mbbl/day of high-value transportation fuels.

Oil shales (kerogen that has not completed the full conversion to oil due to insufficient heat and pressure) represent a potential resource of 20,000 EJ with a current production of just 0.024 EJ/yr, mostly in US, Brazil, China and Estonia. Around 80% of the total resource lies in the western US with 500 Gbbl of medium quality reserves yielding 95 l of oil per tonne of rock and with twice as much potential if utilizing lower-quality rock.

Around 80% of the known global oil sand resource of 15,000 EJ is in Alberta, Canada, which has a current production of 1.6 EJ/yr representing around 15% of national oil demand. Around 310 Gbbl is recoverable. Production at nearly 2 Mbbl/day by 2011 will provide more than half of Canada's projected total oil production. Total resources represent at least 400 Gt of stored C and will probably be added to as more are discovered and assuming that the technology, together with natural gas and water (steam) to extract the hydrocarbons are available and at a reasonable cost.

Technologies for recovering oil sands include open cast (surface) mining where the deposits are shallow enough (which accounts for 10% of the resource but 80% of current extraction), or injection of steam to in wells to reduce the viscosity of the oil prior to extraction. In both cases cleaning and upgrading is necessary to produce oil feedstock suitable for refining. The mining process uses about 4 volumes of water to produce 1 of oil but produces a refinable product. The *in situ* process uses about 2 volumes of water to 1 of oil, but the very heavy product needs blending with something lighter and treatment at the refinery (National Energy Board, 2006). [No paragraph break] Mining and upgrading of oil shale to syncrude fuel costs around $11/bbl and producing and upgrading tar sands is about $15 /bbl (IEA, 2006a). If CCS is used, then at least an additional $5 a barrel should be added.

Large-scale mining leaves behind larger quantites of pollutants and areas of disturbed land compared with conventional petroleum production. The energy efficiency of the oil sand upgrading process is 74% and net emissions amount to between 4 and 9 kgC (15 - 34 kgCO_2) /GJ of transport fuel compared with around 1.3-2.7 kg C (5-10 kgCO_2) /GJ for conventional oil refining (IEA, 2005d, Woyllinowicz *et al*, 2005). Shell, for its Athabascan oil sands project, is currently reporting refining energy expenditures of 1 GJ energy input per 6GJ bitumen processed and emissions of 3 kgC (11 kgCO_{2eq})/GJ and has set a reduction goal of 50% by 2010 (Shell, 2006).

4.3.2 Nuclear energy

In 2004, 2620 TWh of electricity (16–17% of the world total) was generated by nuclear power requiring about 65,500 t of natural uranium (WNA, 2006a). Nuclear power capacity forecasts out to 2030 (IAEA, 2005c; WNA, 2005a; Maeda, 2005; Nuclear News, 2005) vary between 279–740 GW_e when both proposed new plants together with the decommissioning of older ones are considered.

At May 2006 440 nuclear power plants were in operation with a total installed capacity of about 368 GW_e (WNA, 2006a). Six plants were in long-term shut down with a further 28 under construction and many more either planned or proposed in China, India, Japan, Korea, Russia, South Africa and US (WNA, 2006a). In Japan 54 nuclear reactors currently provide nearly a third of total national electricity but immediate plans for construction of 13 new reactors have been scaled down due to anticipated future reduced power demand from efficiency and population decline (METI, 2005). Their target is now to expand the current installed 45 GWe to 50 GWe by adding four new plants by 2010 (IEA, 2004c) with six more planned to reach 58 GWe by 2030 so as to provide around 40% of electricity. In China there are 9 reactors in operation, 2 under construction and proposals for 28 to 40 new ones by 2020 (WNA, 2006b; IAEA, 2006) giving a total capacity of 41-46 GWe (Dellero & Chessé, 2006). China has purchased thousands of tonnes of uranium from Australia, which has 40% of the world's reserves. In India 8 reactors are under construction, with plans for 16 more to give 20 GWe of nuclear capacity installed by 2020 (Mago, 2004).

Power reactors being built today are of safer and more economical third-generation designs. The worldwide operational performance of nuclear power plants has improved and the 2002-2004 average unit capacity factor was 82.4% (IAEA, 2006). The average capacity factors in US increased from less than 60% to about 90% between 1980 and 2003, while average marginal electricity production costs (operation, maintenance and fuel costs) declined from US 3.3¢/kWh in 1988 to US 1.7¢/kWh in 2003 (Nuclear Energy Institute, 2005).

The economic competitiveness of different nuclear energy production forms is dependent upon plant-specific features, number of plants previously built, annual hours of operation and local circumstances. Comparing nuclear generation costs with coal, gas, or renewable systems (section 4.4.2) should use full life cycle cost analyses (NEA/IEA, 2005) including for—

- investment (around 45–70% of total generation costs for design, construction, refurbishing, decommissioning and expense schedule during the construction period);
- operation and maintenance (around 15-40% for operating and support staff, training, security, and periodic maintenance); and
- fuel cycle (around 10–20% for purchasing, converting and enriching uranium, fuel fabrication, spent fuel conditioning, reprocessing, transport and disposal of the spent fuel).

Decommissioning is a major cost component for older plant designs exemplified by the cost of £12.6 billion (US$500/kW undiscounted) for the UK 4452 MW Magnox gas-cooled reactors plus a further £43.2 Bn for decommissioning other nuclear infrastructure including £31.5 Bn for the Sellafield reprocessing plant (NDA, 2005). These costs are thought to be higher than for decommissioning newer generation designs built today (section 4.4.2).

Total life-cycle GHG emissions from nuclear power per unit of electricity produced are below 10 gC_{eq}/kWh (40 gCO_{2eq}/kWh) and at levels similar to those of renewable energy sources (see Figure 4.3.4). Hence, nuclear is an effective GHG mitigation option especially through license extensions by means of investments in retro-fitting and upgrading of existing plants.

Power from nuclear energy currently avoids approximately 2.2–2.6 $GtCO_2$/yr if that power were instead produced from coal without carbon capture and storage (WNA, 2003; Rogner, 2003) or 1.468 $GtCO_2$/yr using the world average carbon dioxide emissions electricity production in 2000 of 150 gC/kWh (WEC, 2001).

Taking advantage of improved neutronic utilization heat-to-work conversion efficiencies, next generation nuclear energy technologies have a strong potential to become even more sustainable by moving to closed fuel-cycle systems with more efficient use of uranium and thorium resources. The introduction of fast-neutron reactors (breeder or burner), together with advanced reprocessing, partitioning and transmutation technologies, can minimize the volumes and toxicity of wastes for geological disposal but uncertainties of proliferation and cost remain. Fast-neutron reactors utilize uranium more efficiently by recycling new material suitable for use as fuel after reprocessing.

4.3.2.1 Uranium exploration, extraction, and refining

In the long term, the potential of nuclear power is dependent upon the uranium resources available. Extraction is relatively straightforward since the energy contained in uranium is 1 million times more concentrated than that in fossil fuels. Reserve estimates of the uranium resource vary with assumptions for its use (Figure 4.3.2). Used in typical light water reactors (LWR) the identified resources of 4.7 Mt uranium at prices up to USD130/kg correspond to about 2400 EJ of primary energy and will be sufficient for close to hundred years (NEA/IEA, 2005) at the current level of consumption. The total conventional proven (identified) and probable (yet undiscovered) uranium resources are about 14.8 Mt (7400 EJ). If used in present reactor designs with a "once-through" fuel cycle, only a small percentage of the energy content is utilized from the fissile isotope U-235 (0.7% in natural uranium). With fast reactors operated in a "closed" fuel cycle by reprocessing the spent fuel and extracting the un-utilized uranium and plutonium produced, the reserves of natural uranium may be extended to several thousand years at current consumption levels, and centuries at heavier levels of use (see Table 4.3.1). Thorium-based thermal fast reactors appear capable of at least doubling the effective resource base, but the technology remains undeveloped.

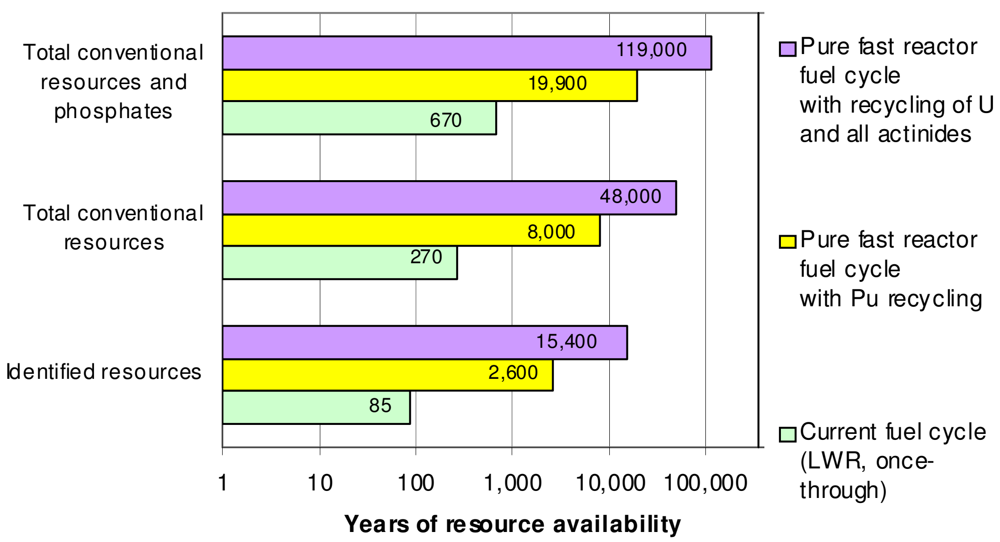


Figure 4.3.2: *Estimated years of uranium resource availability for various nuclear technologies at 2005 utilization level employing the data and category definitions of "Red Book 2005" (OECD 2006)*

Nuclear fuels could also be based on thorium, the proven and probable resources (OECD, 2004a) being about 4.5 Mt, slightly less than uranium. However, except in India, there are not yet sufficient commercial incentives for thorium-based reactors using the thorium fuel cycle, which, although claimed to be more proliferation-resistant than other fuel cycles, produces fissionable U-233. Technological development is still needed to ascertain the commercial feasibility (IAEA, 2005a).

4.3.2.2 Risks and environmental impacts

Regulatory requirements demand that radiation doses to the staff and general public (individual and collective exposures) from the operation of nuclear facilities be kept as low as reasonably achievable and below statutory limits. Within the nuclear fuel cycle the front-end operations (mining and milling), power plant operation, and reprocessing of spent fuel, dominate the collective radiation doses (OECD, 2000b). Carefully designed but feasible protective actions for mill tailing piles are needed to prevent or reduce long-term impacts from radon emissions to the atmosphere.

Operators of nuclear power plants are liable for any damage caused by them to third parties, regardless of fault (UIC, 2005), as defined by both international conventions and national legislation. In 2004, contracting parties to the OECD Paris and Brussels Conventions signed Amending Protocols, setting liability limits at €1500 million. Non-OECD countries have similar arrangements through the IAEA's Vienna Convention. In the US, the national Price-Anderson Act was passed so that damages are covered by insurance backed by the US government for damages limited to USD 200M, and reactor operator pool which provides up to USD 9.43 billion per accident.

4.3.2.3 Nuclear-waste management and disposal

Repositories are already in operation for the disposal of low- and medium-level radioactive wastes in several countries. For high-level waste (HLW), such as spent fuel, deep geological repositories are the most extensively studied option. There is general agreement on the main safety objective of nuclear waste management (IAEA, 1997; IAEA, 2005b) in that human health and the environment need to be protected now and in the future without imposing undue burdens on future generations. Worldwide, no repositories for HLW from nuclear power stations yet exist or are under construction and resolution of both technical and political/societal issues is still needed.

In 2001, the Finnish Parliament ratified the Government's decision concerning the siting of a spent fuel repository in the vicinity of the Olkiluoto nuclear power plant. After detailed rock characterisation studies, construction is scheduled to start soon after 2010 for use around 2020. Similarly, in Sweden a repository siting process is now concentrating on the comparison of several site alternatives close to the Oskarshamn and Forsmark power plants. In the US, the Yucca Mountain area has been chosen amidst much controversy as the preferred site for a repository of HLW (spent LWR fuel) and extensive site characterisation and design studies are underway, although not without significant opposition. The Yucca Mountain repository is not expected to begin accepting HLW until after 2015. France is also progressing on deep geological disposal as the reference solution for high-level and long-lived radioactive wastes and sets 2015 as the target date for licensing a repository and 2025 for opening it. Reprocessing and reuse of spent nuclear fuel further reduces the volume and radionuclide inventory of HLW.

The enrichment of uranium (U-235), reprocessing of spent fuel, and separation of pure plutonium are critical steps in terms of nuclear-weapons proliferation. The Treaty on Non-Proliferation of Nuclear Weapons (NPT) has been ratified by nearly 190 countries. Compliance with the terms of the NPT are verified and monitored by the IAEA. Improving proliferation resistance is a key objective in the development of next-generation nuclear reactors and advanced fuel cycle technologies. For once-through uranium systems, stocks of plutonium are continuously built up in the spent fuel, but only become accessible if reprocessed. Recycling through fast reactors on the other hand allows most of this material to be burned up in the reactor to generate more power, although there are vulnerabilities in the reprocessing step and hence still need for careful safeguards.

4.3.2.4 Development of future nuclear-power systems

Present designs of reactors are classed as Generations I through III (Figure 4.3.3) whereas Generation III+ advanced reactors are now being planned and aim to be in operation during 2010 - 2020 (GIF, 2002). These plants include evolutionary reactor designs with improved economics, simpler safety systems and impacts of severe accidents limited to the close vicinity of the reactor site. They are likely to become state-of-the-art nearer 2020 to meet possible increased demand, an example being the European pressurized water reactor (EPR) scheduled to be in operation in Finland around 2010 and the Flamanville plant planned in France.

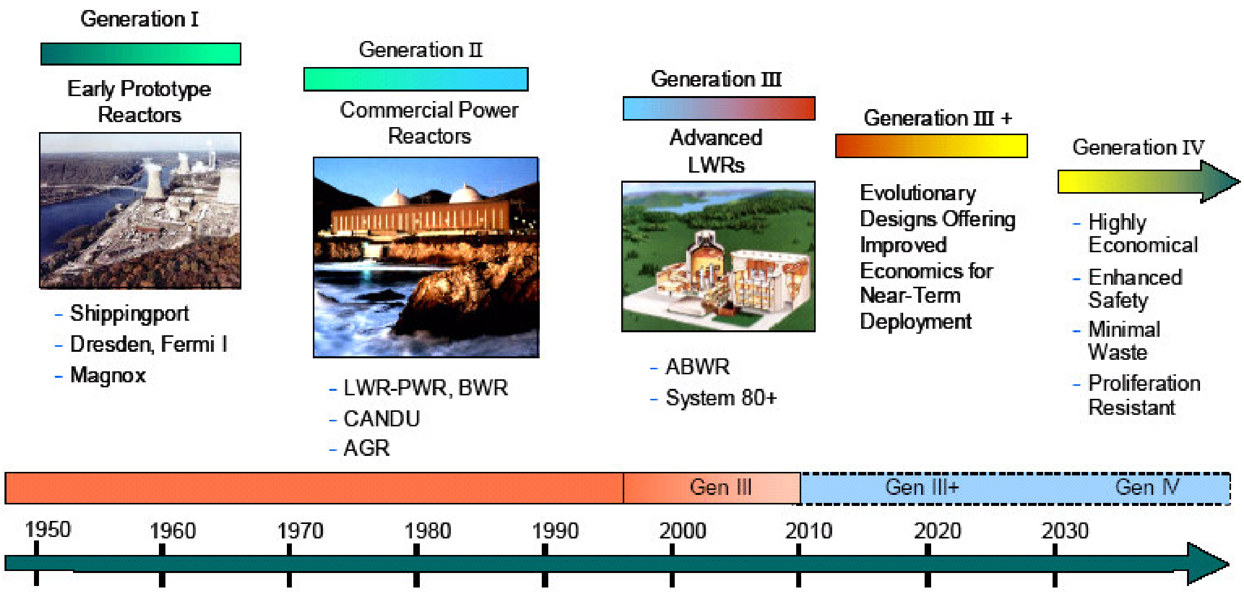


Figure 4.3.3: *Evolution of nuclear power systems from Generation I commercial reactors in 1950s up to the future Generation IV systems which could be operational after about 2030 (GIF, 2002). Notes: LWR = light-water reactor; PWR = Pressurized water reactor; BWR = boiling-water reactor; ABWR = advanced boiling-water reactor; CANDU = CANada Deuterium Uranium.*

Generation-IV designs are being pursued mainly by the Generation-IV International Forum (GIF, a group of ten nations plus the European Union and co-ordinated by US Department of Energy) as well as the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) coordinated by the IAEA. These initiatives focus on the development of reactors and fuel cycles that provide economically competitive, safe and environmentally sound energy services based on technology designs that exclude severe accidents, involve proliferation resistant fuel cycles decoupled from any fuel resource constraints, and minimize HLW. Much additional technology development is needed to meet these long-term goals so require strategic public RD&D funding since there is little initial industrial/commercial interest.

GIF has developed a framework to plan and conduct international cooperative research on advanced nuclear energy systems (GIF, 2002) including three designs of fast-neutron reactor (FNR), sodiumcooled (SFR), gas-cooled (GFR) and lead-cooled (LFR), as well as high temperature reactors (VHTR). Reactor concepts capable of producing high temperature nuclear heat are intended to be employed also for hydrogen generation either by electrolysis or directly by special thermo-chemical water splitting processes or steam reforming. There is also an ongoing development project by the South African utility ESKOM for an innovative high temperature, pebble bed modular reactor (PBMR). Specific features include its smaller unit size, modularity, improved safety by use of passive features, lower power production costs and the direct gas cycle design utilizing the Brayton cycle (Koster *et al.*, 2003; NER, 2004). The supercritical light-water reactor (SCWR) is also one of the GIF concepts intended to be operated under supercritical water pressure and temperature conditions. Conceivably some of these concepts will come into practical use and offer still better prospects for future use of nuclear power.

In summary, the experience of the past three decades has shown that nuclear power can be very beneficial if employed carefully, and can be a great problem if not. It shows substantial potential for an expanded role, but must be improved economically and in terms of its ease of use. The problems of potential reactor accidents, nuclear waste management and disposal, and nuclear weapon proliferation will remain as constraints that can likely be managed successfully with continued vigor.

4.3.2.5 Nuclear fusion

Energy from the fusion of heavy hydrogen fuel (deuterium, tritium) is actively being pursued as a long-term almost inexhaustible supply of energy. A major international effort is underway (ITER, http://www.iter.org/) to demonstrate magnetic containment of sustained, self-heated plasma under fusion temperatures. The scientific feasibility of fusion energy has been proven, but technical feasibility remains to be demonstrated in experimental facilities, such as ITER. Construction of a pilot plant is being planned to operate for 20 years. Resolution of many scientific and engineering challenges is still needed. Commercialization of fusion power production has been contemplated to become commerically viable by about 2050, assuming successful initial demonstration (Smith *et al.*, 2006; Cook *et al.*, 2005).

4.3.3 Renewable Energy

Renewable energy accounted for approximately 17% of world primary energy supply in 2004, including traditional biomass (9%), large hydro-electricity (6% when counted as equivalent primary energy), and "new" renewables (2%) (Martinot *et al.,* 2005; IEA, 2005). Wind power (<0.7% of total renewable energy) has grown by 24% of installed capacity per year since 1990. In recent years, solar thermal hot water has grown by 20% annually and grid-connected solar photovoltaics (PV) by 50–60%. Modern biomass and geothermal have also significantly exceeded the annual primary world energy demand growth of 1.6%. Even so, under a business-as-usual case of continued growing energy demand, renewables start from a low base and are not expected to greatly increase their market share during the next decades without continued and sustained policy intervention. IEA's World Energy Outlook (IEA, 2004a) projected a fairly constant share of renewables in global primary energy through 2030. In OECD countries renewable energy sources fuelled 24% of electricity generation in 1970 but this had fallen to 15% by 2001 due to increased fossil fuel and nuclear supply (IEA, 2004a). The long-term vision held by many that renewable energy can make a significant contribution to world primary energy supply while not increasing

GHG emissions within a few decades have led to renewed support for renewable energy from many governments.

Renewable energy systems can contribute to the security of energy supply and protection of the environment. These and other benefits of renewable energy systems were defined in a declaration by 154 nations at the international "Renewables2004" conference held in Bonn, June 2004 (Renewables, 2004) following on the 2002 World Summit on Sustainable Development in Johannesburg.

Renewable energy technologies can be broadly classified into four categories:
1) technologically mature with established markets in at least several countries:- large and small hydro, woody biomass combustion, geothermal, landfill gas, solar water heating, on-shore wind, bioethanol from sugars and starch (mainly Brazil and US);
2) technologically mature but with relatively new and immature markets in a small number of countries:- crystalline silicon PV (except Germany and Japan closer to category 1) in municipal solid waste-to-energy, anaerobic digestion, biodiesel, co-firing of biomass, concentrated solar dishes and troughs, solar-assisted air conditioning, mini- and micro-hydro, and off-shore wind;
3) under technological development with demonstration or small-scale application, but approaching wider market introduction:- thin film PV, concentrating PV, tidal range power, biomass gasification and pyrolysis, bioethanol from ligno-cellulose, bio-refineries, and solar thermal towers; and
4) still in technology research stages:- organic and inorganic nanotechnology solar cells, artificial photosynthesis, hydrogen production from algae and water, wave power, and energy from ocean thermal and saline gradients and ocean currents.

The most mature renewable technologies (large hydro, biomass combustion, and geothermal) have, for the most part, been able to compete in today's energy markets without policy support. In the best locations and in countries with the most mature markets, several forms of "new" renewable energy compete on an average-cost basis with conventional energy sources. Solar water heating in China, grid-connected solar PV in Japan, wind farms in Spain and New Zealand, bioethanol in Brazil, and forest residues in Sweden are all competitive today. In countries where market deployment is slow due to less optimal resources, higher costs (relative to conventional fuels), and/or a variety of market and social barriers, these technologies still require government support (IEA, 2006c). Typical construction costs for new power plants are high, up to US$2500/kW for some technologies, but on good sites they can generate power for around 3-4UScents/kWh (Martinot *et al.*, 2005). On other sites, the costs are very variable (see Table 4.3.1). In areas where the industry is growing, many of the best sites with good resources for wind, geothermal, biomass and hydro have already been utilized. The less mature technologies are usually not yet competitive (Figure 4.3.4).

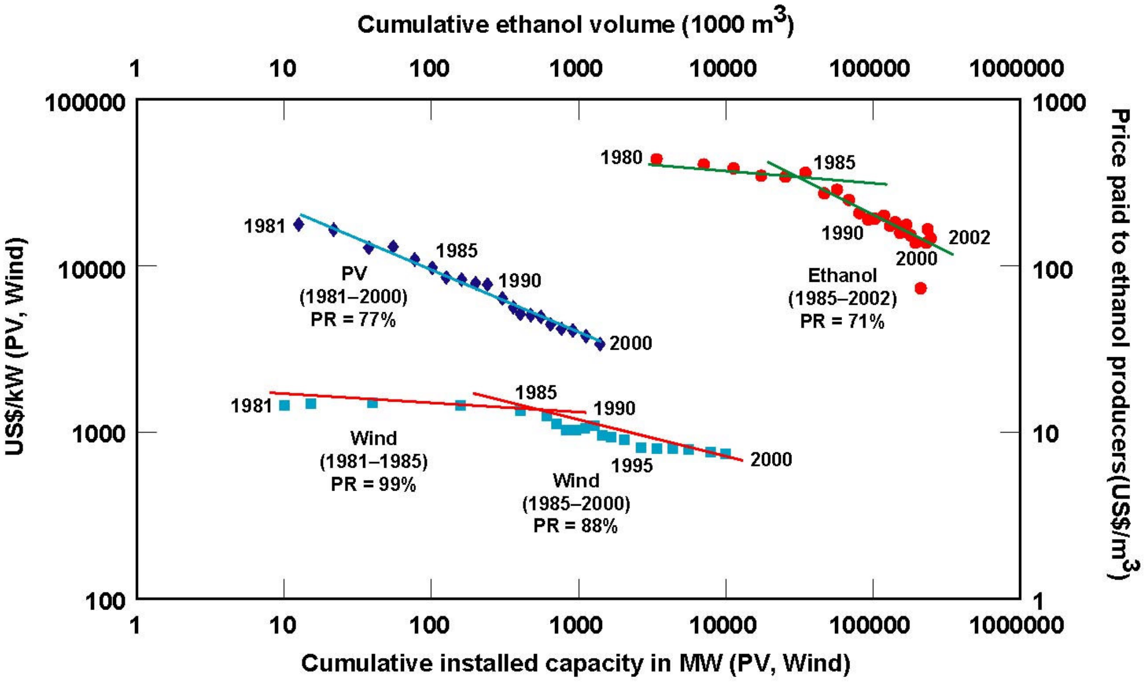


Figure 4.3.4: *Investment costs and penetration rates for PV, wind and ethanol systems showing cost reductions of 20% due to technological development and learning experience for every doubling of capacity (Johansson et al., 2004).*

A wide range of policies and measures exist to enhance the deployment of renewable energy (IEA, 2004c; Martinot *et al*., 2005, and section 4.5). Over 45 nations, including all EU countries, along with numerous individual states/provinces of the USA, Canada and Australia and a number of developing countries such as Brazil, China, Egypt, India, Malaysia, Mali, Mexico, Philippines, South Africa and Thailand have set renewable energy targets (Renewables, 2004). Some targets focus on electricity, while others include renewable heating and cooling and/or biofuels as in Brazil, Canada, China, India, Netherlands, New Zealand, Thailand, and the United States. By 2004, at least 20 states/provinces and two countries had mandates in place for blending bioethanol or biodiesel with petroleum fuels. A new IEA implementing agreement on "Renewable Energy Technology Deployment" aims to encourage international collaboration particularly on policy development.

Many renewable energy sources are intermittent over hourly, daily and/or seasonal time frames. Thus energy storage technologies may be needed, particularly for wind, wave and solar, though stored hydro reserves, geothermal and biomass fuels can all be used as back-up sources as can thermal power plants. Studies on intermittency continue (UKERC, 2006).

Since the TAR large industry corporate companies such as General Electric, Siemens, Shell and BP have invested in renewable energy along with a wide range of public and private sources. Many commercial banks such as Fortis, ANZ Bank, and Royal Bank of Canada are financing a growing number of projects; investment firms such as Goldman Sachs and Morgan Stanley are acquiring renewable energy companies; traditional utilities are developing more of their own renewable energy projects; commercial reinsurance companies such as Swiss Re and Munich Re are offering new insurance products targeting renewable energy; and venture capital investors are taking note of future market projections for wind and photovoltaics (PV). New CDM-supported and carbon-finance projects for renewables are emerging and the OECD has improved the terms for Export Credit Arrangements for renewable energy by extending repayment terms (Martinot *et al*., 2005).

There has also been increasing support for renewable energy deployment in developing countries, not only from international development and aid agencies (currently about $500 million per year from all sources), but also from large and small local financiers with support from donor governments and market facilitators to reduce their risks. As one example, total donor funding pledges or requirements in the "Bonn Renewables 2004 Action Programme" amounted to around $US50 billion (Renewables, 2004).

Numerous detailed and comprehensive reports, web sites, and conference proceedings have been produced since the TAR on renewable energy resources, conversion technologies, industry trends and government support policies (see for example Renewables, 2004; BIREC, 2005; Martinot *et al*, 2005; IEA, 2004cd; IEA, 2005d; IEA 2006a; IEA 2006c; WEC, 2004; ISES, 2005; WREC, 2006; WREA, 2005). The following sections address the major key points relating to progress in each major renewable source.

4.3.3.1 Hydroelectricity

Large (>10 MW) hydroelectricity systems account for 25 EJ/yr of global energy (BP, 2004). They provide 17% of global electricity (90% of renewable electricity) and avoid releasing 2.202 $GtCO_2$/yr of carbon into the atmosphere if generated from a similar amount of coal-fired power. Hydro projects under construction could increase their share of electricity by about 4.5% on completion (WEC, 2004d).

Expansion of hydropower capacity, at both large and small scales, requires continuous technology improvements to maximize the use of existing plants and improve their capacity factor. Some, such as the 12.6 GW-Itaipu plant in Brazil, run with an average capacity factor of >80%, whereas others (as in Japan) are closer to 40%. Evaluation of hybrid hydro/wind systems, hydro/hydrogen systems, low head run-of-river systems and pumped (by wind or thermal power plants) river storage to offset peak power demands all require R & D investment (IEA, 2006b).

Hydro power is one of the industrial-scale renewable technologies that can be deployed in a routine, straightforward fashion. It is estimated that there is the capability to produce a further 60 EJ/yr of electricity from building more large hydropower systems (BP, 2004) mainly in developing countries, but obtaining consents is often a constraint due to environmental concerns. In addition, about 25% of water reservoirs in the world have associated generation facilities, but many more irrigation and urban water supply schemes could have small hydro-power generation retrofits added. The benefits of hydro electricity, irrigation resource creation, recreational lakes, and flood control need to be taken into account for any given development. However questions have arisen over the environmental impacts of large hydropower development schemes even by environmental groups which normally support renewable energy, so several sustainability guidelines have been produced (Rowe, 2005; Hydro Tasmania, 2005; WCD, 2000).

Where expansion is occurring, particularly in China and India, major social disruptions as well as gross carbon dioxide and methane emissions (due to gradual decay of flooded vegetation, particularly in tropical regions), ecological disruptions to existing river ecosystems and fisheries, and related evaporative water losses are stimulating strong opposition from human rights and "green" groups based in wealthy countries. Whether large hydro-power systems bring electricity to the poorest is also questionable (Collier, 2006). GHG emissions were measured in several Brazilian hydro-reservoirs and compared through life cycle analyses with combined cycle natural gas turbine (CCGT) plants of 50% efficiency (dos Santosa *et al.*, 2004). Emissions from flooded reservoirs tended to be less per kWh generated than those produced from thermal power plants. Large hydro-power complexes with greater power density (W capacity/m^2 area flooded) had the best environmental performance. Lower power density systems produced similar or more GHG emissions than CCGT plants.

Small (<10 MW) and micro (<1 MW) hydro-power systems, usually run-of-river systems, have provided electricity to many rural communities in developing countries such as Nepal, but in total they generate slightly less than 1 EJ/yr (WEC, 2004d). The global technical potential of small and micro hydro is around 150-200 GW with many unexploited resource sites available at generating costs between USD0.02-0.06/kWh but with additional costs needed for power connection and distribution. These costs can be prohibitive in remote areas, even for mini-grids, and some form of financial assistance from aid programmes or governments will be necessary.

4.3.3.2 Wind

The technical potential of the wind energy resource greatly exceeds the 0.5 EJ/yr of wind power generated in 2003 (WEC, 2004d). Wind provided only around 0.6% of the 16,074 TWh global electricity production in 2002 (IEA, 2004a). Installed capacity increased from 2.3 GW in 1991 to 47.9 GW at the end of 2004 when it generated 95 TWh (GWEC, 2005) at an average capacity factor of around 23%. New wind installation capacity has grown at an average of 28%/yr since 1999 (IEA, 2006b) due to lower costs, government support from feed-in tariff and renewable energy certificate policies (section 4.5), and improved technology development. Off-shore wind capacity now exceeds 500 MW with the expectation that it will soon grow rapidly due to higher mean annual wind speeds as experienced offshore in most regions.

Wind energy accounted for 18.5% of Denmark's electricity generation in 2004, and up to 25% in West Denmark where 2.4 GW of wind capacity is installed (the highest capacity per capita in the world). However to maintain stability in the domestic grid, most of this power was exported, sometimes at a loss, through interconnectors to Sweden, Norway, and Germany such that in 2004 only about 6% of Denmark's domestic consumption was provided by wind (Vestergaard, 2005). The additional cost burden of wind energy in Denmark to provide reliability was estimated to be between €1-1.5 billion per annum (Bendtsen, 2003) and €2-2.5billion per annum (Krogsgaard, 2001).

Public objections due to the perceived negative visual impacts need to be addressed if rapid growth of both on- and off-shore wind farms is to continue. Various best-practices guidelines have been produced and issues such as noise, bird strike, EMF interference, airline flight paths, and protection of areas with high landscape value are better understood.

The average size of wind turbines has increased in the last 25 years from less than 50 kW to the Enercon E-112 6-MW machine, the largest commercially available in 2006 with a rotor diameter exceeding 125 m (http://www.repower.de/index.php?id=237&L=1). The average turbine size being sold currently is around 1.6–2 MW but there is also a market for smaller turbines <100 kW.

Total costs of a wind farm range from USD1000–1400 /kW depending on location, road access, proximity to load, etc. Current capital costs for land-based wind turbines are below USD900 /kW with 25% for the tower and 75% for the rotor and nacelle. Operation and maintenance costs vary from 1% of investment costs in year 1 rising to 4.5% after 15 years. Thus power generated is around USD0.03 -0.04 /kWh on good sites with capacity factors exceeding 35% (IEA, 2006b). Generation costs continue to decline based on a learning rate experience of 15-20% cost reduction per doubling of installed capacity (see Figure 4.3.3) as has been the case in Denmark since 1985. By 2010 the cost of wind power is projected to be USD0.024-0.03 /kWh depending on the mean annual wind speed and the roughness class of the site (Morthorst, 2004) (Figure 4.3.5).

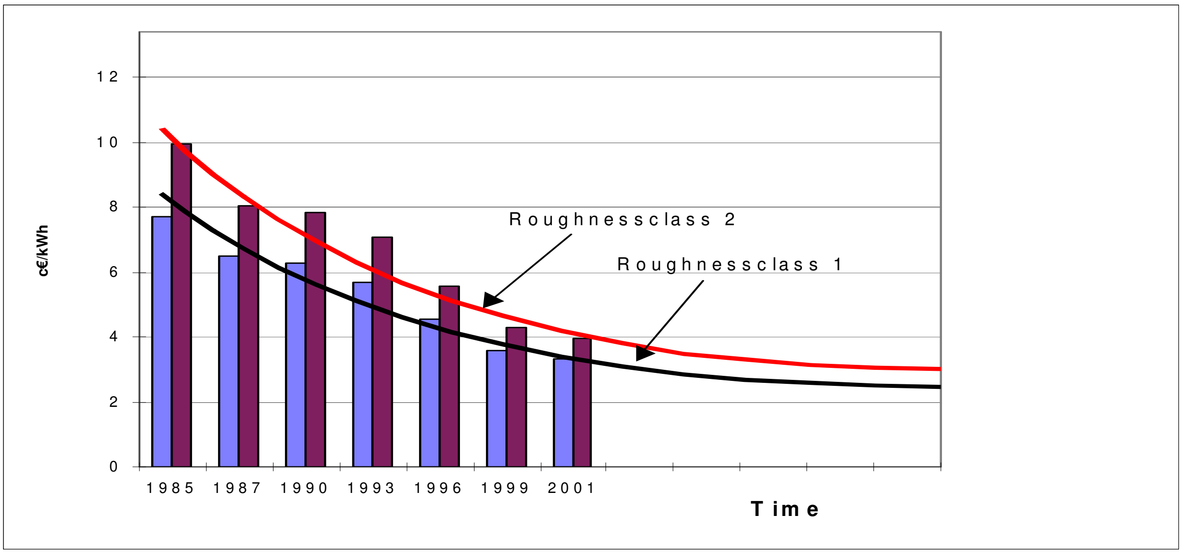


Figure 4.3.5: *Development of wind-generation economics based on Danish experience since 1985 with variations shown due to land surface and terrain variations (as indicated by roughness indicator classes which equal 0 for open water up to 3 for rugged terrain) (Morthorst, 2004).*

Wind energy cannot yet be considered to be a true global market as the main investment has been in only Europe, Japan, China, the US, and India (Wind Force 12, 2005). The Global Wind Energy Council assumes this will change and has a target of 1250 GW installed capacity in 2020, which would supply 12% of the world's electricity. The European Wind Energy Association set a target of 75 GW (168 TWh) for EU-15 countries in 2010 and 180 GW (425 TWh) in 2020 (EWEA, 2004). Australasia and several U.S. states have similar ambitious targets, mainly to meet the increasing demand for power rather than to displace nuclear or fossil fuel plants. Rapid growth in Russia, China, Mexico, Brazil, and India is also expected where private investment interest is increasing (Martinot *et al*., 2005). A global technical potential of 72 TW (http://www.stanford.edu/group/efmh/winds/global_winds), assuming a 20% average capacity factor, would generate 126,000 TWh/yr. This exceeds current world primary energy production and is double the 600 EJ potential estimated by Johansson *et al*., 2004. The actual utilization is likely to be much lower, however, as objections from local residents increase. In addition, there are questions surrounding the maximum proportion of intermittent wind power acceptable to a transmission grid and the amount of back-up required.

Due to the fluctuating and somewhat unpredictable nature of wind, the contribution to the total electricity demand is constrained in order to maintain system reliability. To supply over 20% of a total grid's demand from wind power requires several conditions, including accurate forecasting; regulations that set wind near the top of access; reducing grid access to <5 hours; reserves to provide operational and capacity; demand side response measures connections with other grid systems (Gul and Stenzel, 2005); and a means of storing surplus energy (EWEA, 2005; Mazza and Hammerschlag, 2003). Effective storage would enable the wind-energy component of a power system to meet a larger fraction of total electricity demand.

The trend is to replace older and smaller wind turbines with larger, more efficient, quieter, and reliable designs giving higher power outputs from the same site but at a lower density of turbines per hectare. More accurate aero-elastic models are being developed and more advanced control strategies used to keep the wind loads within the turbine design limits. Improved wind forecasting, larger turbines, taller towers, the use of carbon fibre technology in longer wind turbine blades replacing glass-reinforced polymer, noise reduction, dedicated offshore turbines with maintenance strategies to overcome difficulties with access for maintenance activities due to bad weather/rough seas and high costs, and optimized turbine designs to maximize energy capture for lower wind-speed sites are also under development. Sites with lower wind speeds (less than 7-8 m/s) in regions where power prices are around $US0.05-0.06/kWh are not usually economically viable for wind power using the latest designs of turbines without some form of government support (Oxera, 2005).

4.3.3.3 Biomass and bioenergy

Biomass continues to be the world's major source of food, stockfeed, fibre, and is the only renewable resource of hydrocarbons for cooking and as a source of heat, electricity and liquid fuels, chemicals and materials production. It can be used for materials which at the end of their life can be recycled for energy. Biomass sources include forest, agricultural and livestock residues, short rotation forest plantations, dedicated herbaceous energy crops, the organic component of municipal solid waste (MSW), and other organic waste streams. These are used as feedstocks to produce energy carriers in the form of solid fuels (chips, pellets, briquettes, logs), liquid fuels (methanol, ethanol, diesel), gaseous fuels (synthesis gas, biogas, hydrogen) and heat (Figure 4.3.6). This biomass section concentrates on the conversion technologies of biomass resources to provide bioenergy in the form of heat, electricity and transport fuels to the energy market.

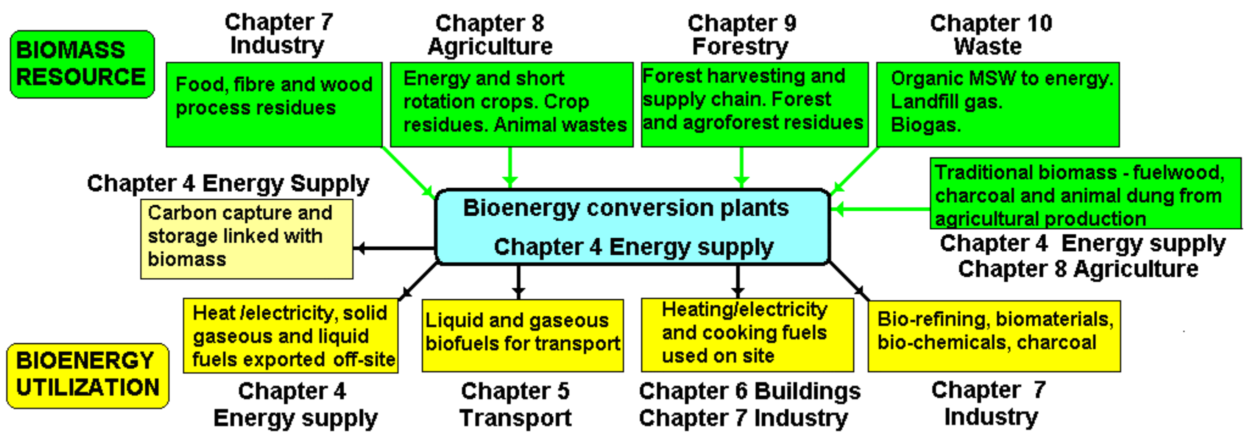


***Figure 4.3.6** Biomass supplies originate from a wide range of sources and, after conversion in many designs of plants from domestic to industrial scales, are converted to useful forms of bioenergy. Chapters containing sections on specific biomass resources and the use of bioenergy carriers and biomaterials are shown.*

Bioenergy carriers range from a simple firewood log to a highly refined transport fuel. Different biomass products suit different situations and specific objectives for using biomass are affected by the quantity, quality and cost of feedstock available, location of the consumers, type and value of energy services required, and the specific co-products or benefits (IEA Bioenergy, 2005). Biomass tends to have low-energy density per volume or mass compared with equivalent fossil fuels that makes transportation, storage and handling more costly per unit of energy (Sims, 2002). These costs will be minimized if biomass can be sourced from a location where it is already concentrated (IEA Bioenergy, 2005).

Globally, biomass currently provides around 46 EJ of bioenergy in the form of combustible biomass and wastes, liquid biofuels, renewable MSW, solid biomass/charcoal, and gaseous fuels (Figure 4.3.7). This share is estimated to be over 10% of global primary energy supply though the volume of traditional biomass consumed in developing countries is uncertain (IEA, 2005b).

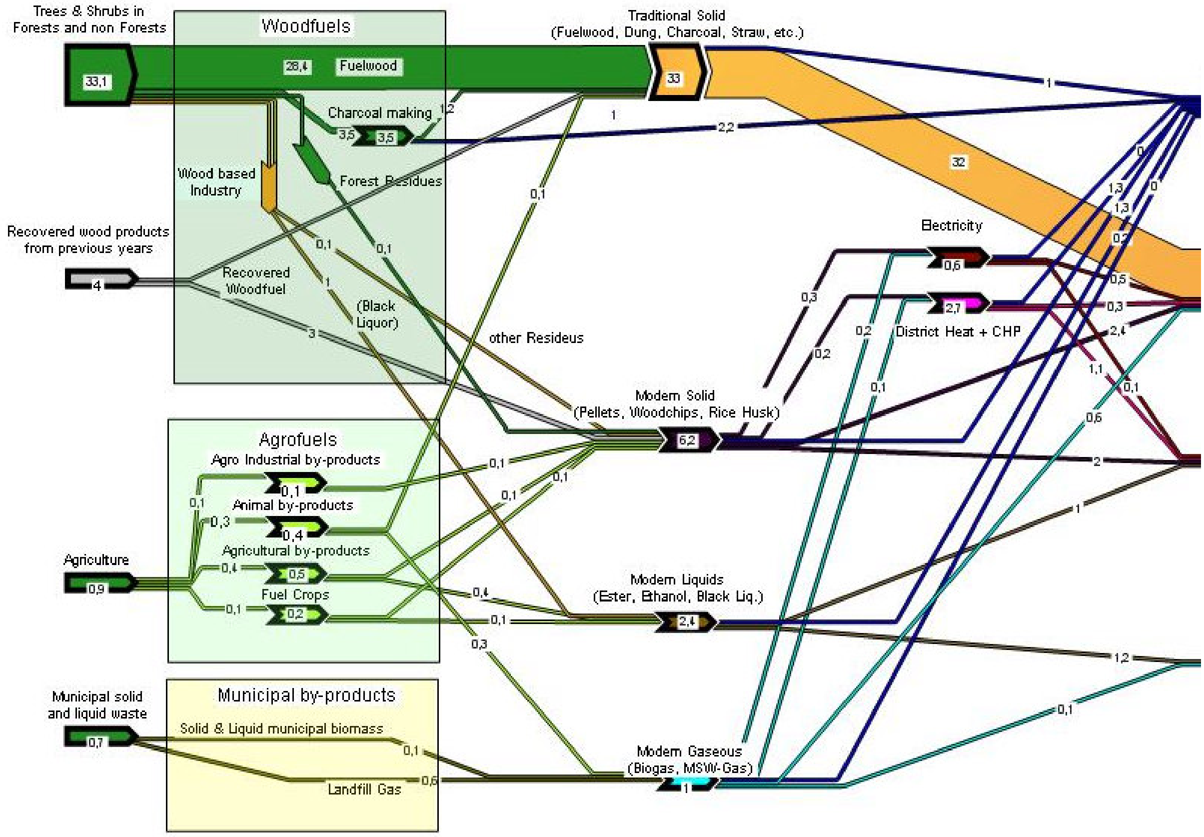


Figure 4.3.7 World biomass energy flows and their thermochemical and biochemical conversion routes to produce heat, electricity, and biofuels.

If fossil fuels with an average carbon intensity at 75 tCO_2/TJ were to displace the energy services presently provided by the 46 EJ/yr of biomass primary energy, about 3.67 $GtCO_2$/yr would be released to the atmosphere (assuming the same efficiency as for biomass and that all biomass is produced sustainably and replanted so as to be carbon neutral). Since much of the biomass is used less efficiently, the actual savings would be lower.

In 2003, approximately 32–37 EJ of biomass was consumed as non-commercial fuelwood, crop residues, charcoal, and dung (IEA, 2004a) used for cooking, heating, and brickmaking in developing countries (IEA, 2004f). Such low-grade biomass provides around 35% of primary energy supply in many developing countries. The existence of many forms of biomass and ways of using it have caused the UN Food and Agricultural Organization (FAO), in association with the IEA, to better define the terminology to be used for energy and forestry statistics as well as for future international standards required as biomass trade develops (FAO, 2001). The FAO has compiled a woody biomass database for 215 countries from 1961 to 2003 with projections out to 2030 (FAO, 2004).

Traditional biomass conversion is based on inefficient combustion, often combined with significant local and indoor air pollution and unsustainable use of biomass resources such as native vegetation (Venkataraman *et al*. 2004). A range of alternative cooking fuels which could be produced within a rural community (Goldemberg *et al*., 2004a) include di-methyl ether from coal (Larson & Yang, 2004), synthetic fuels from biomass (Williams *et al*., 2006) and ethanol gel (Utria, 2004).

Residues from industrialised farming, plantation forests and food and fibre processing operations that are currently collected worldwide and used in modern bioenergy conversion plants are difficult to quantify but probably supply approximately 6 EJ /yr. They can be classified as primary, secondary and tertiary (Figure 4.3.8). Energy crops grown for transport biofuels contributed close to 1EJ in 2005, supplying around 2% of the world gasoline market and 0.2% of the diesel market. Current combustion of over 130 Mt of MSW annually provides a further 0.6 EJ/yr (though this includes plastics etc). Much more organic waste is deposited in landfills, which in turn creates large volumes of GHGs, mainly methane. The small portion currently collected as landfill gas also contributes to bioenergy supply with a technical potential of around 3 EJ/yr (Chapter 10).

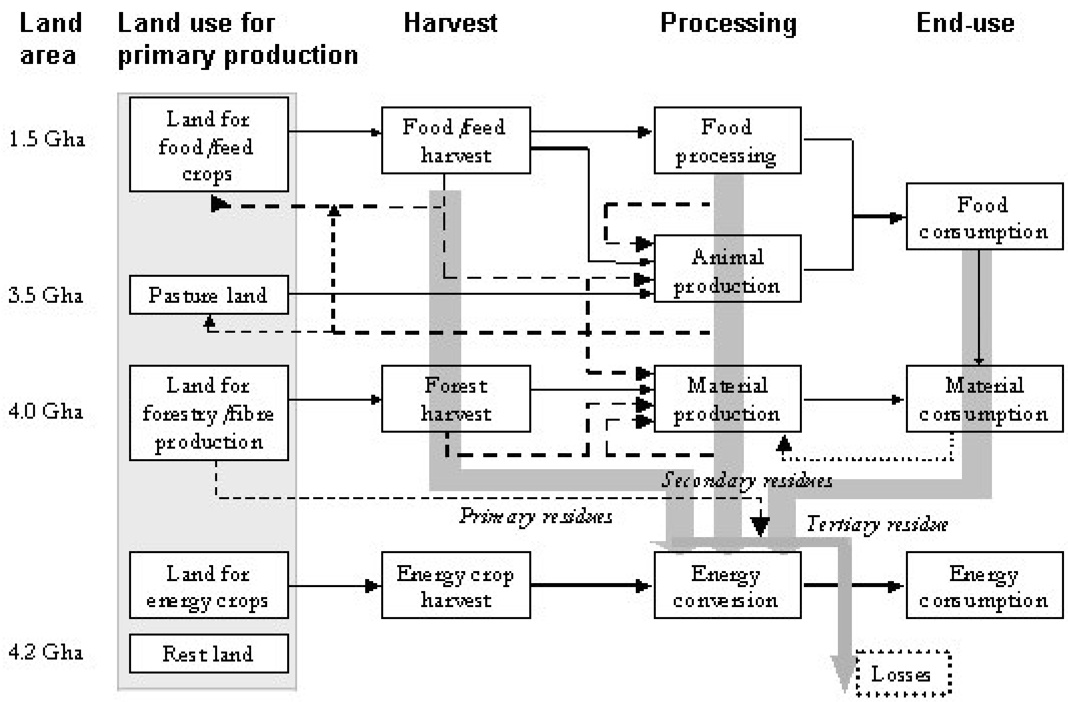


Figure 4.3.8: Biomass sources from primary, secondary and tertiary residues (van den Broek, 2000)

Organic residues and wastes are often cost effective feedstocks for current bioenergy conversion plants which have resulted in niche markets for forest, food processing and other industries. Industrial use of biomass in 2002 in OECD countries equated to 5.6 EJ (IEA, 2004a) mainly in the form of black liquor in pulp mills, biogas in food processing plants, and bark, sawdust, rice husks, etc. in process heat boilers. In non-OECD countries bagasse is another important residue for cogeneration. All options have applicability as CDM projects.

A wide range of conversion technologies is under continuous development to produce bioenergy carriers for both small- and large-scale applications (Figure 4.3.9). The use of biomass for cogeneration (combined heat and power) and industrial, domestic and district heating continues to expand (Martinot *et al.*, 2005). Combustion of biomass for heat and steam generation remains the state of the art, but advancing technologies include second-generation biofuels, biomass integrated gasification combined cycle (BIGCC) systems, co-firing (with coal or gas), and pyrolysis. Many are close to commercial maturity but awaiting further technical breakthroughs and demonstrations to increase the efficiency and further bring down the costs.

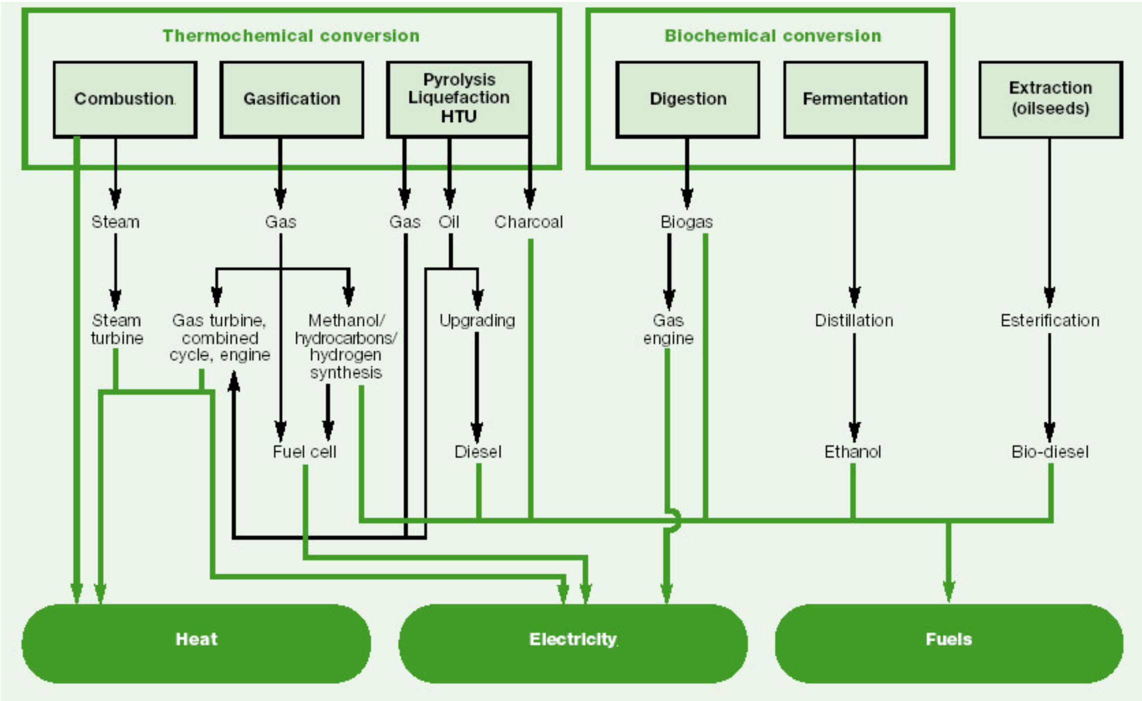


Figure 4.3.9: *Thermochemical and biochemical conversions from a range of biomass feedstocks to energy carriers and then to useful bioenergy*

Biochemical technologies can convert cellulose to sugars that, in turn can be converted to bioethanol, biodiesel, di-methyl ester, hydrogen and chemical intermediates in bio-refineries. Biochemical and Fischer-Tropsch based thermochemical synthesis processes can be integrated in a single biorefinery such that the biomass carbohydrate fraction is coverted to ethanol and the lignin-rich residue gasified and used to produse heat, electricity and/or fuels thus greatly increasing the overall system efficiency to 70-80% (OECD, 2004b; Sims, 2004).

Combustion and co-firing

Biomass can be combined with fossil fuel technologies by co-firing solid biomass particles with coal; mixing synthesis gas, landfill gas or biogas with natural gas prior to combustion; blending diesel with biodiesel and gasoline with bioethanol; and using flexible fuel engines in vehicles. There has been rapid progress since the TAR in the development of the co-utilisation of biomass materials in coal-fired boiler plants. Worldwide more than 150 coal-fired power plants in the range 50-700 MW_e have operational experience of co-firing with woody biomass or wastes, at least on a trial basis (IEA, 2004c). Commercially significant lignites, bituminous and sub-bituminous coals, anthracites, and petroleum coke have all been co-fired up to 15% by energy content with a very wide range of biomass material, including herbaceous and woody materials, wet and dry agricultural residues and energy crops. This experience has shown how the technical risks associated with co-firing in different types of coal-fired power plants can be reduced to an acceptable level through proper selection of biomass type and co-firing technology. It is a relatively low cost and low risk means of adding biomass capacity, particularly in developing countries where old coal-fired plants are prevalent.

Gaseous fuels

Gasification of biomass (or coal, section 4.3.2.1) to synthesis (producer) gas, mainly CO and H_2, has a relatively high conversion efficiency (40–50%) when used to generate electricity through a gas engine or gas turbine. The gas produced can also be used as feedstock for a range of liquid biofuels. Development of efficient BIGCC systems is nearing commercial realization but the challenges of gas cleanup remain. Several pilot and demonstration projects have been evaluated with varying degrees of success (IEA, 2006b).

Recovery of methane from anaerobic digestion plants has increased since the TAR. More than 4,500 installations (including landfill gas recovery plants) in Europe, corresponding to 3.3 Mt methane or 92 PJ / year, were operating in 2002 with a total market potential estimated to be 770 PJ (assuming 28 Mt methane is produced) in 2020 (Jönsson, 2004). Biogas can be used for production of electricity and/or heat. It can also be fed into natural gas grids or distributed to filling stations for use in dedicated or dual gas-fueled vehicles which requires upgrading of the biogas.

Biofuels for transport (also see Chapter 5)

OECD countries value biofuels mainly as a means of reducing greenhouse gases, meeting clean air policies and achieving greater energy supply security by reducing foreign oil dependence. Developing countries also consider biofuels to be a means of stimulating rural development, creating jobs, and saving foreign exchange. Concerns about conventional oil availability and prices in all regions have increased interest in biofuels for transport, as they are, besides coal and gas to liquids (section 4.3.2.4), the only near-term alternative fuel since hydrogen may only become available in the medium to long term.

Global biofuel consumption in 2002 was between 0.35 EJ (IEA, 2004g) and 0.50 EJ and in 2005 38 billion litres of bioethanol (1.2 EJ) were produced mainly in Brazil, USA, China for use up to 85% blends in flexi-fuel engines or 100% engines (Chapter 5) and over 3 billion litres of biodiesel were produced, mostly in Germany. Process demonstration units for second generation biofuels from ligno-cellulosics have been installed in the National Renewable Energy Laboratory, USA (http://www.nrel.gov/docs/fy00osti/28397.pdf), University of British Columbia, Canada (Boussaid *et al.*, 2000), and Sweden (Wingren *et al.*, 2004). Anaerobic digestion and Fischer-Tropsch processes can also be used for producing gaseous and liquid fuels at the small scale (Larson and Jin, 1999) though Fischer-Tropsch is currently only viable at the larger scale.

Commercial bioethanol production costs currently range from USD 0.25 per litre of gasoline equivalent (lge), (sugarcane, Brazil) to USD 0.80/lge (sugar beet, UK) with corn ethanol around USD 0.60/lge (USA) and ligno-cellulosic ethanol from pilot-scale plants claimed to be between USD 0.80 to 1.00/lge. Biodiesel costs range from USD 0.42/l (animal fats, New Zealand) to USD 0.90/l (oilseed rape, Europe; soybean, USA; palm oil; Malaysia) (Figure 4.3.8). Technology development and larger-scale plants could lower production costs of bioethanol by 2030 to USD 0.23-0.65/lge and biodiesel to USD 0.40-0.75/lge.

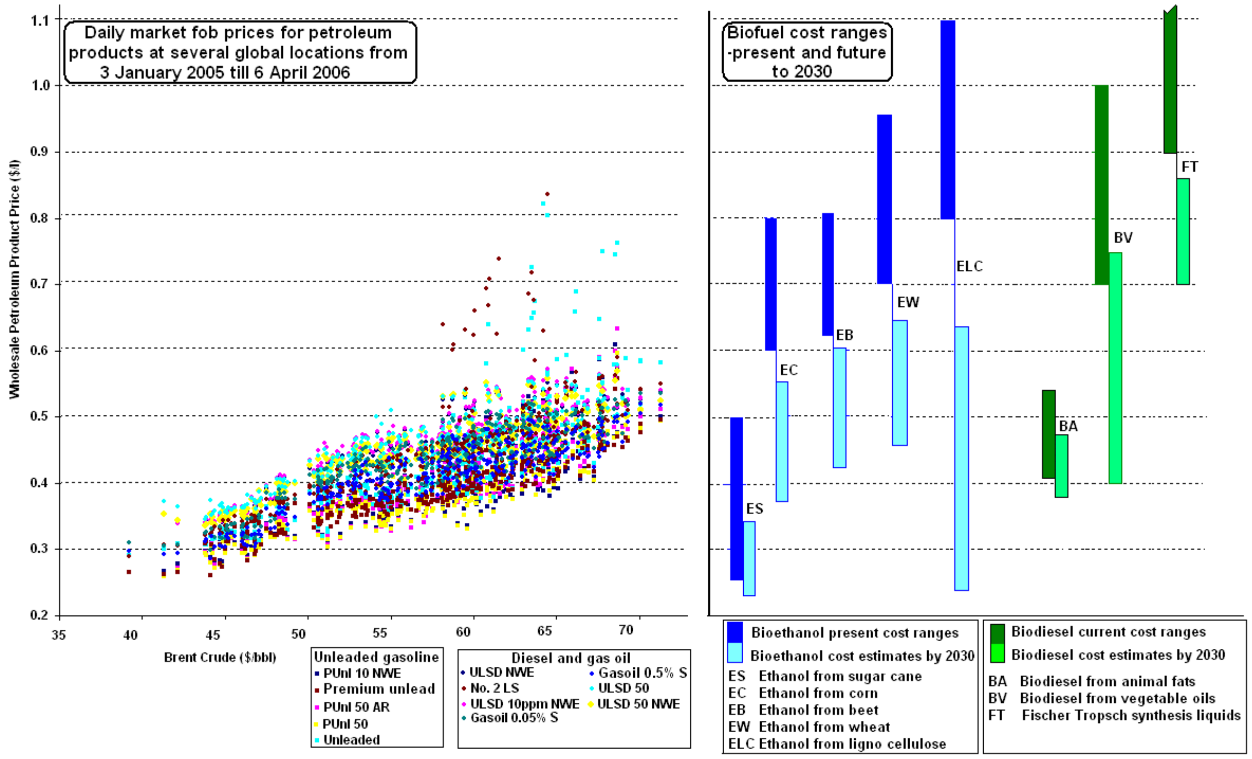


Figure 4.3.10: *Comparison between current and future biofuels prices versus gasoline and diesel ex-refinery (fob) prices for a range of crude oil prices (IEA, 2006g).*

Ethanol from sugar cane (ES) can compete with oil price around USD 40/bbl and biodiesel from animal fats (BA) around USD 60/bbl. Other biofuels will only compete when oil is above USD 70/bbl unless the production costs can be significantly reduced by plant scale-up, research, development and demonstration (RD&D), investment, and learning experience. Otherwise, they continue to be dependent on government interventions from agricultural subsidies, and excise tax exemptions.

Greenhouse gas mitigation

Bioenergy is usually assumed to be CO_2 neutral. For example, the latest IPCC Guidance for National GHG Inventories (IPCC 2006) stipulated that CO_2 emissions from biomass are not counted within energy-sector CO_2 emissions. If biomass is not renewable, i.e., leads to a depletion of carbon stocks in forests, agricultural or other lands over time, this will be accounted as an emission from the Agriculture, Forestry, and Other Land Use (AFOLU) sector of the national inventory. At the project level, the CDM Executive Board has provided a definition of renewable biomass for the purpose of CDM projects (UNFCCC 2006). If biomass is not renewable according to this definition, the possible negative impact on carbon stocks in land use shall be subtracted from net GHG emission reductions. Biomass use is considered non-renewable especially where it leads to deforestation, forest degradation, or other vegetation losses. Carbon stocks in ecosystems tend to be increasing in most industrialized countries so that bioenergy use can be considered renewable, whereas there is still large-scale deforestation and forest degradation in tropical regions, in some cases directly linked to the use of fuelwood and charcoal. On the other hand, where bioenergy is linked to carbon-stock enhancing activities such as reforestation or revegetation, it can constitute an energy system with net removals of GHGs.

Fossil energy is usually consumed in producing bioenergy carriers, but usually this energy input is a small fraction of the total energy output. Net carbon emissions from generation of a unit of heat and/or electricity using renewable biomass are 10 to 20 times lower than emissions from fossil fuel-based generation (Matthews & Robertson, 2005). For some biofuels, the whole process from growing the feedstock to combustion can be close to carbon neutral, but for corn to ethanol in coal fired process plants in the US the savings, as compared to conventional gasoline, may be only around 13%. The crucial factors are the amount of fossil fuel used to produce and transport the feedstock (including fertiliser) and for processing it. Bioethanol from sugar cane typically has a fossil fuel input / energy output ratio of 1:8; biodiesel 1:3 and for corn bioethanol below 1:2.

While energy input / output ratios and comparisons of GHG emissions per unit of energy or fuel are often quoted, they should be used with care. Biomass can be produced and converted independently of external fossil energy by using its own product. However, this means that less of the product can be sold to markets to displace fossil fuels. Also energy ratios or emissions per unit of energy do not indicate any net GHG mitigation since this depends on the fossil fuel reference system. In some cases transporting biomass over longer distances may yield greater GHG benefits if a more carbon intensive and less efficient fossil fuel system can be replaced. Where land resources are limited, the GHG benefits per unit of land are the most appropriate measure, even if this means greater emissions per unit output (Schlamadinger *et al*., 2005).

Different bioenergy systems have varying degrees of effectiveness in mitigating GHG emissions per unit of final energy for the biomass system including all upstream energy inputs (*GHG*) can be compared with the emissions from the fossil reference system (also including all upstream energy inputs) that would have resulted in the absence of bioenergy use (*GHGref*). The *GHG/GHGref* relative comparison (Figure4.3.11) will be increased by a) reducing energy inputs into the biomass system and using low-carbon fuels, b) increasing the efficiency of biomass conversion, or c) replacing inefficient fossil systems which use carbon intensive fuels. The vertical axis in the figure indicates the productivity of land in terms of final energy per hectare. Low productivity means low growth rates, low final energy yield per unit of raw biomass, and thus low *GHG* and *GHGref* per hectare. The GHG balance is optimal for high productivity systems with low *GHG/GHGref* (as indicated by the arrow). The “by-product or co-product” columns represent biomass systems that use residues and hence where land resources are not limited. The *GHG/GHGref* indicates the efficient use of the biomass to produce final energy for the market. For example, *GHG/GHGref* may be lower if the biomass uses its own co-product to operate the process. However this may yield less final energy to the market, and the biomass use efficiency may thus be lower, with little to no net GHG benefit of this measure (dotted arrow). Conversely if that biomass would not have been used at all, then using it for the process is desirable.

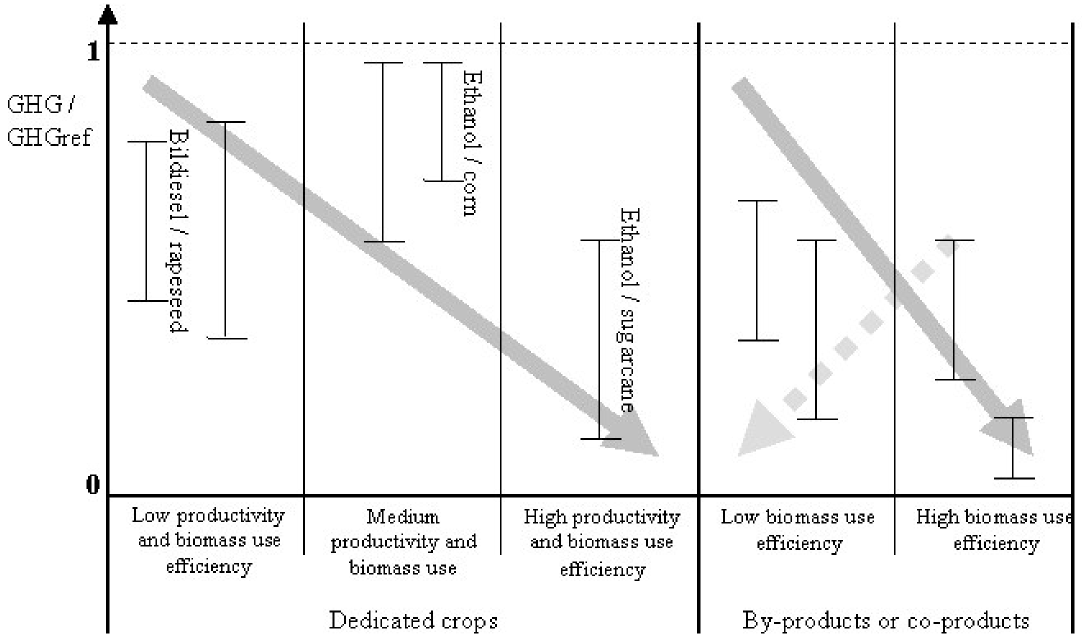


Figure 4.3.11: *GHG effectiveness of different bioenergy systems.*

Other environmental and social impacts

Bioenergy implementation depends on securing a reliable supply of sustainably produced biomass. It can create employment opportunities in rural areas while reducing dependence on imported energy sources, though high labour content can also be a cost disadvantage. Low production costs give significant potential for biomass production in Eastern Europe, the former USSR, Oceania, Latin America, East and Western Africa and South-East Asia. Increasing biomass supply in future will depend to a greater degree on the active production of energy crops from either surplus productive or marginal lands. Improved quality of degraded soils can result and if grown as riparian strips, the quality of waterways and lakes can be improved by reducing nutrient loadings. On the other hand, if done improperly increased biomass production can lead to loss of terrestrial carbon and degradation of biological diversity.

There can be synergies between the greater uptake of modern biomass and sustainable development (section 4.7.4), at least until increased competition for industrial raw materials or fertile land results. For example, due to the EU emissions trading system and other biomass related policies, raw materials for industry are already being directed to energy uses in Scandinavia and other European countries. There are also possible conflicts with food production and biodiversity. On the other hand, biomass provides potential for engaging the agricultural community, especially in many industrialised countries, by shifting support from food, feed and production, especially where there is a prospect of surpluses (Chapter 8). Some of these aspects can vary from region to region, and are very different between developing and industrialised countries.

Barriers to bioenergy include its occasional perception as “dirty and using low technology”; concerns about large-scale monocultures negatively impacting biodiversity; the challenge to secure long term biomass fuel supplies; its relatively low energy density compared with fossil fuels; high demand for water and nutrients by some biomass crops—although possibly no higher than for traditional food crops; difficulties in achieving economies of scale for conversion plants using widespread feedstocks, negotiating financing and contractual arrangements, and obtaining resource and planning consents.

Future bioenergy potential

One estimate of the available global economic potential from biomass residues and wastes (which would have no-regrets use and avoid disposal costs), was around 100 EJ/yr (WEC, 2004c). To increase this biomass potential would require changes to agricultural and forestry production and active energy crop growth (Chapters 8 and 9). Hall & Rao (1999) estimated 2900 EJ of potential biomass was available globally of which 270 EJ could be utilized for energy on a sustainable basis at competitive prices. Hoogwijk (2004) analysed potential biomass from 17 different scenarios and showed the "research focus" supply side potential by 2025 to 2050 was between 67 EJ and 450 EJ and the "demand driven" potential between 28EJ to 220 EJ. The global technical potential of bioenergy is therefore large.

Land use for commercial energy crops is often heavily subsidized and may involve non-sustainable agricultural practices (OECD, 2004b). Up to about 130–270 EJ/yr of energy crops may be produced in future at costs below USD2006 2/GJ equivalent to relatively high cost of coal (Hoogwijk, 2004). Crops used for biofuels have potential to rise to over 50 EJ in 2050 based on economic analysis (Fischer and Schrattenholzer, 2001). Such low costs presume significant productivity improvements over time, and that land and water are readily available (Hoffman, 2005). Cost reductions may occur due to technical learning and capital/labor substitution. For example capital investment costs for a high pressure, biomass, direct gasification combined-cycle plant up to 50 MW are estimated to fall from over US$2,000/kW to around US$1,100/kW by 2030, with operating costs, including delivered fuel supply, also declining to give generation costs around USD0.10 to 0.12 /kWh (Martinot *et al*., 2005). Commercial bioenergy options using small-scale steam turbines, Stirling engines, organic Rankin cycle systems etc. can generate power for between USD0.07 to 0.12 /kWh, but with the opportunity to further reduce the capital costs by mass production and experience (Martinot *et al*., 2005). Overall bioenergy is envisaged to remain a significant contributor to global renewable energy in the short to medium term (Faaij, 2005; IEA, 2006b).

4.3.3.4 Geothermal

Geothermal resources have long been used for direct heat or, where ground water temperatures above 100^{o}C exist, for conversion to electricity using binary power plants (with low boiling point transfer fluids and heat exchangers), organic Rankin cycle systems, or steam turbines (when natural temperatures are above 250^{o}C). High enthalpy fields, located in geodynamically active regions, allow for direct electricity production from natural steam by drilling at shallow depths less than 2 km. Low enthalpy fields, located in sedimentary basins of geologically stable platforms, allow for direct heat extraction for district urban heating, industrial processing, domestic heating, leisure and balneotherapy applications. The heat can also be obtained from "hot dry rock" systems where water is injected into artifically fractured rocks at depth and then heat extracted as steam. Pilot schemes exist but tend not to be cost effective at this stage.

Fields of natural steam are rare. Most are a mixture of steam and hot water requiring single or double flash systems to separate out the hot water which can then be used in binary plants or for direct use of the heat (Martinot *et al*., 2005). Binary systems have become state-of-the-art technologies but often at added cost. Re-injection of the fluids maintains a constant pressure in the reservoir and hence increases the life of the field as well as overcoming any concerns at environmental impacts. Growing sustainability concerns relate to land subsidence, the long-term outlook for a project where heat is extracted faster than it can be naturally replenished (Bromley and Currie, 2003), chemical pollution of waterways (e.g., with arsenic), and CO_2 emissions. These have resulted in some geothermal resource consents being declined but can be partly overcome by re-injection techniques.

The installed geothermal generation capacity of over 8.9 GW_e in 24 countries produced 56.8 TWh (0.3%) of global electricity in 2004 and is growing at around 20%/yr (Bertani, 2005). Plant capacity factors range from 40–95%, thus making some suitable for base load (WEC, 2004b). Over 10 GW of proven resources are not yet utilized from which over 1,000 TWh/yr of electricity could be produced (Martinot *et al*., 2005).

Enhanced geothermal systems have a long-term potential of 88 GW in the USA with 36 GW projected to be developed by 2050 if R&D goals are met (DOE, 2005). The thermal resource is usually obtained from wells drilled to depths of 1–4 km but deeper drilling up to 8 km may be cost effective in future to reach the molten rock magma. New drilling technology will help to develop widely abundant hot dry rock and wet rock resources if deeper wells can reach rock temperatures high enough for viable heat extraction.

Several energy conversion technologies are becoming available to enhance the use of geothermal heat including combined cycle for steam resources, trilateral cycles for binary total flow resources, remote detection of hot zones during exploration, absorption/regeneration cycles (e.g., heat pumps) and improved power generation technologies (WEC, 2004c). It is expected that improvements in characterizing underground reservoirs, low-cost drilling techniques, more efficient conversion systems, and utilization of deeper reservoirs, will improve the uptake of geothermal resources as will the market value for extractable co-products such as silica, zinc, manganese, lithium, etc. (IEA, 2006b).

Heat extraction costs vary between high and low enthalpy geothermal fields and the use of shallow or enhanced and deep sources. Capital costs have declined by around 50% from the USD3000-5000/kW in the 1980s for all plant types (with binary cycle plants being the more costly). Power generation costs from large, high enthalpy geothermal fields running at base load are competitive varying between USD 0.03–0.08/kWh depending on size of field, resource consent conditions and quality of resource (high quality being >250^{o}C, low being <150^{o}C) (IEA, 2006b). Operating costs will increase if related CO_2 emissions released from the well are included in future as either a carbon charge or for carbon capture and storage.

4.3.3.5 Solar thermal electric

Concentrated solar power (CSP) plants are categorized according to the way the solar flux is concentrated by parabolic trough-shaped mirror reflectors (30-100 suns concentration), central tower receivers requiring numerous heliostats (500-1000 suns), and parabolic dish-shaped reflectors (1000-10,000 suns). The receivers transfer the solar heat to a working fluid, which in turn transfers it to a thermal power conversion system based on Rankine, Brayton, combined or Stirling cycles. To give a secure and reliable supply, solar intermittency problems can be overcome by using supplementary energy from natural gas or thermal bioenergy systems at night and during cloudy periods (IEA, 2006b), as well as by the storage of surplus solar heat. Capacity factors around 50% could rise to 70% by 2020 (DOE, 2005).

Solar trough technology is the most mature CSP technology with a maximum peak efficiency of 21% in terms of conversion of direct solar radiation into grid electricity. Tower technology has been successfully demonstrated by two 10-MW systems in the USA with commercial development giving long term levelized energy costs similar to trough technology. Advanced technologies include troughs with direct steam generation, Fresnel collectors which can reduce costs by 20%, energy storage including molten salt, integrated combined cycle systems and advanced Stirling dishes. The latter are arousing renewed interest and could provide opportunities for further cost reductions (WEC, 2004d; IEA 2004b).

Solar thermal power generating plants are best sited in areas receiving high direct insolation of 2000-2500kWh m^2, usually at lower latitudes (Figure 4.3.12). In these areas, 1 km^2 of land is enough to generate around 125 GWh from a 50 MW plant at 10% conversion of solar energy to electricity (Philibert, 2004). Thus about 1% of the world's desert areas could theoretically be sufficient to meet total global electricity demand as forecast out to 2030 (Philibert, 2005; IEA, 2006b).

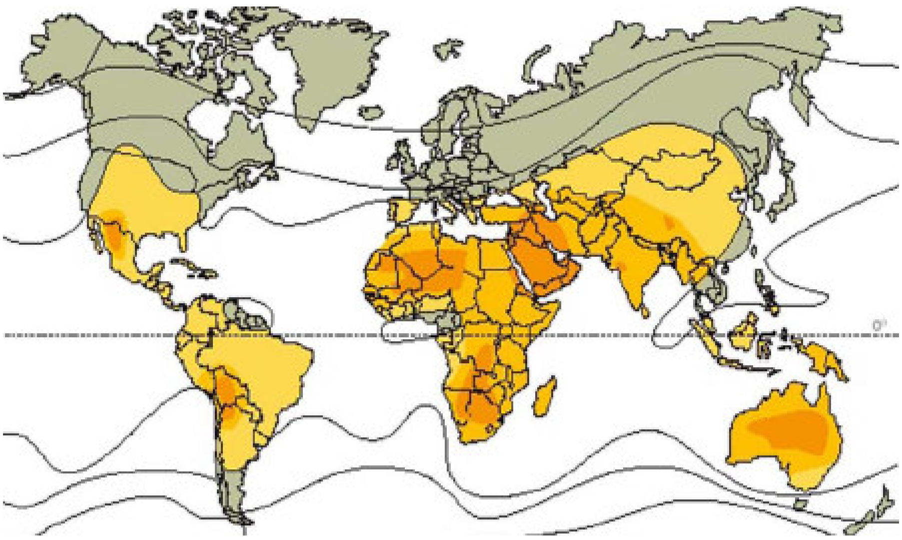


***Figure 4.3.12**: Regions of the world with high direct insolation (WEC, 2004c).*

Installed capacity in California was 354 MW_e from nine plants ranging from 14 to 80 MW_e with over 2 million m^2 of parabolic troughs. Connected to the Southern California grid during 1984–1991 they generate 0.001 EJ/yr at US$0.10–0.126 /kWh (WEC, 2004d). New projects totaling over 1400 MW are being constructed or planned in 11 countries including Spain (500MW supported by a new feed-in tariff) (ESTIA, 2004; Martinot *et al*., 2005) and Israel for the first of several 100-MW plants (Sagie, 2005). The African Development Bank has financed a 50-MW combined cycle plant in Morocco which will generate 55GWh /yr and two new Stirling dish projects totaling 800MW_e planned for the Mojave Desert of the US (ISES, 2005) are estimated to generate for below USD0.09/kWh (Stirling, 2005). Installed capacity of 21.5 GW_e by 2020 would produce 54.6 TWh with a further possible increase leading towards 5% coverage of world electricity demand by 2040 (ESTIA, 2003). Technical potential estimates for global CSP vary from 630 GW_e installed by 2040

(Aringhoff *et al.,* 2003) to 4700 GW_e by 2030 (IEA, 2003h). Generating costs for trough and tower plants could fall over time to compete with mid-load power at around USD0.35-062 /kWh by 2020 (Sargent and Lundy, 2003). Concentrated solar energy could also be used to produce hydrogen fuels or metals.

4.3.3.6 Solar heating and cooling

Buildings can be designed to use efficient solar collection for passive space heating and cooling (Chapter 6), active water and space heating using circulating fluid and glazed collectors, and active cooling using absorption chillers or desiccant regeneration (U.S. Climate Change Technology Program, 2003). In a typical mid-latitude temperate region, 30% of building energy (and up to 50% in higher latitudes) is used for space and water heating with cooking and appliances making up the balance (WEC, 2004d).

Solar heating and cooling of buildings can reduce conventional fuel consumption and reduce peak electricity loads. Particularly in urban situations, there is a risk of lower performance due to shading of windows or solar collectors by new building construction or nearby trees. Local "shading" regulations have a role to play in preventing such conflicts by identifying a protected "solar envelope" (Duncan, 2005). A wide range of design measures, technologies, and opportunities are covered by the IEA Solar Heating and Cooling implementing agreement (www.iea-shc.org).

Active systems of capturing solar energy for direct heat are used mainly in small scale, low temperature, domestic hot water installations; building space heating; swimming pools; crop drying facilities; industrial processes; desalination plants and solar-assisted district heating. The vast majority of existing installations and energy production, however, come from domestic water heating.

More than 130 million m^2 of solar thermal collector area were in operation around the world at the end of 2003 to provide around 0.5 EJ of heat from around 91 GW_{th} installed capacity (Weiss *et al.,* 2005). Active solar hot water alone was 115 million m^2 (77 GW_{th}) in 2004 (Martinot *et al*, 2005). The main technologies for heating water include both unglazed and glazed systems. Unglazed collectors are mainly used to heat swimming pools in the USA and Europe, and represented about 28 million m^2 in 2003. China is the world's largest market for glazed domestic solar hot water, with 80% of annual global installations and existing capacity of 79 million m^2 (55 GW_{th}) by the end of 2005. Most new installations in China are now evacuated-tube in contrast with Europe (the second-largest market), where most collectors are still flat-plate (Zhang *et al.,* 2005). Domestic hot water systems are also expanding rapidly in other developing countries beyond China. For example over one-third of homes in Barbados are equipped with these systems and in India solar hot water is considered among the country's most commercialized renewable energy technologies. Brazil and Turkey are also active markets.

Estimating annual solar thermal energy production based on the collector areas in operation depends on the solar radiation available and the solar thermal technology used. For example, estimated annual yields for glazed flat-plate collectors ranged between 400 kWh/m^2 in Germany and 1000 kWh/m^2 in Israel. In Austria, annual solar yields were estimated to be 300 kWh/m^2 for unglazed, 350 kWh/m^2 for flat-plate, and 550 kWh/m^2 for evacuated tube collectors. The estimated annual global solar thermal collector yield of domestic hot water systems is around 80 TWh (0.3 EJ) (Martinot *et al*., 2005; IEA, 2004d).

Solar thermal costs for a family unit differ with location and government support ranging from around USD700 in Greece for a thermo-siphon system with a 2.4 m^2 collector and 150 l tank, to USD4500 in Germany for a pumped system but double the size at 4–6 m^2 and 300 l tank. The cheapest systems are manufactured in China, typically USD200-300 per system. Combining solar thermal and photovoltaic power generation (PV) systems into one unit has good potential with an improved efficiency of the combined system by cooling the PV cells (Zondag, 2005).

A number of commercial solar cooling technologies exist with 19,000m^2 in Europe having a cooling power of 4.8MW_{th}. In spite of high potential energy savings versus conventional electric vapour-pressure air conditioning systems, the costs remain much higher (Philibert, 2005).

4.3.3.7 Solar photovoltaic (PV)

The proportion of solar radiation that reaches the earth's surface is more than 10,000 times the current annual global energy consumption. The average annual surface insolation varies with latitude ranging between 1000 kWh/m^2 in temperate regions and 2500 kWh/m^2 in dry desert areas. Electricity generated directly by utilizing solar photons to create free electrons in a PV cell is estimated to have a technical potential of at least 1600 EJ per year (Renewables, 2004; WEC, 2004d).

Estimates of current global installed capacity vary (3100 MW, Maycock, 2003; 2400 MW, Greenpeace, 2004; and >4000MW generating more than 21 TWh, Martinot *et al.*, 2005). Half of this total was grid-connected, primarily in Germany, Japan, and the U.S. state of California and is growing at annual rates of 50-60% in contrast to more modest annual growth rates of 15-20% for off-grid PV. Annual PV module production grew from 740 MW in 2003 to 1150 MW in 2004, and to 1700 MW in 2005, as new manufacturing plant capacity was built to meet growing demand for PV (Maycock, 2003). Japan is the world market leader, producing over half the present annual production (IEA, 2003f).

Expansion is also taking place at around 30% per year in developing countries where around 20% of new PV capacity was installed in 2004, mainly in rural areas where grid electricity is either not available or unreliable (WEC, 2004c). Decentralised generation by solar PV is already economically feasible for villages with long distances to a distribution grid and providing basic lighting and radio is socially desirable.

The cost of solar PV power is continually decreasing (see Figure 4.3.4) due to solar cell efficiency improvements as a result of R&D investment, mass production of solar panels and learning through project experience giving a 20% cost reduction for every doubling of accumulated capacity. Costs in new buildings can be reduced because PV systems are well designed to be an integral part of the roof, the walls or even windows.

Most commercially available solar PV modules are based on crystalline silicon cells, with monocrystalline, at up to 18 % efficiency, having 33.2% of the market share. Polycrystalline cells at up to 15% efficiency are cheaper /W_p and have 56.3% market share. Modules cost about USD3 /W_p from which electricity can be generated for around USD 0.20-30 /kWh in high sunshine regions (U.S. Climate Change Technology Program, 2005). Assuming continued annual production growth of 27% /yr, cost reductions are expected to fall to USD2 /W_p by 2010 and to USD1/W_p by 2015

(UNDP, 2000). If achieved the installed PV capacity by 2020 will be 205 GW generating 282 TWh/yr and amounting to about 1% of global electricity demand (EPRI, 2003). More than half of new capacity will be installed in non-OECD countries and by 2040 over 20% of global electricity demand could be met by PV (Jäger-Waldau, 2003).

Other cell types using thinner and cheaper materials may have greater prospects for cost reduction including thin film silicon cells (8.8% of market share in 2003), thin film copper indium diselenid cells (CIS, 0.7% of market), photochemical cells and polymer cells. Commercial thin film cells have efficiencies up to 8%, but 10-12% seems to be within reach during the next years. It is uncertain whether new technologies will supercede silicon cells. Experimental cells have reached laboratory efficiencies of up to 37% for super thin flexible cells but their commercial cost is very high. Work on reducing the cost of manufacturing, using low-cost polymer materials, and developing new materials such as quantum dots and nano-structures, will allow the solar resource to be more fully exploited.

4.3.3.8 Ocean energy

The potential marine energy resource is huge (Renewables, 2004; Table 4.3.1). It involves capturing the energy in wind-driven waves, the gravitational tidal range, thermal gradients between warm surface water in tropical and sub-tropical latitudes and the colder water at depths of 1000 m or greater, salinity gradients, and marine currents induced by waves, tides and gradients. All the related technologies (with the exception of tidal range barriers which are similar to hydropower systems) are at an early stage of development with several prototypes deployed. The British government funded European Marine Test Centre in the Orkney Islands for example has several tidal current devices under evaluation. Commercial projects are few but include three tidal barrages amounting to 260 MW (no more are planned) and two commercial wave power projects with a total of 750 kW peak power. To combat the harsh environment and withstand extreme weather conditions, installed costs of a marine energy technology are usually high. Environmental impacts vary with location and type of device but can be a major barrier to development. The marine energy industry is now in a similar stage of development that the wind industry was in the 1980s (Carbon Trust, 2005). Oceans are used by a range of stakeholders so that the siting of devices will involve considerable consultation.

The best *wave energy* climates exist at the southern tip of South America, Western Australia and to the west of the British Isles (Figure 4.3.13) where deep water power densities of 60-70 kW/m exist but falling to about 20 kW/m at the foreshore (Heath, 2004). Around 2% of the world’s 800,000km of coastline exceeds 30kW/m that has a technical potential of around 0.5 TW assuming wave energy devices have 40% efficiency. The economic potential is estimated to be half of this (WEC, 2004d). Generating costs are difficult to estimate since no commercial plants exist but are claimed to be around 8-11USc/kWh on good sites (IEA, 2006b).

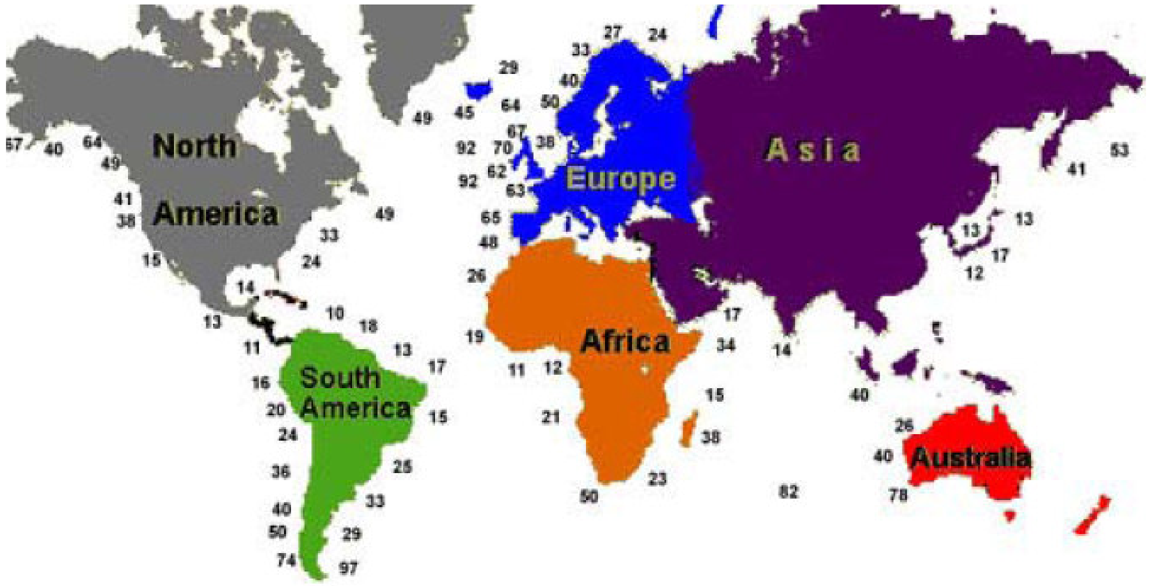


Figure 4.3.13: *Annual average wave power flux (kW/m) across the oceans (Wavegen, 2004).*

Marine currents offer an immense technical potential. For example preliminary investigations of the Agulhas current off the coast of South Africa, the swiftest sea current in the world, showed that on the 100m deep seabed, a 1km stretch of permanent turbines would produce 100 MW (Nel, 2003). Demonstrations of marine current prototype devices have been undertaken off the west coast of southern England. Extracting electrical energy from marine currents could yield in excess of 10 TWh/yr (0.4 EJ/yr) if major estuaries with large tidal fluctuations like the Bay of Fundy or the Solway Firth could be tapped, but the cost estimates range from 45–135 c/kWh (IEA, 2006b) and the environmental effects on tidal mud flats, wading birds, invertebrates etc would need careful analysis. In order for these new technologies to enter the market sustained government and public support will be needed.

Ocean thermal and *saline gradient* energy conversion systems remain mainly in the research stage and it is still too early to estimate their technical potential. Initial applications have been for building air conditioning (www.makai.com/p-pipelines/) and in future could benefit tropical island nations where power is presently provided by expensive diesel generators and for desalination in open and hybrid cycle plants using surface condensors.

4.3.4 Energy carriers

Energy carriers include electricity and heat as well as solid, liquid, and gaseous fuels. They occupy intermediate steps in the energy-supply chain between primary sources and end-use applications. An energy carrier is thus a transmitter of energy. For reasons of both convenience and economies, energy carriers have shown a continual shift from solids to liquids and more recently from liquids to gases (WEC, 2004b), which is expected to continue (Figure 4.3.12). At present, about one-third of final energy carriers reach consumers in solid form (as coal and biomass which are the primary cause of many local, regional, and indoor air-pollution problems associated with traditional energy uses); one third is in liquid form, (consisting primarily of oil products used in transportation); and one-third is through distribution grids in the form of electricity and gas (mostly natural gas methane).

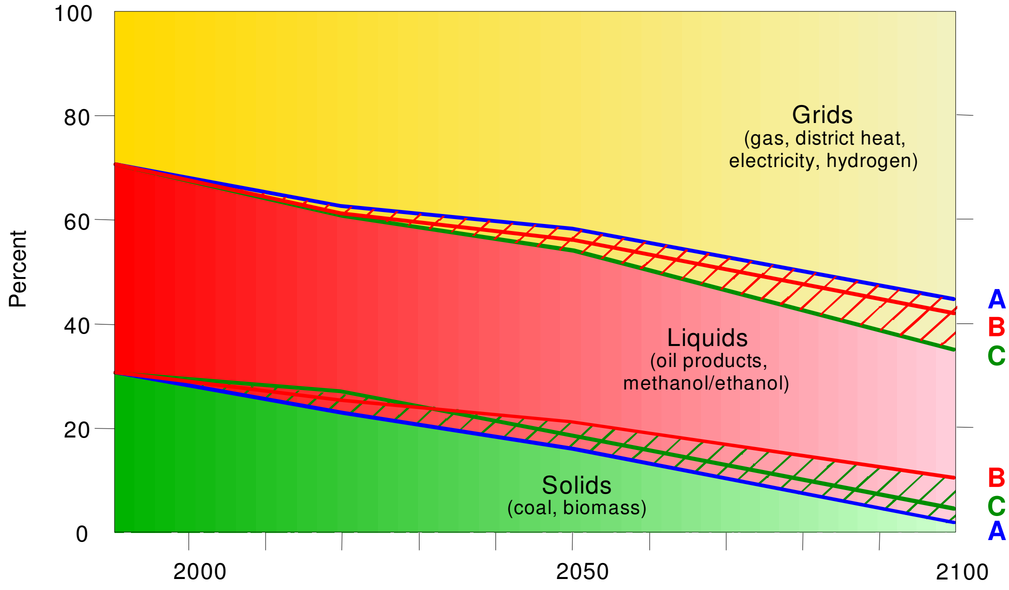


Figure 4.3.14*: Final energy across three scenarios (A, B, C) showing a gradual shift this century towards grid-oriented energy carriers and away from the direct use of solids, which are instead converted to liquid fuels, electricity, and energy gases (WEC, 2004 based on IIASA, 2002).*

The share of grid-oriented energy carriers could increase to about one half of all consumer energy by 2100. New energy carriers such as hydrogen (section 4.3.1.4) will only begin to make an impact around mid-century whereas the development of smaller scale decentralized energy systems and micro-grids (section 4.3.7.1) could occur much sooner (Datta *et al*., 2002; IEA, 2004d*)*. Technology issues surrounding energy carriers involve the conversion of primary to secondary energy, transporting the secondary energy, in some cases storing it prior to use, and converting it to useful end-use applications (Figure 4.3.15).

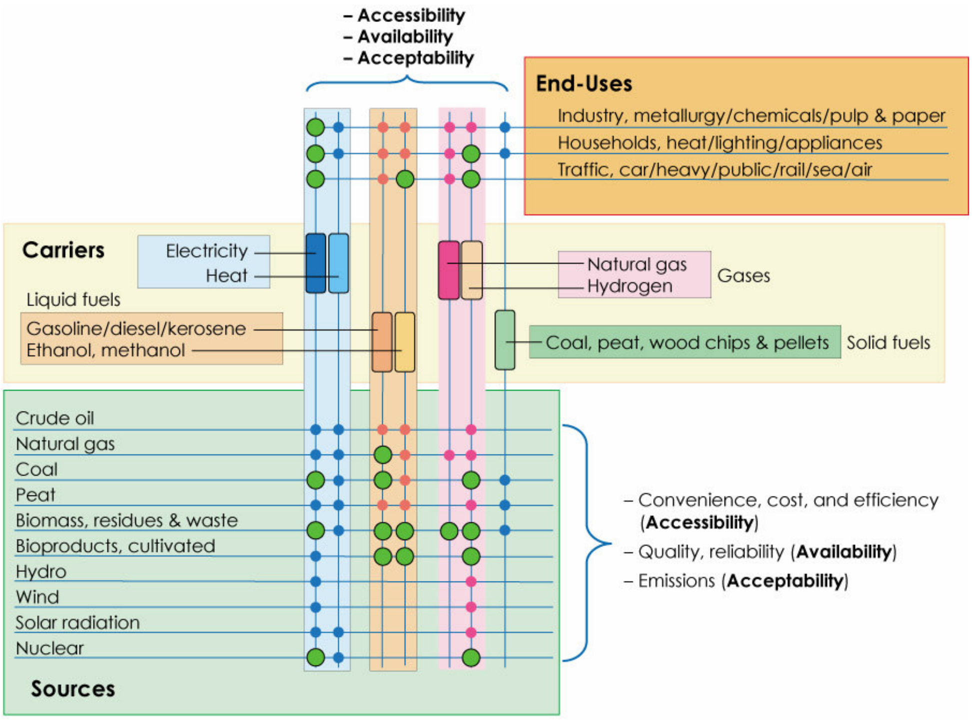


Figure 4.3.15: *Dynamic interplay between energy sources, energy carriers and energy end-uses. Note: Energy sources are at the lower left; carriers are vertical in the middle; and end-uses at the upper right. Important intersections are noted with circles, small blue for transformations to solid energy carriers and small pink to liquid or gaseous carriers. Large green circles are critical transformations for future energy systems (WEC, 2004a).*

Where a conversion process transforms primary energy near the source of production (e.g. passive solar heating) a carrier is not involved. In other cases the primary energy source also becomes the carrier (e.g., natural gas). The carrier can also store energy either in place (e.g. coal, woody biomass) or as transportable energy (e.g., oil, liquefied natural gas), or both. Over long distances, the primary transportation technologies for gaseous and liquid materials are pipelines, shipping tankers and road tankers; for solids they are railways, boats and trucks; and for electricity by wire conductors.

Each energy conversion step in the supply chain invokes additional costs for energy losses, carbon emissions and capital investment in equipment. These directly affect the ability of an energy path to compete in the marketplace. The final benefit/cost calculus ultimately determines market penetration of an energy carrier and hence the associated energy source and end-use technologies. Thus, utilization of a cost-effective and efficient energy carrier will help promote the source and the end-use technology.

Hydrocarbon substances produced by fossil fuels and biomass are utilized widely as energy carriers. They divide into solid, slurry, liquid, and gas based on an energy form (Table 4.3.3). Coal, oil, natural gas, and biomass can be used to produce a variety of synthetic liquids and gases for transport fuels, industrial processes and in domestic heating and cooking including petroleum products refined from crude oil. Liquid hydrocarbons have relatively high energy densities that are superior in transport and storage properties.

Table 4.3.3: Energy carriers of hydrocarbon substances.

Primary energy	Energy carriers of secondary energy			
	Solid	**Slurry**	**Liquid**	**Gas**
Coal	Pulverized coal. Coke.	Coal/water mix. Coal/oil mix.	Coal to liquid (CTL). Synthetic fuel.	Coal gas. Producer gas. Blast furnace gas. Water gas. Gasified fuel. Hydrogen.
Oil	?	?	Oil refinery products. LPG.	Oil gas. Synthetic gas. Hydrogen.
Natural gas	?	?	LNG. Gas to liquid (GTL). GTL alcohols. Di-methyl ethers.	Methane. Hydrogen.
Biomass	Wood residues. Energy crops. Refuse derived fuel.	?	Methanol. Ethanol. Biodiesel esters. Di-methyl ethers.	Methane. Producer gas. Hydrogen.

4.3.4.1 Electricity

Electricity is the highest value energy carrier today because it is clean at the point of use, and can be used in so many end-use applications for relatively little cost. It is effective as a source of motive power (motors), for lighting, heating and cooling, and as the prerequisite for electronics and computer systems. Generating electricity involves converting a primary energy source (EPRI, 2003). Although global energy intensity (E/GDP) continues to decrease, the percentage of primary energy used to generate electricity has steadily increased as exemplified by the US (Figure 4.3.16) such that the ratio of electricity produced to GDP has remained constant. It can be assumed that global electricity production will probably keep pace with future GDP growth if the world economy continues to grow and develop at expected rates.

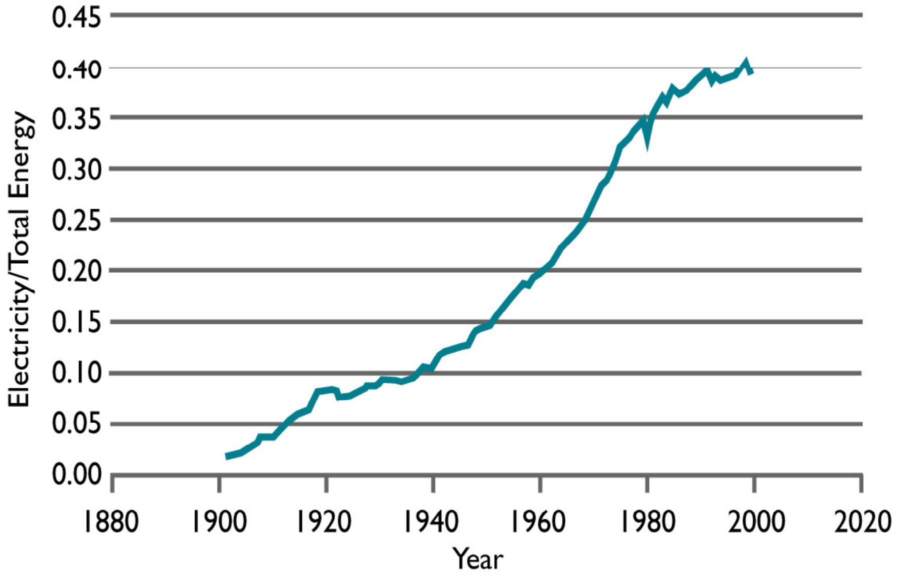


Figure 4.3.16*: Ratio of electricity to total primary energy in the U.S. since 1900 (EPRI, 2003).*

Life cycle GHG emission analyses (WEC 2004a; Vattenfall, 2005; Dones *et al.,* 2005; Van de Vate, 2002; Spadaro *et al*., 2000; Uchiyama and Yamamoto, 1995, Hondo, 2005) shows the high CO_2 emissions from fossil fuel plants (Figure 4.3.17). Substitution by nuclear or renewable energy decreases carbon emissions per kWh by the difference between the full-energy-chain emission coefficients and allowing for varying plant capacity factors (WEC 2004a; Sims *et al*., 2003a). Direct emissions from combustion of fossil fuel in a thermal power plant are 10-20 times higher than the indirect emissions associated with the total energy requirements for plant construction and operation during the plant's life. The average thermal efficiency for electricity generation plants has improved from 30% in 1990 to 36% in 2002 as estimated from IEA energy balances, thereby reducing GHG emissions.

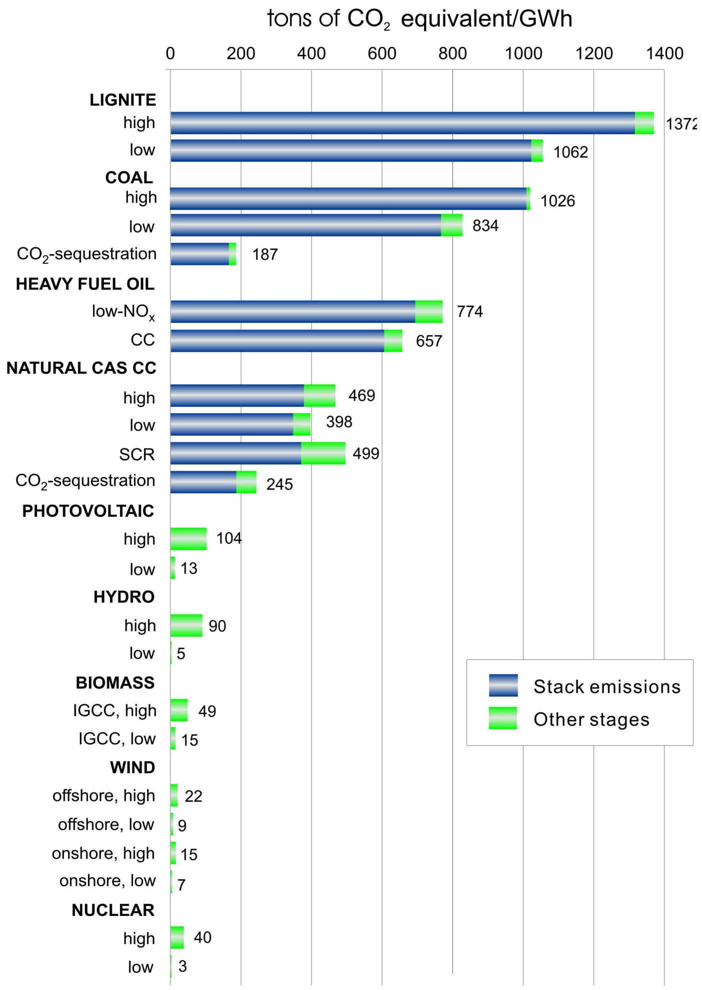


***Figure 4.3.17**: GHG emissions for alternative electricity generation systems (WEC, 2004b). Note: 1 tCO_2 eq/GWh = 0.27 tC eq/GWh.*

Traditional electricity conversion technologies such as coal-fired, steam power plants are expected to be displaced over time with more advanced technologies such as combined cycle natural gas technology (CCGT) or advanced coal with carbon capture and storage (CCS), nuclear, fuel cells, wind turbines, concentrated solar thermal, photovoltaics, and bioenergy. All of these would reduce the production of greenhouse gases and increase the overall efficiency of energy use. Previous IPCC (2001) and WEC (2001) scenarios suggested that nuclear and CCGT with CCS may become the dominant technologies early this century (section 4.4). Solar PV and hydrogen fuel cells may eventually become commercially viable and even dominate, but because of their current costs, complexity, and state of development, they may only do so later this century, even though they will probably begin to penetrate the market earlier.

4.3.4.2 Heat

Heat, whether from fossil fuels or renewable energy, is a critical energy source for all economies being used in industrial processes (for food processing, petroleum refining, timber drying, pulp production, etc.) (Chapter 7), as well as in commercial and residential buildings for space heating, hot water and cooking (Chapter 6). Many industries co-generate both heat and electricity as an integral part of their production process (section 4.3.6) in most cases being used on-site but at times sold for other uses outside the industry such as district heating schemes. Efficient use of district heat could play an important role in the development of transition and developing economies (IEA, 2004h). Heat pumps can be used for simple air-to-air space heating, domestic air to water heating and for utilizing waste heat in domestic, commercial and industrial applications (Chapter 6).

Heating and cooling from renewable carbon-free energy can be provided by biomass, geothermal and either passive or active solar thermal (IEA, 2006e). Biomass derived energy used for heat already provides about 10% of world primary energy supplies for cooking and heating (section 4.3.4.3; Johansson, 2004). The preparation of the fuel for combustion in a boiler or appliance is often the critical step in assuring that it can be used effectively and efficiently due to the wide variation in the characteristics of the readily available fuels. In some instances, the best use of biomass will be co-firing with coal at blends up to 5 to 10% biomass or with natural gas as a co-fuel.

4.3.4.3 Liquid and gaseous fuels

Crude oil is the most energy-efficient fuel to transport over long distances from source to refinery and then to product demand points. When petroleum, diesel oil, and other light and medium distillates are extracted at the refinery, the residues are used to produce bitumen and heavy fuel oil used as an energy source for industrial processes, oil-fired power plants, and shipping fuel. Oil products are particularly important for the transport sector that depends almost exclusively on carbon-based petroleum products such as gasoline, diesel fuel, and jet fuel.

Gaseous fuels already provide the majority of heating requirements in the developed world. In any future market penetration, CO_2 reduction and urban air pollution reduction will be benefits, especially if ultimately hydrogen fuel can be made and used without releasing CO_2 into the atmosphere.

Coal, natural gas, petroleum and biomass can all be used to produce a variety of synthetic liquid fuels for transport, industrial processes and, in some regions of the world, domestic heating. These include petroleum products from crude oil or coal; methanol from coal or natural gas; ethanol and fatty acid esters (biodiesel) from biomass; liquefied natural gas; and synthetic diesel fuel and di-methyl ether from coal or biomass.

4.3.4.4 Hydrogen

A hydrogen economy depends on low-cost, high-efficiency methods for producing, transporting, and storing the hydrogen. Most commercial hydrogen production today is based on steam reforming of methane, but electrolysis of water may be a viable approach in the future, depending on natural gas and electricity prices. Current costs of electrolysers are high but declining and renewable energy systems could have application. Producing hydrogen from fossil fuels on a large scale will also need integration of CCS if GHG emissions are to be avoided. A number of pathways to produce hydrogen from solar energy are also feasible (Figure 4.3.18). International cooperative programs, such as the IEA Hydrogen implementing agreement (IEA, 2005f), and more recently the International Partnership for the Hydrogen Economy (www.iphe.net)) advance RD&D on hydrogen and fuel cells across the application spectrum (IEA, 2003g; EERE, 2005).

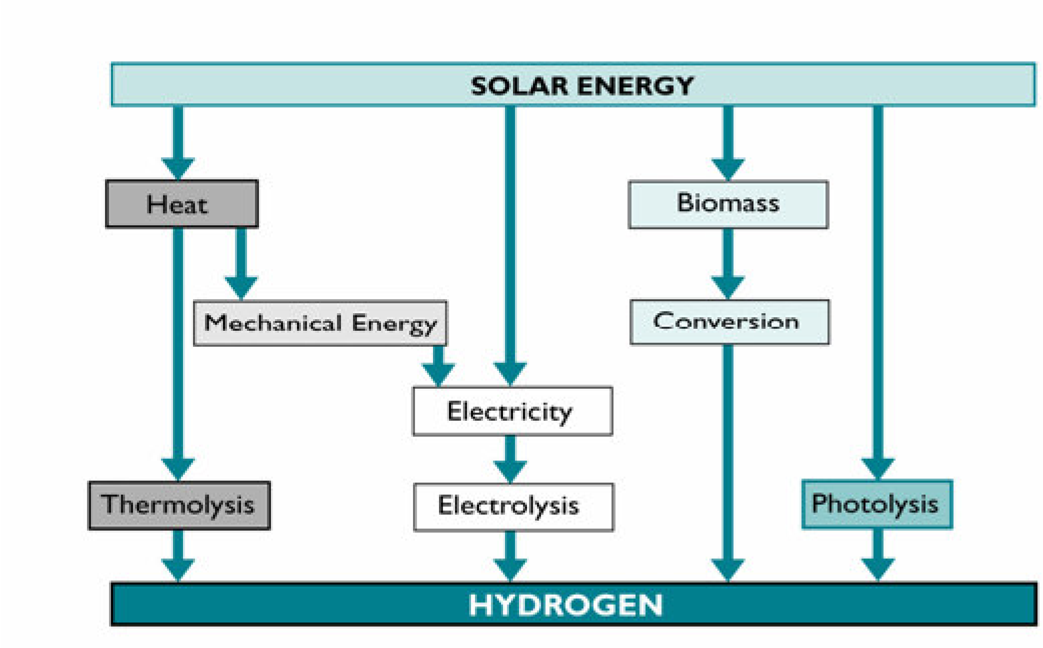


Figure 4.3.18: *Sustainable paths to hydrogen energy carriers from solar energy sources (EPRI, 2003)*

4.3.5 Combined heat and power (CHP) and heat pumps

Up to two-thirds of the primary energy used to generate electricity in traditional thermal power plants is lost in the form of heat. The switch from conventional condensing steam turbines to CHP (cogeneration) plants still produces electricity but also captures the excess heat for use by municipalities for district heating (Chapter 6), commercial buildings or industrial processes (Chapter 7). CHP is usually implemented as a distributed energy resource (Jimison, 2004), the heat energy usually coming from steam turbines and internal combustion engines. Current designs can boost overall energy conversion efficiencies to over 80% leading to cost savings (Table 4.3.4) and hence significantly reduce carbon emissions per kWh generated. About 75% of district heat in Finland for example is provided from cogeneration plants with a typical overall annual efficiency of 85-90% (Helynen, 2005). In future CHP energy may also come from small-scale micro-gas-turbines, fuel cells, gasification, and Stirling engines (Whispergen, 2005).

Table 4.3.4 Characteristics of CHP (cogeneration) plants.

Technology	Fuel	Capacity MW_e	Electrical efficiency (%)	Overall efficiency (%)
Steam turbine	Any combustible	0.5-500	17-35	60-80
Gas turbine	Gaseous & liquid	0.25-50+	25-42	65-87
Combined cycle	Gaseous & liquid	3-300+	35-55	73-90
Diesel and Otto engines	Gaseous & liquid	0.003-20	25-45	65-92
Micro-turbines	Gaseous & liquid	0.05-0.5	15-30	60-85
Fuel cells	Gaseous & liquid	0.003-3+	37-50	85-90
Stirling engines	Gaseous & liquid	0.003-1.5	30-40	65-85

CHP plants can range from less than 5 kW_e to 50 MW_e and be based on a wide variety of fuels including biomass (Kirjavainen *et al*., 2004), with individual installations accepting more than one fuel. Environmental benefits are part of an economically attractive investment since between 160 - 500 gCO_2 /kWh can be avoided if the alternatives to provide electricity and heat are individual fossil fuel based plants (Figure 4.3.19). The amount of GHG emissions produced from CHP plants depends on the type of fuel being used, the efficiency of the power plant, and electricity transmission and distribution losses. A well-designed and operated CHP scheme will provide better energy efficiency than conventional plant, leading to both energy and cost savings (UNEP, 2004; EDUCOGEN, 2001).

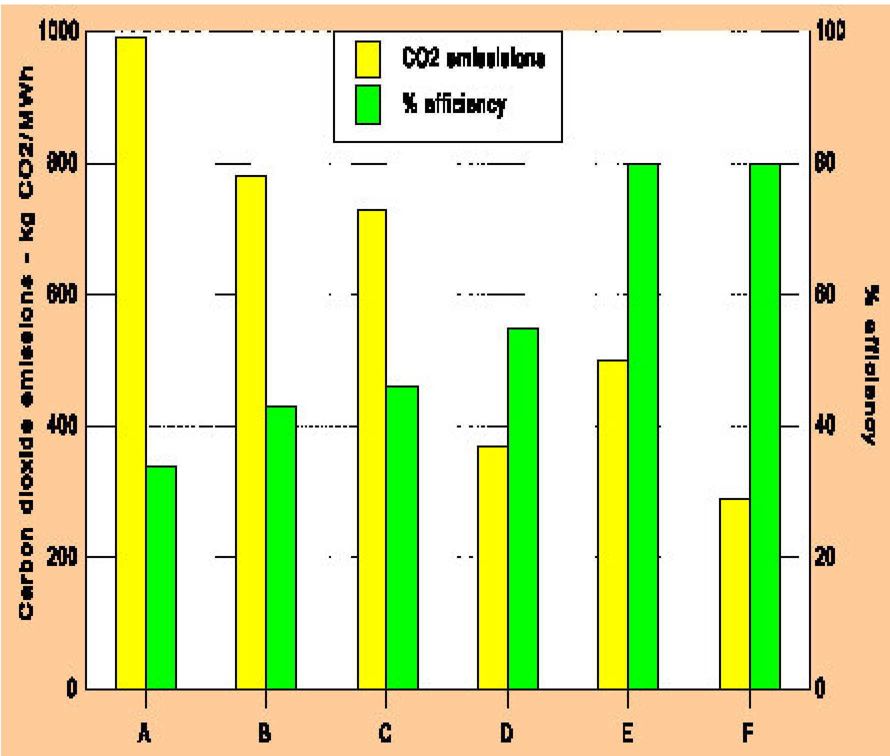


Figure 4.3.19 *Carbon emissions and conversion efficiencies of selected coal and gas-fired power generation and CHP plants*

A) Traditional coal-fired steam turbine
B) New clean coal-fired steam turbine
C) Coal gasification/ gas turbine
D) New combined cycle gas turbine (CCGT)
E) CHP coal-fired
F) CHP gas-fired

Heating of building space or water can be provided by thermo-dynamically reversed Carnot cycle heat pumps. These are more demand side technologies so covered in Chapter 6 but are also linked with sustainable energy supply. Their efficiency is evaluated by the coefficient of performance (COP) with 3 to 4 available commercially and over 6 using advanced turbo refrigeration (www.mhi.co.jp/aircon/). A combination of CCGT with advanced heat pump technology is expected to reduce carbon emissions for supplying heat more than conventional CHP plants fuelled by natural gas.

4.3.6 Carbon Capture and Storage (CCS)

The potential to separate CO_2 from anthropogenic single point sources, transport it to a storage location, and isolate it from the atmosphere to reduce emissions was covered in a Special Report (IPCC, 2005a). Capture of CO_2 can best be applied to large point sources including coal, gas or biomass-fired electric power generation or cogeneration facilities, major energy-using industries, synthetic fuel plants, natural gas fields and chemical facilities for producing hydrogen, ammonia, cement and coke that also produce CO_2. Potential storage methods include injection into underground geological formations, in the deep ocean or industrial fixation as inorganic carbonates (Figure 4.3.20). Application of CCS to biomass energy sources (such as when co-fired with coal) could result in the net removal of CO_2 from the atmosphere.

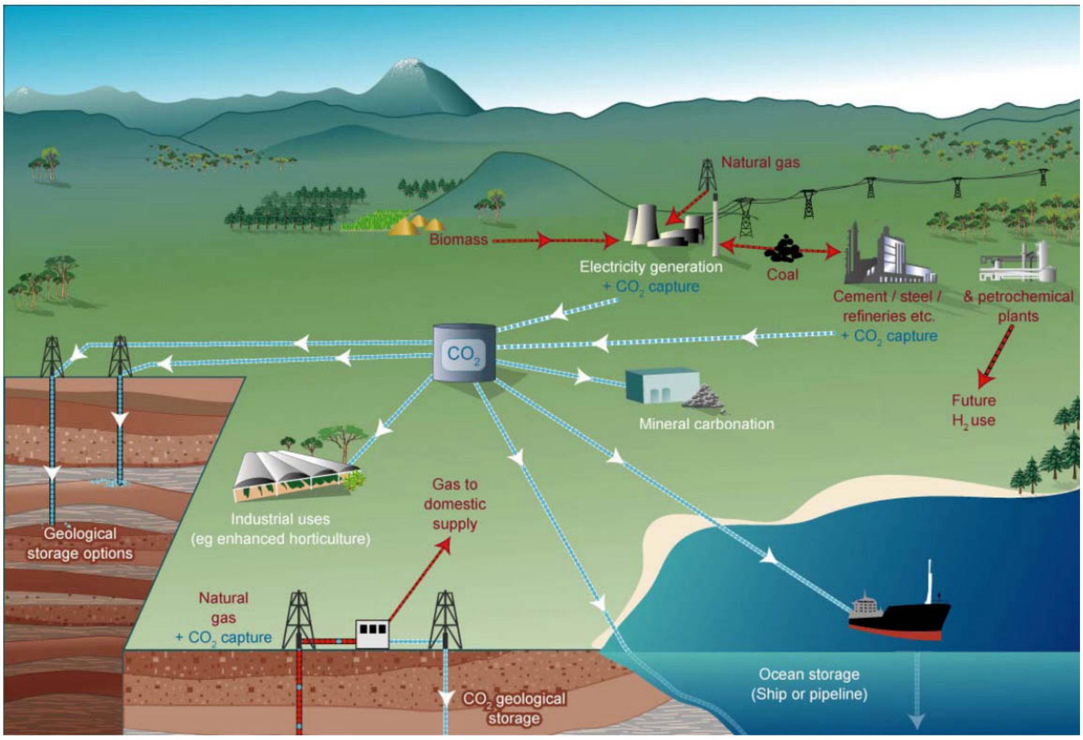


Figure 4.3.20: *CCS systems showing the carbon sources for which CCS might be relevant, and options for the transport and storage of CO_2 (IPCC, 2005a).*

Geological storage technology is the most developed storage option and the only one with commercial projects operating at this time. Research and development efforts conducted over the past decade have identified some promising options for reducing costs and energy requirements for implementing large scale CO_2 capture and storage from power plants, although costs are still USD0.01-0.05 /kWh higher than power plants that emit CO_2 into the atmosphere (IPCC, 2005a). Significant research regarding the biological impacts of ocean injection is needed before this option would be deployed (IPCC, 2005a). The dynamic nature of ocean storage also requires consideration of the retention time of CO_2 in the ocean. Industrial fixation by formation of mineral carbonates requires a large amount of energy and costs are high, thus, significant technological breakthroughs will be needed before deployment is considered, although certain applications for using waste streams have reached the demonstration phase.

To allow the continued combustion of fossil fuels, CCS is projected to be deployed as a transition technology from 2015 onwards, peaking after 2050 as existing heat and power plant stock is turned over, and then declining in the long term as a more sustainable energy system is developed (IEA, 2006a).
Currently many new power plants are being built without CO_2 capture and storage but, since they have an expected life of around 40 years, to avoid future 'carbon lock-in', it might be important that capture equipment can be retrofitted. There is therefore a move to consciously design such new plants to be 'capture-ready'[3]. 'Capture-ready' can be defined from primarily a technical, (a), or an economic, (b), perspective:

(a) *As a minimum, this requires that a feasibility study of how capture will be added later be conducted and that space and essential access requirements be included in the original plant to allow capture-related equipment to be retrofitted* (Gibbins, 2006)

(b) *A plant can be considered 'capture-ready' if, at some point in the future it can be retrofitted for carbon capture and storage and still be economical to operate* (Bohm, 2006)

As Bohm also states, *the concept of 'capture-ready' is not a specific plant design; rather it is a spectrum of investments and design decisions that a plant owner might undertake during the design and construction of the plant*. In general, however, beyond space and access, significant capital pre-investments at build time do not appear to be justified by the cost reductions that can be achieved when capture is added (Bohm, 2006; Sekar, 2005). A plant location with feasible and preferably inexpensive access to geological storage is also a prerequisite for a capture-ready plant.

Pipeline transport of CO_2 operates as a mature market technology costing USD 1-5/tCO_2 per 100km for large volumes (IEA 2006a). Several thousand kilometres of pipelines transport 40 Mt/year of CO_2 to EOR projects, primarily in West Texas, US (IPCC, 2005a). Dry CO_2 is not corrosive to pipelines even if it contains contaminants but it is when moisture is present, so any water should be removed from the CO_2 stream to prevent corrosion and thus avoid the alternative high cost of constructing pipes made from corrosion resistant material. Transport of CO_2 by ship is economically feasible under specific conditions but is currently carried out only on a small scale due to limited demand (IPCC, 2005a).

[3] The term 'storage-ready' is sometimes used interchangeably with 'capture-ready', but since it is also in widespread use to describe a CO_2 stream which is separated, compressed and ready to go to storage (or a plant that is producing such a stream) its use is best avoided.

Storage of CO_2 can be in deep saline formations, oil and gas reservoirs, and deep unminable coal seams using injection and monitoring similar to technologies developed for the oil and gas industry. Of the different types of potential storage formations, storage in coal formations is the least well understood. If injected into suitable saline formations or into oil or gas fields at depths below 800 m, various physical and geochemical trapping mechanisms prevent the CO_2 from migrating to the surface. CO_2 storage has been proven to be economically feasible under specific conditions for Enhanced Oil Recovery (EOR) and also in saline formations to avoid carbon tax charges from offshore gas fields in Norway. More projects in all kinds of reservoirs are planned. For example, with government support, Statoil intends to build an 860 MW_e gas-fired power plant and to also increase production at a methanol plant in Trondheim, Norway. The post-combustion captured CO_2 will be piped to two Shell offshore oil fields which will store 2.5 $MtCO_2$/yr and increase oil production by an estimated 85% (Hileman, 2005). BP is operating a CCS project in Algeria and is planning two in the United Kingdom and the United States.

How much storage capacity exists in oil and gas fields, in saline formations and in coal beds is subject to debate. The IPCC SRCCS (IPCC, 2005a) reported numbers of 675 to 900 $GtCO_2$ for the relatively well-characterized gas and oil fields, more than 1,000 $GtCO_2$ (possibly up to an order of magnitude higher) for saline formations, and 3-15 to 200 $GtCO_2$ for coal beds. Bradshaw *et al.* (2006) highlight the incomparability of localized storage capacity results as all have been established using different assumptions and methodologies. They also criticise any top-down estimate of storage capacity that is not based on a detailed site characterisation and a clear methodology, and emphasise the value of conservative estimates. In the literature, however, specific estimates are done nevertheless based on top-down data, and vary more than the numbers cited in the IPCC (2005a). Dooley *et al.* (2005), for instance, report a potential of >4000 $GtCO_2$ for saline formations in North America alone. Plouchart *et al.* (2006) report numbers CO_2 injection in oil and gas fields between 560 and 1170 $GtCO_2$. Agreement on a common methodology for storage capacity estimates on the country- and region-level is needed to give a more founded statement on storage capacities.

It is possible to remove the CO_2 from a power plant exhaust stream by passing it through an algae or bacteria containing solution. Removal rates of 80% CO_2 and 86% NO_x have been reported at the Massachusetts Institute of Technology Cogeneration facility. The company that developed the technology claims that the high oil containing algae used can produce directly around 130,000 l/ha of biodiesel compared to 600 l/ha from soybean crops (Greenfuels, 2004). The other 50% of biomass remaining can be fermented into ethanol or directly sequestered into soils. Researchers at Ohio State University have developed a system for photosynthetic removal of CO_2 using high temperature (60+^{o}C) cyanobacteria sourced from Yellowstone hot springs (Greenshift, 2005). From a carbon accounting perspective, the net emissions from biodiesel produced from fossil fuel based CO_2 would be reduced by half, whereas if the power plant fuel was biomass, the process would provide very low carbon liquid fuels on a continuing basis. Genetically modified soil microbial feedstocks that can convert CO_2 into methane and other products are under investigation (Patrinos, 2006).

Capture of CO_2 directly from air instead of from flue gases of an industrial installation has been proposed but was out of the scope of IPCC (2005a). The obvious advantage of this technique would be that installations could be built close to storage sites independent of CO_2 point sources, but the drawback is the relatively low concentration of CO_2 in the atmosphere compared to CO_2 in flue gases. Studies claim costs less than 75 USD/tCO_2 (Zeman, 2003) and energy requirements of a minimum of 30 % using a recovery cycle with $Ca(OH)_2$ as a sorbent (Lackner *et al.*, 2001). However, no experimental data on the complete process are available yet to demonstrate the concept, its energy use and engineering costs.

4.3.6.1 Costs

Estimates of the various components of a CCS system vary widely depending on the base case and the wide range of source, transport and storage options (Table 4.3.5). In most systems, the cost of capture (including compression) is the largest component but this could be reduced by 20–30% over the next few decades using new technologies still in the research phase (IPCC, 2005a). The costs of transport and storage of CO_2 could also decrease slowly as technology matures further and the plant scale increases.

Table 4.3.5: Current cost ranges for the components of a CCS system applied to a given type of power plant or industrial source (IPCC, 2005a)

CCS system components	**Cost range**	**Remarks**
Capture from a coal- or gas-fired power plant	15–75 US\$/tCO_2 net captured	Net costs of captured CO_2 compared to the same plant without capture.
Capture from hydrogen and ammonia production or gas processing	5–55 US\$/tCO_2 net captured	Applies to high-purity sources requiring simple drying and compression
Capture from other industrial sources	25–115 US\$/tCO_2 net captured	Range reflects use of a number of different technologies and fuels
Transport	1–8 US\$/tCO_2 transported	Per 250 km pipeline or shipping for mass flow rates of 5 (high end) to 40 (low end) MtCO_2/yr.
Geological storage[a]	0.5–8 US\$/tCO_2 net injected	Excluding potential revenues from EOR or ECBM.
Geological storage: monitoring and verification	0.1–0.3 US\$/tCO_2 injected	This covers pre-injection, injection, and post-injection monitoring, and depends on the regulatory requirements
Ocean storage	5–30 US\$/tCO_2 net injected	Including offshore transportation of 100-500 km, excluding monitoring and verification
Mineral carbonation	50–100 US\$/tCO_2 net mineralized	Range for the best case studied. Includes additional energy use for carbonation

[a] Over the long term, there may be additional costs for remediation and liabilities

4.3.7 Transmission, distribution, and storage

Transport fuels are normally produced at a large scale then distributed via ships or pipelines over long distances. Heat can be stored but is normally transferred only over distances up to a few kilometres in district heating schemes. Electricity transmission networks over hundreds of kilometres are very inefficient having high losses (Figure 4.3.21) but have successfully provided the vital supply chain link between electricity generators and consumers for decades. The fundamental architecture of these networks has been developed to meet the needs of large, predominantly fossil fuel-based generation technologies, often located remotely from demand centres and hence requiring transmission over long distances using copper wires to provide the energy services to consumers. Any losses of electricity or leakage of natural gas and heat result in increased GHG emissions per unit of useful consumer energy delivered as well as lost revenue.

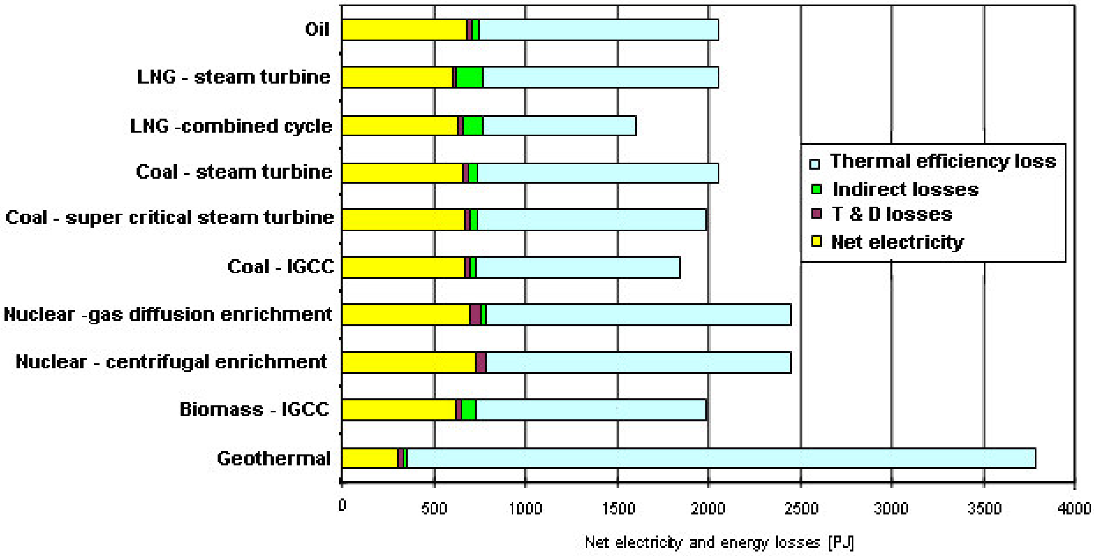


Figure 4.3.21: *Comparison of net electricity production per 1,000MW$_e$ of installed capacity for a range of power generation technology systems in Japan when analyzed over a 30-year plant life, and showing primary fuel use efficiency losses and transmission losses assuming greater distances for larger scale plants (Data updated from Uchiyama, 1996). Note: Load factor of nuclear power plants is around 85% in Japan. T&D losses taken as 4% for fossil fuel and bioenergy, 7% for nuclear*

For the same capacity, the electricity generated in Japan from thermal and nuclear plants is greater than from comparable renewable power generation plants due to their lower capacity factor. For example the nuclear plant capacity is over six times higher than that of a similar size solar PV system.

Globally transmission and distribution (T&D) accounts for 54% of the capital costs of electric power (IEA, 2004d). Aging equipment, network congestion and more extreme peak load demands contribute to losses and low reliability, especially in developing countries, such that substantial upgrading is often required. Future infrastructure and control systems will need to become more complex in order to handle higher, more variable loads; to recognize and dispatch small-scale generators; and to enable the integration of intermittent and decentralized sources without reduced system performance as it relates to higher load flow, frequency oscillations, and voltage quality (IEA, 2006a). Existing infrastructure will need to be modernized to improve security, improve information and controls, and incorporate low-emission energy systems. New networks being built in both OECD and developing countries should have these features incorporated automatically, though due to private investors seeking to minimize investment costs, this is rarely the case.

Superconducting cables, sensors, and rapid response controls that will enable electricity costs and line losses to be reduced are all under development. Superconductors may possibly incorporate hydrogen as both a cryogenic coolant and an energy carrier. Energy storage systems including compressed air and flywheels could offset intermittency problems of some renewables. Charge carriers such as vanadium redox batteries and capacitors are under evaluation but have low energy density and high cost. System management will be improved by providing advanced information on grid behavior; incorporating devices to route current flows on the grid; introduce real time pricing and other demand side technologies including smart meters; and better system planning. The energy security challenges that many OECD countries currently face from technical failures, theft, physical threats to infrastructure, and geopolitical actions are concerns that can be partly overcome by greater deployment of distributed energy systems to change the electricity generation landscape (IEA, 2006f).

4.3.7.1 Decentralized energy

Decentralized (or distributed) energy systems (DES) located close to customer loads often employ small- to medium-scale facilities to provide multiple-energy services referred to as "polygeneration." DES are already commercial in both densely populated urban markets requiring supply reliability and peak shedding as well as in rural markets with high grid connection costs and abundant renewable energy resources. Such systems can play an important role in lowering GHG emissions from the electricity sector but fossil fuel systems based on reciprocating engines can also have benefits over main grid connections.

- Small decentralized systems do not need costly transmission systems and can be brought on stream over shorter periods than larger, central power stations and hence continually meet growing demand in urban and industrial areas.
- Localized decentralized generation systems can substantially reduce grid power losses over long transmission distances and result in deferred costs for upgrading transmission and distribution infrastructure capacity to meet a growing load.
- DES can improve the reliability of industrial parks, information technology and data management systems including stock markets, banks and credit card providers where outages would prove to be very costly (IEA, 2006f).
- The proximity to demand for heating and cooling systems can increase the total energy recovered from fossil fuels from 40–50% up to 70–85% with corresponding reductions in CO_2 emissions of 50% or more.
- Zero-carbon, renewable energy sources such as solar and wind are widely distributed. Hence, developing a decentralized power grid is essential if these sources are to make significant contributions to electricity supply and emission reductions.

The World Alliance for Decentralized Energy (WADE, 2005) reported that at the end of 2004, just 7.2% of global electric power generation was supplied by decentralized systems, having a total capacity of 281.9 GW_e. Capacity of DES expanded by 11.4% between 2002 and 2004, much of it as combined heat and power (CHP) using natural gas or biomass to combine electric power generation with the capture and use of waste heat for space heating, industrial and residential hot water, or for cooling. Growth in the USA, where capacity stands at 80 GW_e, has been relatively slow because of regulatory barriers and the rising price of natural gas. The European market is expected to expand following the "2003 Cogeneration Directive" from the European Commission whilst India has added decentralized generation to enhance system reliability. Brazil, Australia and elsewhere are adding CHP facilities that use bagasse from their sugar and ethanol processing. Brazil has the potential to generate 11% of its electricity from this source. A new Brazilian electricity law, and natural gas discoveries are driving more additions in the urban and industrial areas near Sao Paulo and Rio de Janeiro. China is also adding small amounts of decentralized electric power in some of its major cities (50 GW_e in 2004), but central power still dominates. In 2005 24% of electricity markets from all newly installed power plants were claimed to be from DES (WADE, 2006).

The trend towards DES is growing, especially for distributed electricity generation (DG), in which local energy sources (often renewable) are utilized or energy is carried as a fuel to a point at or near the location of consumption where it is then converted to electricity and distributed locally. As well as wind, geothermal and biomass fuelled technologies, DG systems can use a wide range of fuels to run diesel generators, gas engines, small and micro-turbines, and Stirling engines with power outputs down to <1 kW_e and widely varying power-heat output ratios between 1-3 and 1-36 (IEA, 2006a). Fuel cells can operate on hydrogen (either reformed on-site from natural gas, electrolyzed from water, or fed directly with fossil fuel based hydrogen from a pipeline, section 4.3.1.4) so in future may be used extensively for DG applications. A critical objective however will be to first increase the power density of fuel cells, reduce the installed costs and store the hydrogen safely. Batteries, pumped hydro or flywheels can be used for storage on critical local systems where reliability is an important feature. Small to medium CHP systems at a scale of 1-40 MW_e are in common use as the heat can be usefully employed on-site or locally, but CCS systems will probably not be economic at such a small scale. Mass production of technologies as demand increases will help reduce the current costs of up to around USD5000/kW_e for many small systems. Reciprocating engine generator sets are commercially available, micro CHP Stirling engine systems close to market (Whispergen, 2005) and fuel cells with the highest power-heat ratio needing significant capital cost reductions.

The recent growth in DG technologies, mainly fossil fuel based to provide reliable back-up systems, is apparent in North America (Figure 4.3.22). Technology advances will encourage the emergence of a new generation of higher-margin energy services, including power quality and information-related services.

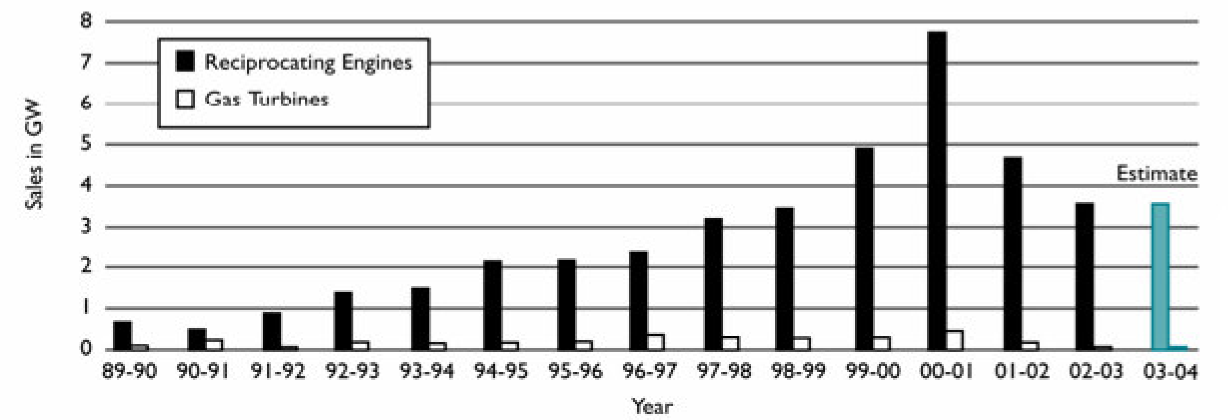


***Figure 4.3.22** Recent growth in distributed electricity generation using fossil-fuel resources in North America (EPRI, 2003)*

Flexible alternating current transmission systems (FACTS) are now being employed as components using information technology (IT) and solid-state electronics to control power flow whereby numerous generators can then be controlled by the utility or line company to match the ever changing load demand. Improved grid stability can result from appliances such as cool stores shedding load and generation plants starting up in response to system frequency variations. In addition, price sensitivities and real time metering could be used to stimulate selected appliances to be used off-peak. IT could help provide a better quality product and services for customers but in itself may not reduce emissions if say peak load is switched to base load and the utility uses gas for its peaking plants and coal for base load plants. It could however enable the greater integration of more low carbon emitting technologies into the grid. The intermittent nature of many forms of renewable energy may require some form of energy storage or the use of a mix of energy sources and load responses to provide system reliability. To optimize the integration of intermittent renewable energy systems, generator preference could be given by way of IT and a pre-determined merit order based on both availability and market price.

4.3.8 Recovered energy

The use of surplus heat generated during the manufacturing process by some industries (such as fertilizer manufacturing) and used on-site to provide process heat and power is covered in Chapter 7.

4.4 Comparing mitigation costs and potentials of energy supply

Assessing future costs and potentials for the range of energy-supply options is challenging. It is linked to the uncertainties of political support initiatives, technological development, future energy prices, the level of private and public investment, the rate of technology transfer and public acceptance, experience learning and capacity building, and future levels of subsidies and support mechanisms. The length of time before commercial delivery of the concept of a future hydrogen economy may occur is one such example that encompasses all these uncertainties leading to considerable debate on its future technical and economic potential, and whether a hydrogen economy will ever become feasible, and if so, when? (USCCTP, 2005; IEA 2003b).

Biofuels exemplify the difficulties when analysing current costs and potentials for a technology, particularly one with such a wide range of energy sources, geographic locations, production systems and hence costs (see Figure 4.3.10) as well as for future projections largely dependent upon RD&D success and economies of plant scale. Bioethanol from ligno-cellulose for example has been researched for over three decades with little commercial success to date, so there can be little certainty over the timing of future success in spite of the recent advances of novel biotechnology applications. Nevertheless, energy technological learning is an established fact (WEC, 2001; Johansson, 2004) and gives some confidence in projections of future market penetration.

4.4.1 Carbon dioxide emissions from energy supply by 2030

Scenarios out to 2030 from IEA Reference, IEA Alternative, SRES A1, SRES B2 (Table 4.2.2) and ABARE reference, Global Technology, and Global technology +CCS were compared. They give widely differing views of future energy-supply systems, the primary energy mix, and related emissions (Fig 4.4.1). Neither higher energy prices (as experienced in 2005/06) and projections that they will remain high (section 4.3.2.3), nor current assessments of CCS deployment rates (section 4.3.5) were included in the IEA and SRES scenarios. Hence more recent studies (for example IEA 2006a, IEA 2006d; ABARE, 2006) are perhaps more useful for evaluating future energy-supply potentials though they still vary markedly.

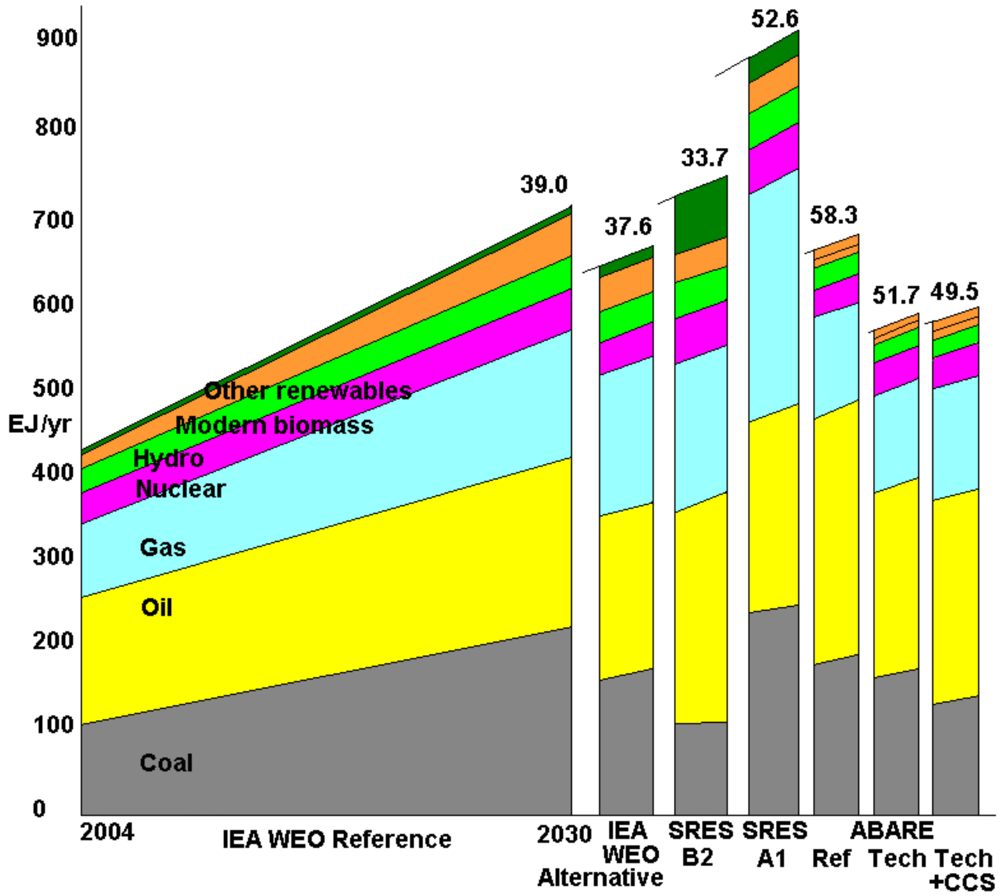


***Figure 4.4.1**: Indicative comparison of selected primary energy-supply scenarios to 2030 and related total carbon dioxide emissions in that year ($GtCO_2$) (based on IEA, 2004d; IPCC 2001; Price et al., 2006; ABARE, 2006)*

The ABARE global model, based on an original version produced for the Asia Pacific Partnership (US, Australia, Japan, China, India, Korea) (Fisher, 2006), particularly relates to this section as it did account for current higher energy prices and CCS opportunities. It did not separate "modern biomass" from "other renewables" and the modellers assumed CCS would play a more significant mitigation role after 2050, rather than the 2030 timeframe discussed here. The reference case ("Ref" in Figure 4.4.1) is a projection of key economic, energy and technology variables assuming the continuation of current or already announced future government policies and no significant shifts in climate policy.

The Global Technology scenario ("Tech") assumed that development and transfer of advanced energy efficient technologies occurs at an accelerated rate compared with the reference case. Collaborative action from 2006 was assumed to effect technology development and transfer between several leading developed countries and hence lead to more rapid uptake of advanced technologies in electricity, transport and key industry sectors. A moderate level of technological change was assumed across all industries in line with forecasts by the IEA, US Energy Information

Administration (EIA) and various other literature sources. For example all new coal and gas capacity was assumed to achieve specific efficiency targets by 2050 although some benefits from investment in efficiency improvements will be seen much earlier. For natural gas, it is assumed all new capacity additions in developed regions will achieve a 75% efficiency target by 2040 and developing regions by 2045. All new coal plants will reach 65-66% efficiency (LHV) by 2050 and IGCC and ultra supercritical plants will become competitive much earlier compared to the reference case.

The "Tech+CCS" scenario assumed similar technology developments and transfer rates for electricity, transport and key industry sectors but in addition CCS was utilized in all new coal and gas fired electricity generation plant from 2015 in US, Australia and Annex I countries and from 2020 in China, India and Korea. The costs of non-hydro renewable electricity technologies were assumed to decline 10% by 2030 as a result of collaborative action on R&D and beneficial learning by doing. Higher energy efficiency improvements for air, water and rail transport of 55%, 44% and 35% respectively were also assumed by 2050. Several of these assumptions were used in section 4.4.3.

The future energy supply by 2030 for one low-carbon-emitting scenario (based on the SRES B2) is analysed here in more detail to illustrate the potential mitigation role of the energy-supply sector. Global energy resource flows and carriers to meet an assumed 2030 total primary energy demand of 710 EJ and final (consumer) energy demand of just over 400 EJ/year are presented (Figure 4.4.2). Estimated available reserves of coal, gas, oil and uranium are illustrated. Annual carbon emissions by 2030 in this scenario rise to 33.7 $GtCO_2$ (9.2 GtC), the lowest of the scenarios in Figure 4.4.1, even without CCS.

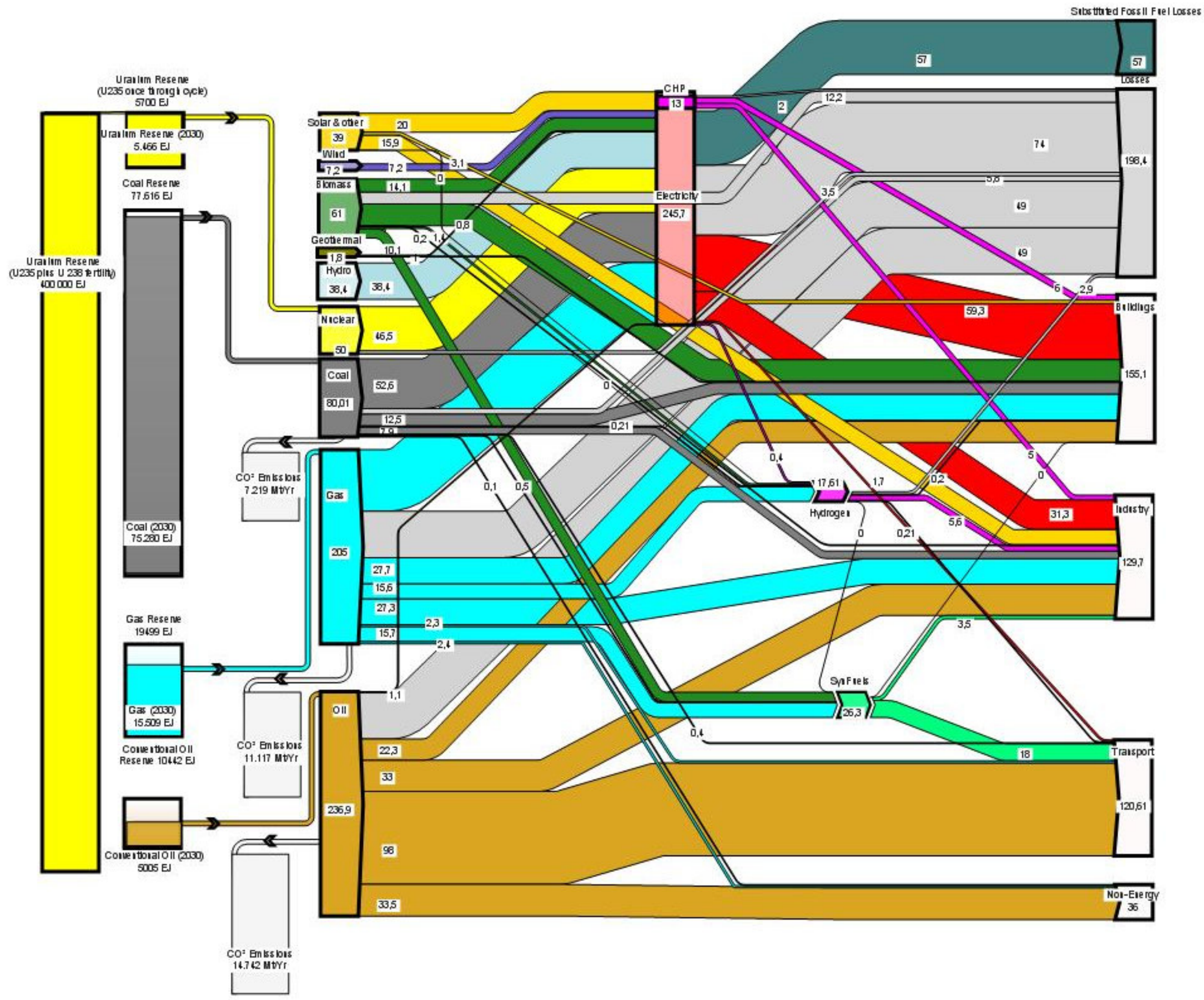


Figure 4.4.2 *Predicted world energy sources to meet growing demand by 2030 based on updated SRES B2 scenario (IPCC, 2001, IIASA, 1998)*

Note: The ratio by which fast-neutron technology increases the power generation capability per tonne of natural uranium varies greatly from the latest OECD assessment of 30:1 based on a rather detailed fuel-cycle analysis to 167:1.

Based on the SRES B2, SRES A1, WEO 2004 alternative emissions data comparisons for 2002 and 2030 (Price *et al.,* 2006), together with the report, *Energy Technology Perspectives* (IEA, 2006a), 2030 carbon dioxide emissions used as a basis for further evaluations were taken as 39 $GtCO_2$ (10.6 GtC) (Table 4.4.1).

Table 4.4.1 *Estimated carbon dioxide emissions from energy use by sector for 2002 and 2030 ($GtCO_2$/yr).*

	2002	2030
Transport Includes marine bunkers	5999	10631
Industry	9013	13400
of which: electricity	4088	6667
heat - coal	2086	2413
- oil	1436	2098
- gas	1403	2222
Buildings	8967	14994
of which: electricity	5012	9607
heat - coal	495	356
- oil	1841	2693
- gas	1618	2338
Total	**23979**	**39025**

4.4.2 Cost Analyses

Cost estimates are sensitive to assumptions used and inherent data inconsistencies. Costs vary over time and with location and chosen technology, with a tendency for developing countries to select the cheapest option regardless of total emission or environmental impact (Sims *et al,* 2003a). Based upon full life-cycle analyses, only broad cost comparisons are possible due to wide variations in the assumptions used for labour charges, currency exchange rates, appropriate discount rates, plant capacity factors etc. For example hydro plants provide baseload at over 80% capacity in Canada, Norway and New Zealand but capacity is only around 45% in Japan which greatly affects the unit generation cost. Cost uncertainty also exists in the electricity sector due to the rate of market liberalization and the debate over the maximum level of intermittent renewable energy sources acceptable to the grid without giving unreliability issues.

One major study compared the levelized investment, O&M, fuel and total generation costs from 27 coal-fired, 23 gas-fired and 13 nuclear power plants either operating or planned in several countries (NEA/IEA, 2005). The technologies and plant types included several units under construction or due to be commissioned before 2015 and for which cost estimates had been developed through paper studies or project bids (section 4.3.3 and Figure 4.4.3).

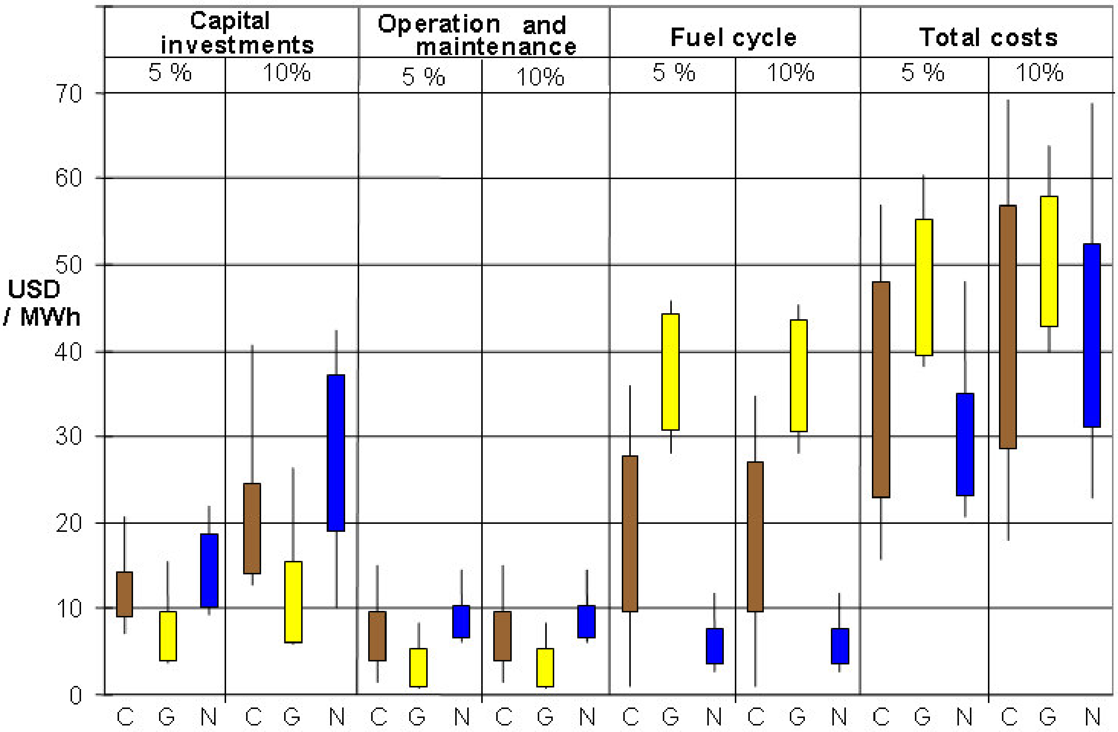


Figure 4.4.3: Projected power-generating levelized costs for coal (C), gas (G), and nuclear (N) power plants with assumed capital interest rates of 5 or 10% (NEA/IEA, 2005).
Note: Bars depict 10% and 90% fractiles and lines the minimum and maximum estimates. Cost estimates below the 5% fractile and above the 95% fractile were excluded.

Construction cost assumptions ranged between USD1000-1500 kW_e for coal plants, USD400-800 $/kW_e$ for CCGT, and USD1000-2000 $/kW_e$ for nuclear with the costs of waste management and disposal, refurbishing and decommissioning also accounted for in all the cost studies reviewed. For example in a German case study the value employed for the specific decommissioning costs of an EPR plant was €155/kW_e, being 10% of the capital investment costs (NEA/IEA, 2005).

The economic competitiveness of the selected energy production systems was dependent on plant-specific features. At the 5% discount rate, generation costs for nuclear power were cheaper than coal by a margin of more than 10% in seven countries (including one case in the USA) and cheaper than gas in nine. At a 10% discount rate nuclear costs rose to USD 30 – 50 /MWh in all countries but remained cheaper than coal by a greater margin than 10% in five countries, the exceptions being US and Japan. The difference between gas and nuclear was less than 10% for one plant in Switzerland. Gas was never cheaper than the least expensive nuclear generation cost. Coal power was cheaper than nuclear by a margin of more than 10% in only the US and for one plant in Germany. A reasonable conclusion from this detailed analysis is that under favourable circumstances, nuclear power can be economically justified as a component in a diversified energy technology portfolio.

Other cost comparisons between these three main generation options based upon five studies (WNA, 2005b) and an additional analysis (Tarjanne, 2005) produced differing results (Figure 4.4.4). Owing to the different currencies involved, the five studies were presented in relative units, the normalized cost for nuclear from DGEMP (2003) corresponding to an electricity wholesale price of €28 /MWh. Two studies showed nuclear is up to 40% more costly that coal or gas and others showed it was cheaper. These overlapping projected costs depended on country-specific conditions and assumptions such as economic lifetime of the plants and capacity factors. Nuclear could become more competitive if gas and coal prices rise and if the external costs associated with carbon dioxide emissions begin to play a larger role.

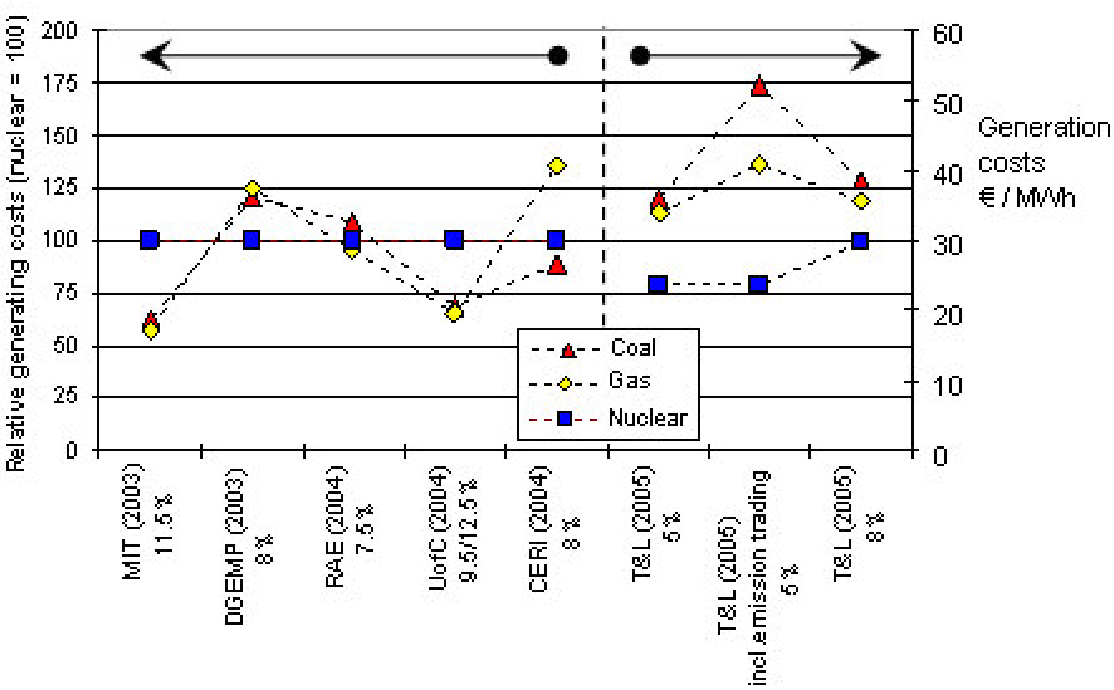


Figure 4.4.4: *Power generation costs of coal, gas and nuclear power plants from six studies with assumed discount (capital interest) rates indicated. Normalized results are shown to the left from MIT, 2003; DGEMP, 2003; UofC, 2004; and CERI, 2004 and a sensitivity analysis (Tarjanne (T&L), 2005) of generation costs using 5% and 8% discount rates plus a €20/tCO_2 emission trading cost to the right*

A European study (EU, 2005) evaluated external costs for a number of power generation options (Figure4.4.5). This emphasised the zero- or low-carbon-emitting benefits of nuclear and renewables in this regard, and reinforced the increased energy efficiency benefits of cogeneration (CHP) systems (section 4.3.6).

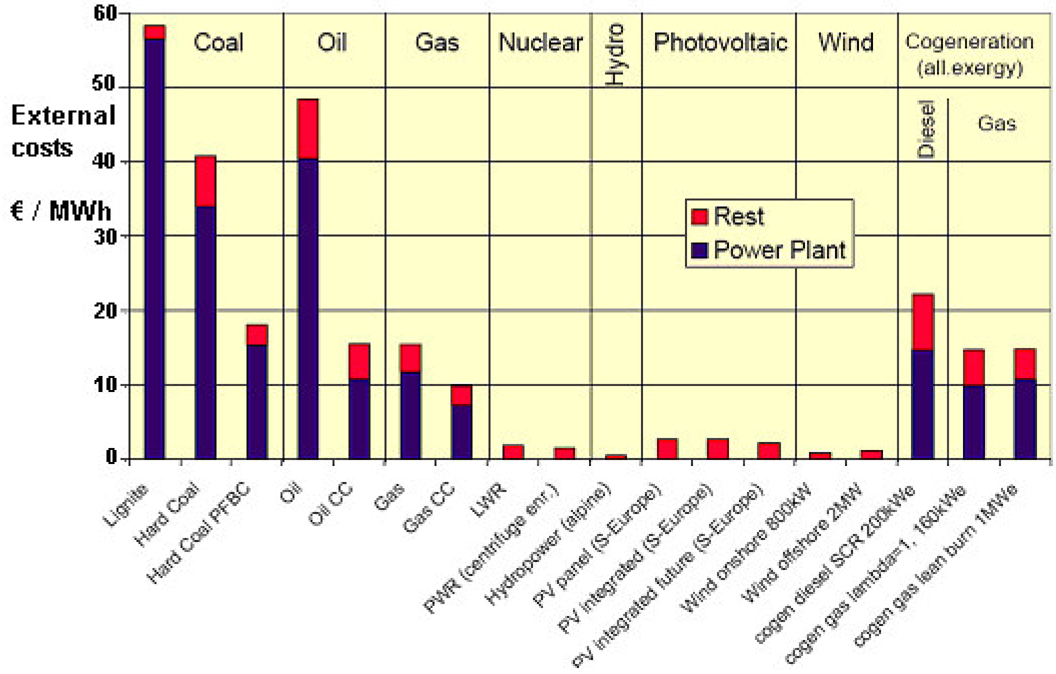


Figure 4.4.5 *External costs (€/MWh) of present and more advanced electricity systems associated with emissions from the operation of the power plant and the rest of the fuel supply chain (EU, 2005)*

A summary of cost estimate ranges (as discussed for the individual energy resource, carrier and conversion technologies in section 4.3) is presented in Table 4.4.2 for energy sources, including biofuels. Costs to 2030 and potentials out to 2050 show that abundant supplies of primary energy resources remain available. Despite uncertainty due to the wide range of assumptions, proven and probable fossil fuel reserves are large and concern over the environmental impact from combusting them should be the main driver for making the transition to non-carbon energy sources. Renewable energy and uranium resources are in sufficient supply to meet future global primary energy demands (Figure 4.4.1). How rapidly the transition can occur will depend on the speed with which the investment costs can be driven down, whether confirmation can be assured that future life cycle costs for nuclear power and renewables are realistic, and how and when external costs are properly valued.

Table 4.4.2: *Approximations of current primary energy use, technical potentials by 2050, and projected costs (USD, 2006) by 2030 for a range of energy resources and carriers. (IEA, 2005a; Johansson et al., 2004; IEA, 2004a; ABARE, 2006; WEC/IIASA, 2001).*

Energy resources and carriers	*Current use* EJ/yr	*Technical potential to 2050* EJ	*Inherent carbon* GtC	*Energy costs[4] in 2005* USD	*Projected costs in 2030* Investment USD/W_e[5]	Generation USD/MWh	*Additional references*
Oil	150	10,000 – 35,000[6]	200 – 800	~8-25 /GJ 15-50 /bbl	n/a	50 -100	Wall St. J, 2006
Natural gas	100	18,000 – 60,000[3]	170 - 850	~5-7 /GJ	0.2-0.8	40 - 60 +CCS 55 - 90	EIA, 2006 Figs. 4.4.3, 4.4.4
Coal	100	130,000	3000	~3-4.5 /GJ	0.4-1.4	40 - 55 +CCS 60 - 85	EIA, 2006 IPCC, 2005a
Nuclear	25	6000 – 400,000[7]	*[8]	10-100 /MWh	1.5-3.0	25 - 65	IAEA, 2004 Figs. 4.4.3, 4.4.4
Hydro >10MW	25	2500	*	20-100 /MWh	1.0-3.0	30 - 70	
Solar PV	0.2	>80,000[7]	*	250-1500 /MWh	0.6-1.2	60 -250	
Solar thermal	0.04		*	150-450 /MWh	2.0-4.0	40 -180	
Wind	0.5	30,000	*	30-80 /MWh	0.4-1.2	30 -100	
Geothermal	2.0	250,000	*	50-60 /MWh	1.0-2.0	30 - 80	
Ocean	0	>375,000	*	80-400 /MWh	?	70 -200	
Biomass – heat and power	Modern 9 Traditional 35	>12,500[6]	*	30-120 /MWh 8-12 /GJ	0.4-1.2	30 -100	
Biofuels	1.2	n/a	*	8-30 /GJ	23-75 c/l		Figure 4.3.19
Hydrogen	0.1	n/a	?	50 /GJ	?		US NAE, 2004

4 Most prices very volatile
5 Excluding carbon capture and storage
6 Includes probable and unconventional oil and gas reserves
7 Assumes nuclear fuel is recycled
8 * = small amount

4.4.3 Evaluation of costs and potentials for low-carbon, energy-supply technologies

There are numerous analyses of costs and potential CO_2 reductions for energy-supply options (IPCC, 2001; Sims *et al.,* 2003a; NEA/IEA, 2005). The TAR showed that GHG emissions from the energy-supply sector in 1990 of 5.94 $GtCO_2$ (1.62 GtC) grew at over 1.5% per year. They reached over 25 $GtCO_2$ (6.8 GtC) by 2005. Potential emission reductions at less than USD27/tCO_2 (USD100/tC) by 2010 were estimated to be between 0.15 – 0.55 $GtCO_2$ (0.05-0.15 GtC) (but with an unlikely probability of success) based on switching from coal to gas; gas and coal to nuclear; gas and coal to wind, hydro, biomass and solar thermal, and co-firing of biomass with coal. By 2020, between 1.3–2.5 $GtCO_2$ (0.35–0.7 GtC) reductions were considered to be probable, including CCS.

The following analysis of the mitigation potentials for the energy-supply sector by 2030 is based on the TAR assessment but using more recent data and revised assumptions. The emphasis is on the electricity sector because cogeneration and heat are more difficult to assess from the literature. A computer model (developed by Ecofys Ltd., Utrecht, Netherlands) enabled costs (Table 4.4.2) and assumptions taken from the literature to be compared and quantified for major energy-supply technologies. The baseline selected was based on the IEA World Energy Outlook (WEO) Reference scenario (IEA, 2004a; Figure 4.4.2) that estimated future consumer heat and power demand from coal, oil, gas, nuclear, hydro, biomass and wastes, and other renewables by 2010, 2020, and 2030 for OECD, EIT, and non-OECD regions. Mitigation potentials by 2030 produced by the model are in addition to those already in the baseline.

BASELINE	Primary energy demand for heat and power by 2030 EJ/yr	Electricity demand by 2030 TWh/yr	Emission factor of power mix by 2030 MtCO2/TWh	Sector emissions in 2030 GtCO2 /yr
OECD	98.2	16,230	0.53	5.9
EIT	27.4	4,230	0.46	1.6
Non-OECD	130.3	19,920	0.56	9.2
World	255.9	40,380	0.52	16.7

The *maximum* technical potential possible by 2030 was estimated for each technology option, given practical constraints of stock turnover, capacity building, etc. but with no competing constraints from other power plants in the future supply mix. Hence, the potentials for each technology cannot be added using this method. An additional analysis (section 4.4.4) identified the total potential for specific energy-supply mixes.

Mitigation in the energy-supply sector can be achieved by optimization of plant conversion efficiencies, fuel switching, substitution by nuclear (section 4.3.3) or renewable energy (4.3.4), CCS (4.3.5), or biological sequestration of the CO_2 in forests and soil (chapters 8 and 9). It is important to note that low-carbon energy source substitutions are unlikely unless they are cheaper or if policies, including carbon trading, support their adoption.

4.4.3.1 Plant efficiency and fuel switching

Reductions in CO_2 emissions can be gained from efficiency improvements in power generation technology through the use of more advanced technologies using the same fuels. For example, a 27% emission reduction is possible by replacing a coal-fired steam turbine with advanced steam, pulverized-coal technology, and a 36% reduction by replacing a single-cycle gas turbine with CCGT (Table 4.4.3).

Table 4.4.3: *Reduction in CO_2 emission coefficient by fuel substitution and energy conversion efficiency in electricity generation (Danish Energy Authority, 2005).*

Existing generation technology			**Mitigation substitution option**			**Change**
Energy source	**Efficiency %**	**Emission coefficient gCO_2/kWh**	**Switching option**	**Efficiency %**	**Emission coefficient gCO_2/kWh**	**gCO_2/kWh**
Coal, steam turbine	35	973	Pulverised coal, advance steam	48	710	-263
Coal, steam turbine	35	973	Natural gas, combined cycle	50	404	-569
Fuel oil, steam turbine	35	796	Natural gas, combined cycle	50	404	-392
Diesel oil, diesel genset	33	808	Natural gas, combined cycle	50	404	-404
Natural gas, single cycle	32	631	Natural gas, combined cycle	50	404	-227

When gas displaces coal for electric power generation, higher temperatures in CCGT result, achieving higher conversion efficiencies (>50%) than in coal-fired steam turbines (>40%) (IEA, 2006a). Conversion efficiencies vary and GHG emission savings (gCO2 /kWh) were calculated for before and after each mitigation option (based on IPCC (1997) factors: 56.9g CO_2/MJ natural gas, 74.1g for diesel, 77.4g for fuel oil and 94.6g for coal). The IEA World Energy Outlook (WEO) (IEA, 2004a) showed a 7% CO_2 reduction for the Alternative scenario from fuel switching in end uses (chapters 6 and 7) and also a 5% reduction from the fossil fuel mix changes (coal to gas; oil to gas etc.). Another IEA report (IEA, 2006a) suggested mitigation potentials by 2030 could be 300-900 $MtCO_2$ as a result of natural CCGT plants displacing coal; new advanced steam coal plants displacing less-efficient designs; and the introduction of new coal IGCC plants to replace traditional steam plants.

The business-as-usual base case assumed consumer electricity demand reaches almost 100 EJ (using 256 EJ of primary fuel), and 130 EJ of oil is consumed for transport fuels by 2030 (Price *et al.*, 2006). By that time, a proportion of old heat and power plants will have been replaced with modern plants having higher energy efficiencies and new plants will also have been built. Selecting the most modern technologies today will have the most impact on future CO_2 emissions.

In this analysis assumptions for switching coal to gas were, a 50-year plant life; a 2%-per-year replacement rate in all regions starting in 2010; 50% of all new thermal plants going to gas by 2030;

and 20% of existing plants replaced by then. New power generation needed to meet the growing world demand by 2030 is shown for each region along with the coal that could be displaced and the additional gas power generation required.

FUELSWITCH	Total new power demand needed between 2002 and 2030 TWh	Coal displaced by gas EJ / yr	Additional gas power required TWh /yr	Emissions avoided by switching coal to gas GtCO2/yr	Cost ranges Lowest USD /tCO2 eq	Highest USD /t $CO_{2\ eq}$
OECD	6,260	8.49	825	0.48	9	17
EIT	1,460	1.17	114	0.21	3	5
Non-OECD	13,850	13.90	1351	0.84	8	16
World	21570	23.56	2290	1.53	9	17

4.4.3.2 Nuclear

Fossil fuels to generate electricity can be replaced by nuclear power. Since the nuclear plant and fuel system is not produced using large quantities of fossil fuels in the fuel cycle, net carbon emissions can be lowered significantly. The WEO "Alternative" scenario (IEA, 2004a) anticipated that a 12.5% increase in nuclear energy (to 36 EJ/yr) occurs by 2030. The ETP report (IEA, 2006a) assumed a mitigation potential of 200–600 $MtCO_2$ by 2030 from the construction of Generation II, III, III+, IV nuclear plants (section 4.3.3). Based on these assumptions it was assumed here that as a maximum, 15% of the power generation capacity could come from nuclear plants generating for between USD25-65 /MWh and would replace coal, gas and oil power plants mainly in developing country regions in proportion to their current share of the baseline.

NUCLEAR	Maximum contribution to mix by 2030 %	GtCO2 /yr avoided	Cost ranges USD /t CO_2 eq Lowest	Highest
OECD	15	1.88	-2	1
EIT	10	0.08	-27	2
Non-OECD	15	0.89	-21	6
World	15	2.85	-27	6

4.4.3.3 Renewable energy

Fossil-fuel plants can also be replaced by renewable energy sources to provide heat (from biomass, geothermal or solar) or electricity (from wind, solar, hydro, geothermal, or bioenergy generation or CHP plants). Most renewable energy systems consume only small amounts of fossil fuels for technology manufacturing, transport, and installation. Therefore, carbon emissions are relatively low for power production, space heating, and in the case of biofuels, for transport.

IEA (2006a) suggested hydro power (both small and large) can offset fossil-fuel power plants to give a mitigation potential in the range 300–1000 $MtCO_2$ by 2030. Biomass for heat and power, wind power, solar PV, solar thermal, and geothermal would each have a mitigation potential of 100–300 Mt CO_2. Ocean energy does not make a significant contribution by this stage. The WEO report (IEA, 2004a) assumed around a 5% increase for bioenergy between the Reference and Alternative scenarios by 2030 and 20% for "other renewables", here split into wind (50%), geothermal (40%), and solar (10%). The assumed maximum potentials below took these assumptions into account.

Hydro

It was assumed that enough hydro sites are available to displace 15% of new fossil-fuel power plants based on their current share of the base load. Costs range from USD30 /MWh for good sites with high hydrostatic heads close to load demand and good all-year-round flow rates, up to USD90 /MWh for smaller plants installed in less-favourable terrain.

HYDRO	Maximum contribution to mix by 2030 %	Additional hydro by 2030 TWh/yr	GtCO2 /yr avoided	Cost ranges USD /t CO_2 eq	
				Lowest	Highest
OECD	10	146	0.09	-12	47
EIT	10	50	0.03	-15	42
Non-OECD	20	1598	0.97	-12	47
World	15	1794	1.09	-15	47

Wind

Wind power can displace new and existing fossil-fuel power plants according to the relevant shares in the baseline and thereby reach an assumed maximum of 5-10% of the global power supply mix by 2030. Any constraints of on- and off-shore wind farm development due to public acceptance, proximity to load, etc. were excluded. Intermittancy issues on most grids would not be limiting at such levels with suitable control and back-up systems in place. The costs are very site specific and it was assumed they would range from USD30 /MWh on good sites to USD100 /MWh on poorer sites neded to be developed if this ambitious share of the total mix is to be met from wind.

WIND	Maximum contribution to mix by 2030 %	Additional wind by 2030 TWh/yr	GtCO2 / yr avoided	Cost ranges USD /t CO_2 eq	
				Lowest	Highest
OECD	5	114	0.08	-11	61
EIT	5	165	0.09	-18	70
Non-OECD	10	1491	0.91	-12	64
World	10	1770	1.08	-18	70

Sola*r*

Solar (both PV and high-temperature thermal concentrated solar power) can theoretically gain a maximum 1-2% share of the global electricity mix by 2030 at the relatively high costs ranging between USD 40 to 180 /MWh for solar thermal and USD 60 – 250 /MWh for PV installed on a wide range of sites with varying solar irradiation levels and using a number of related technologies. Assumed low minimum costs for concentrated solar thermal systems on good sites by 2030 result in low $/ tC avoided in non-OECD countries, and penetration into OECD and EIT markets was assumed to remain small.

SOLAR	Maximum contribution to mix by 2030 %	Additional solar by 2030 TWh/yr	GtCO2 /yr avoided	Cost ranges USD /t CO_2 eq	
				Lowest	Highest
OECD	1	0.02	0.02	3	188
EIT	1	0.03	0.02	1	271
Non-OECD	2	0.29	0.19	4	294
World	2	0.34	0.23	4	294

Bioenergy

A wide range of technical potential exists for biomass resources to be utilised for heat and power by 2030 (Chapters 8, 9 and 10). The resources available will be limited and competition will occur for the feedstock to also produce fuels for transport, materials, and chemicals. The baseline case assumed bioenergy in its various forms (landfill gas, combined heat and power, biogas direct combustion for heat etc.) contributes around 20% to the global power mix by 2030 at costs between USD 30 – 100 /MWh. Little additional bioenergy capacity above that already assumed in the baseline was anticipated in EIT where only a small total bioenergy contribution is expected. Most bioenergy development opportunities are anticipated to occur in developing countries.

BIOENERGY	Maximum contribution in mix by 2030 %	Additional bioenergy by 2030 TWh/yr	GtCO2 /yr avoided	Cost ranges USD /t CO_2 eq	
				Lowest	Highest
OECD	10	779	0.45	-13	69
EIT	5	160	0.08	-18	69
Non-OECD	25	2238	2.56	-12	64
World	10	3177	3.09	-18	69

Geothermal

Power generation at USD30-80 /MWh was assumed to provide a 4-5% share of the energy mix. Direct heat applications were not included. Although C emissions were assumed to be zero, as for other renewables, this may not always be the case depending on carbon dioxide released.

GEOTHERMAL	Maximum contribution in mix by 2030 %	Additional bioenergy by 2030 TWh/yr	GtCO2 /yr avoided	Cost ranges USD /t CO_2 eq	
				Lowest	Highest
OECD	4	91	0.06	-11	29
EIT	4	132	0.07	-17	30

Non-OECD	5	596	0.37	-12	30
World	5	819	0.50	-17	30

4.4.3.4 Carbon capture and storage

Assessing the probability for CCS, as for fuel switching, is closely linked with the carbon price, which is very difficult to predict in 2030. RIVM analysis (den Elzen, 2004) showed that if atmospheric concentrations were to be stabilized at 550 ppm by 2100, a carbon equivalent price of around €60 /t is necessary by 2030, or closer to €30 /t for a level of 650 ppm.

In this analysis, CCS linked with advanced steam coal plants installed with flue gas separation was assumed to begin after 2015 (Dow Jones, 2006). Mitigation assessments vary between 300–1000 $MtCO_2$ by 2030 compared with standard pulverised coal plants (IEA, 2006a). Coal IGCC plants with CCS are similar and advanced steam with oxyfuel systems and CCS are only just entering the market, giving a mitigation potential is between 100-300 Mt CO_2. The ABARE (2006) study suggested 30,143 TWh of electricity demand by 2030 including 1837 TWh from coal with CCS, 7560 TWh from coal without, 1582 TWh from gas with CCS and 6300 TWh from gas without. This resulted in around 3.6 $GtCO_2$ of global GHG emissions avoided, or 15% lower than the reference case level (Figure 4.4.1).

Coal CCS

The assumed life of coal-fired power plants is 50 years (IEA, 2006a). Based on this and assuming 30% of new coal plants will be equipped with CCS, and the replacement rate of old plants by new designs with CCS is 2% per year beginning in 2015, then 9% of new and existing coal-fired plants will have CCS by 2030. Assuming 90% of CO_2 can be captured; power plant conversion efficiency reduces by 35% (leading to less power available for exporting off site – IPCC, 2005a); and additional overall costs range between USD 10 – 50 /MWh depending on ease of CO_2 transport and storage within each location; then costs and potentials by 2030 (compared with the base line scenario of no CCS) are as shown below. In addition, the total CO_2 storage potential for each region (Hendriks *et al.* 2004) was compared with the potential volumes arising from total capture at all coal power plants to ensure sufficient capacity exists for the long term.

COAL CCS	Share of new plants getting CCS by 2030 %	Annual GtCO2/yr avoided	Total captured 2015- 2030 Gt CO_2	Total potential CO_2 storage Gt CO_2	Cost ranges	
					Lowest USD /t $CO_{2\ eq}$	Highest USD /t $CO_{2\ eq}$
OECD	30	0.31	6.34	71 - 1025	34	169
EIT	30	0.04	0.88	114 - 1250	34	169
Non-OECD	30	0.51	10.38	291 - 3600	34	169
World	30	0.86	17.60	476 - 5875	34	169

Gas CCS

The assumed life of a CCGT plant was 40 years, with 20% of new gas-fired plants utilizing CCS by 2030. The replacement rate of old plants by new designs integrating CCS results in 0.5% per year increase in plants with CCS from 2015 to 2030. This results in 8% of new and existing gas-fired plants having CCS in 2030. Assuming 90% of the CO_2 is captured, a reduction of gas-fired power plant conversion efficiency of 15% (IPCC, 2005a), and an additional overall cost ranging from USD 10–30 /MWh generated, then the costs and potentials by 2030 (compared with the baseline scenario of no CCS) are as follows:

GAS CCS	Share of new plants getting CCS by 2030 %	Annual GtCO2 /yr avoided	Total captured 2015-2030 Gt CO_2	Total captured CO_2 from coal + gas, 2015 - 2030 Gt CO_2	Cost ranges	
					Lowest USD /t $CO_{2\ eq}$	Highest USD /t $CO_{2\ eq}$
OECD	20	0.13	2.03	8.37	49	146
EIT	20	0.07	1.15	2.03	49	146
Non-OECD	20	0.14	2.18	12.56	49	146
World	20	0.34	5.26	22.96	49	146

4.4.3.5 Transport biofuels

Various assessments of biofuel uptake range from 4% of transport fuels by 2030 to 20–25% by 2050 and beyond (section 4.3.4.3 and Chapter 5). IEA (2006a) reports mitigation potentials between 50–100 $MtCO_2$ for biodiesel by 2030 and 100–300 $MtCO_2$ for bioethanol from sugarcane and cereals, with possibly up to 50 $MtCO_2$ for ligno-cellulosic ethanol. It is assumed that hydrogen for vehicle fuel will not reach commercial maturity by 2030. The mitigation potential of biofuels by 2030 range between 250-450 $MtCO_2$ eq based on IEA (2006a) assessments (Figure 4.4 6) and is probably lower than emission reductions from improved vehicle efficiencies (Chapter 5).

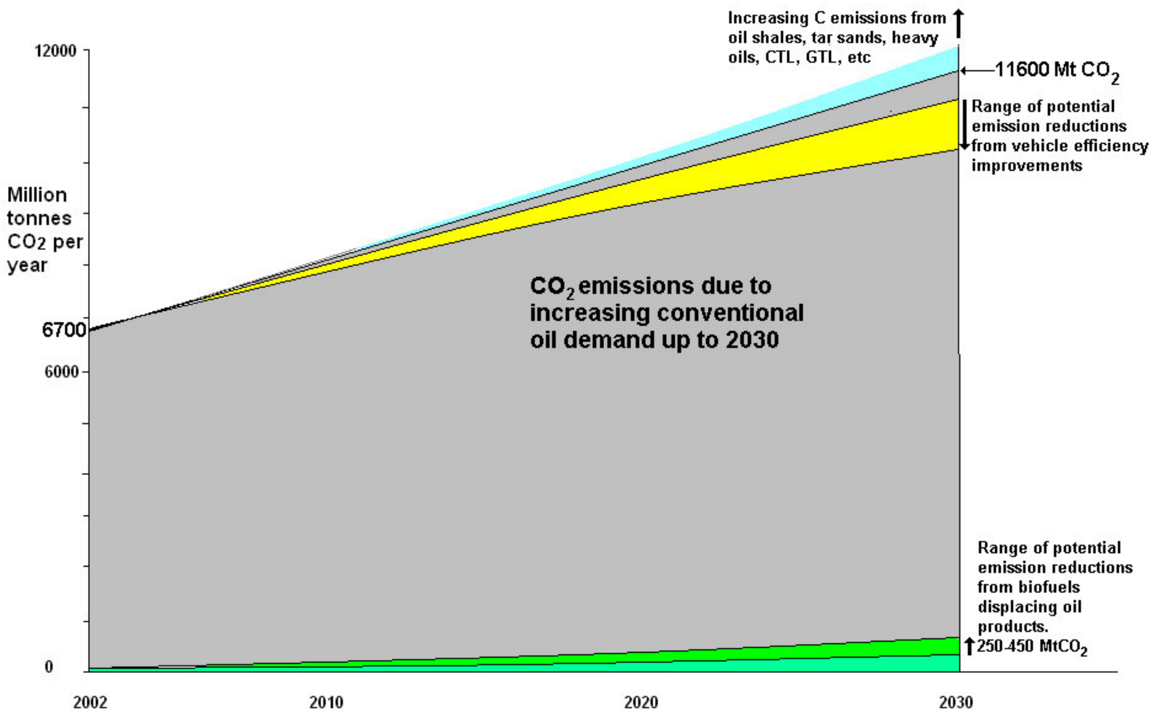


Figure 4.4.6: Carbon dioxide emission growth from oil supplies used for transport with indicative potential reduction ranges from improved vehicle design and biofuels being partly offset by the uptake of unconventional oils (based partly on IEA, 2006a).

4.4.3.6 Heating and cooling

The wide range of fuels and applications used for temperature modifications and the poor data base of existing heat and refrigeration plants makes their mitigation potential difficult to assess. IEA (2006a) assumed a mitigation potential in buildings (Chapter 6) between 300-1000 $MtCO_2$ for new and more efficient heating and cooling technologies; 100-300 $MtCO_2$ for district heating/cooling by fuel switching; 300–1000 $MtCO_2$ from improved building shell materials and insulation and 100-300 $MtCO_2$ for solar heating and cooling systems. In industry applications for process heat (Chapter 7) IEA (2006a) assumed 100–300 $MtCO_2$ mitigation potential for each of basic material production, fuel substitution in materials, materials product efficiency, and between 50–100 $MtCO_2$ for feedstock substitution. The mitigation potentials of cogeneration (combined heat and power) and trigeneration (heating, cooling, and power generation) have not been assessed in the literature.

4.4.4 Energy-supply sector mitigation potential and cost of GHG emission avoidance

The technologies listed in section 4.4.3 can independently contribute to the mitigation potential of the sector at various cost ranges for USD/tCO_2 avoided (Table 4.4.4).

Table 4.4.4: *Potential maximum energy-source greenhouse gas emissions avoided in excess of the IEA World Energy Outlook (2004) Reference case baseline for selected mitigation technologies for heat and power generation, and estimated cost class ranges (USD, 2006).*

[Baseline: WEO Reference scenario]	**Region**	**Potential total CO_2 emissions saved in 2030 ($Gt\ CO_2$)**	**Cost class ranges USD / t CO_2 avoided**				
			<0	**1-20**	**20-50**	**50-100**	**>100**
			%	%	%	%	%
Option 1	OECD	0.48		100			
Fuelswitch	EIT	0.21		100			
	Non-OECD	0.84		100			
	GLOBAL	**1.53**		**100**			
Option 2	OECD	1.88	65	35			
Nuclear	EIT	0.08	90	10			
	Non-OECD	0.89	80	20			
	GLOBAL	**2.85**	**70**	**30**			
Option 3	OECD	0.09	20	35	45		
Hydro	EIT	0.03	25	35	40		
	Non-OECD	0.97	25	35	40		
	GLOBAL	**1.10**	**25**	**40**	**35**		
Option 4	OECD	0.07	15	30	40	15	
Wind	EIT	0.09	20	25	35	20	
	Non-OECD	0.91	15	25	40	20	
	GLOBAL	**1.07**	**15**	**25**	**40**	**20**	
Option 5	OECD	0.02		5	15	25	55
Solar	EIT	0.02		5	10	20	65
	Non-OECD	0.19		5	10	15	70
	GLOBAL	**0.24**		**5**	**10**	**20**	**65**
Option 6	OECD	0.45	15	25	35	25	
Bioenergy	EIT	0.08	20	25	35	20	
	Non-OECD	2.56	15	25	40	20	
	GLOBAL	**3.09**	**15**	**25**	**40**	**20**	
Option 7	OECD	0.06	25	50	25		
Geothermal	EIT	0.07	35	40	25		
	Non-OECD	0.37	30	45	25		
	GLOBAL	**0.50**	**30**	**45**	**25**		
Option 8	OECD	0.31			10	35	55
CCS + coal	EIT	0.04			10	35	55
	Non-OECD	0.51			10	35	55
	GLOBAL	**0.86**			**10**	**35**	**55**

Option 9	OECD	0.13	0	55	45
CCS + gas	EIT	0.07	0	55	45
	Non-OECD	0.14	0	55	45
	GLOBAL	**0.34**	0	**55**	**45**

Since each technology was assessed based on its perceived "maximum" potential and individual potentials cannot be added, a separate analysis ascertains the total potential of the electricity supply mix. The Reference case baseline gives a total power demand of 40,380 TWh/yr by 2030 consuming 256 EJ of primary energy. The fossil fuel share of 198 EJ will release around 17.4 $GtCO_2eq$/yr of GHG emissions. The power generated from burning coal, oil, gas, and biomass is around 15% higher than it would have been as after 2020 advanced plant designs with a high conversion efficiency (see Table 4.4.3) were assumed to be installed.

After 2010, new thermal power stations will be built to replace old stations at the end of their working life (assumed to be 50 years). These plants will generate 9,370 TWh/yr by 2030 and consume 69 EJ/yr of fossil fuels. Additional new plants will be needed to meet the growing demand of a further 16,960 TWh/yr by 2030 consuming 106 EJ/yr of primary energy. The base case assumed that of the total new additional and replacement generation of 26,330 TWh/yr, 19690 TWh/yr would be from coal and gas plants (and a little oil), 1,320 TWh/yr from bioenergy, 1,140 TWh/yr from nuclear, and 4,070 TWh/yr from hydro and other renewables.

The method used to assess the mitigation potential from the electricity sector by substituting much of the fossil fuels with additional hydro and other renewables, bioenergy, nuclear and CCS was as follows:

1. For each major world region (OECD Pacific, US and Canada, OECD Europe, EIT, East Asia, South Asia, China, Latin America, Mexico, Middle East and Africa), the IEA World Energy Outlook 2004 data (Price *et al.*, 2006) was used to show the capacity of thermal electricity generation per year that could be substituted. This assumed a linear replacement starting from 2010 and a 50-year lifetime for nuclear and coal plants but 40 years for renewables.
2. The emissions from the 40% of existing plants remaining in operation by 2030 would be 6.7 $GtCO_2eq$ and the new power plants to be built over the 20-year period from 2010, if all thermal, will produce 10.7 $GtCO_2eq$ by 2030.
3. From 2010, substitution of fossil fuels by renewables, nuclear or CCS was assumed to be at a sufficiently large scale to meet the major challenge of stabilizing GHG emissions from the energy-supply sector.
4. 8% of new gas plants and 9% of new coal plants (as in section 4.4.3) were assumed to integrate CCS by 2030, with 90% of CO_2 emissions captured and a resulting 30% loss of generation output. If the full new generation of 19,690 TWh/yr comes from fossil fuels, then CCS can have a mitigation potential of 0.9 $GtCO_2$ by 2030 at a cost mostly above USD50 /tCO_2.
5. The available renewable energy resources, particularly land needed for biomass production, the amount of uranium fuel needed to supply more nuclear plants, and the volume of CO_2 able to be physically stored from CCS plants (Hendricks *et al.*, 2004), are evaluated on a regional basis to ensure all assumptions can in principle be met. Land and water availability to produce the desired volumes of biomass have considerable uncertainty. The need to

utilize large areas of existing arable land to produce the required volumes of biomass together with increasing competition for the limited resource for biofuels, biomaterials etc. are major constraints to these evaluations.

6. Uranium fuel supplies for nuclear plants will continue to meet the assumed growing demand with the anticipation of fuel recycling plant designs coming on stream before 2030.
7. There is sufficient storage capacity for sequestering the estimated capture of CO_2 volumes in all regions given the anticipated rate of growth of CCS over the next few decades.
8. *Renewables.* Due to constraints of intermittency in power grids, environmental issues, and continued relatively high costs, and also accounting for policy trends and co-benefits, it was assumed that up to 20% of the fossil-fuel generation will be displaced by hydro, wind, solar thermal, solar PV, and geothermal by 2030. This gives a mitigation potential of 0.54 $GtCO_2eq$ at <USD20/t avoided and a further 0.50 $GtCO_2eq$ between USD20-50/t avoided.
9. *Bioenergy.* Should biomass be the only other substitute for fossil-fuel generation, the 116 EJ/yr of biomass fuel required for use in mainly IGCC (55% efficient) and CHP (90% efficient) plants would be 30EJ from agricultural residues (Chapter 8), 30 EJ from forestry residues (Chapter9) and then require around 350 Mha of cropping land (assuming 10t/ha/yr biomass yields at 15GJ/t LHV). Since the total world arable land is only around 1400 Mha, this is obviously impractical. A constraint of 10% of current cropland area for biomass production (including integrated cropping and plantation energy forests) was therefore imposed on each world region. Using the biomass for heat and power generation resulted in 1.08 $GtCO_2eq$ mitigation potential below USD 20/t and 1.03 $GtCO_2eq$ between USD 20-50/t by 2030.
10. *Nuclear.* Should nuclear power be the only additional technology (other than the 20% renewable energy) to substitute for the anticipated coal, gas, and oil generation, then around 140 GW of new plants need to be built each year from 2010 consuming 90 t/yr uranium fuel in 2030 (or proportionally less depending on how many Generation III+ plants are constructed). The rate of build at around 90 x 1500 MW_e power plants a year worldwide starting in 2010 was considered to be impractical and even an average of 30 a year as used in the analysis would be challenging. If this is achieved, then around 1.01 $GtCO_2eq$ could be avoided for less than USD20/t based on full life cycle cost analyses.
11. *CCS.* Together renewables, bioenergy, and nuclear can displace around 55% of the new fossil-fuel generation plant given the constraints outlined. Assuming CCS is integrated into all other new thermal plants built by 2030, then the potential at below USD50/tCO_2 avoided is around 0.06 $GtCO_2eq$ but with a high rate of growth after this date.

It appears from this basic analysis that no single option has sufficient mitigation potential to stabilize atmospheric CO_2 concentrations (Table 4.4.5). OECD countries might provide around one-third of the total mitigation potential, but many countries would need to import biomass and uranium as well as to export CO_2 to reach this level. Around 60% of the total mitigation potential is available in developing countries, but since around 40% of this is from bioenergy and future land use is uncertain (Chapters 8 and 9), this potential must be treated with caution. The total mitigation potential of around 4.3 $GtCO_2eq$/yr equates with the TAR analysis potential for the electricity sector of 1.3 to 2.6 $GtCO_2eq$/yr by 2020. Since the TAR was published, improved public acceptance for nuclear power, an increase in development and deployment of renewable energy technologies, and a better understanding of CCS techniques, together with the later date of 2030, makes the two results closely compatible.

Table 4.4.5: *Mitigation potential ($GtCO_2eq$) for each major world region from renewable energy, bioenergy, and nuclear power displacing thermal power generation, together with CCS for the remaining thermal plants, at cost ranges below USD20 and between USD 20-50/tCO_2 avoided.*

USD/tCavoided	Renewable energy		Bioenergy		Nuclear		CCS		TOTAL
	USD<20	**USD20-50**	**USD<20**	**USD20-50**	**USD<20**	**USD20-50**	**USD<20**	**USD20-50**	
OECD	0.18	0.16	0.19	0.16	0.32	0	0	0.02	1.03
EIT	0.06	0.04	0.13	0.10	0.10	0	0	0.01	0.44
Non-OECD	0.30	0.29	0.77	0.77	0.59	0	0	0.03	2.76
Global	**0.54**	**0.49**	**1.08**	**1.03**	**1.02**	**0**	**0**	**0.06**	**4.23**

Mitigation potentials for the electricity sector based on the overview evaluation presented here together with others in the literature (for example IEA, 2006a) provide a wide range of possibilities (Figure 4.4.6). Emission reductions from improved thermal generation plant efficiency, buildings and appliances (Chapter 6) and industry (Chapter 7) will reduce the total emissions prior to the potentials analysed here (Chapter 11). The extreme ranges as shown are indicative only but technical solutions to reduce emissions in the energy-supply sector are feasible. Achieving the highest potentials by 2030 will be a major challenge due to the high investment costs needed, the difficulties in rapidly building sufficient capacity and expertise, and the perceived threat from introducing new technologies to the incumbents in the existing market.

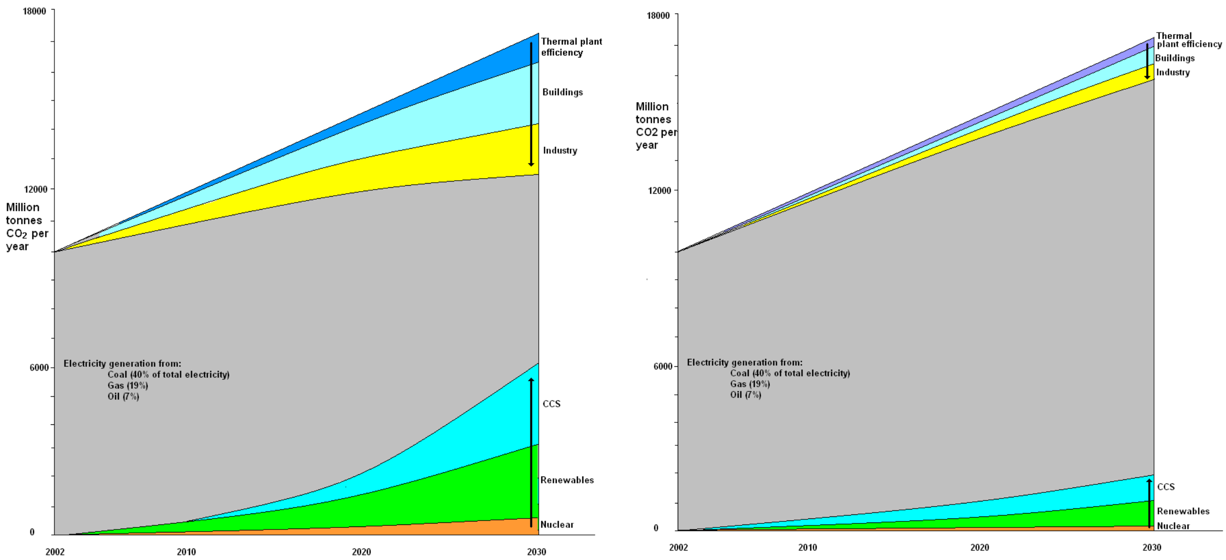


Figure 4.4.7: *Indicative low and high range estimates of the mitigation potential of the electricity sector based on substitution of existing thermal power stations with nuclear, renewable energy and CCS, coupled with energy efficiency improvements in power generation (as well as energy efficiency in buildings, Chapter 6, and industry, Chapter 7) (based on IEA, 2006a).*

4.5 Polices and instruments

4.5.1 Emission reduction policies

There are many technologies, behavioural changes, and infrastructural developments that society could adopt to counter climate change and reduce the environmental impacts of current energy-supply systems as covered in more detail (see Chapter 13). The reduction of GHG emissions from energy-supply systems is being actively pursued through a variety of government research and policies. Whereas, planning policies provide background for climate change mitigation programmes and for implementation of particular instruments, most climate policies relating to energy supply tend to come from three policy "families" (OECD, 2002a):

- economic instruments (subsidies, taxes, tax exemption and tax credit);
- regulatory instruments (mandated targets, minimum performance standards, vehicle exhaust emission controls and other regulations); and
- policy processes (strategic planning, dissemination of information, research investment and consultation).

In addition governments support R D&D programmes aimed to stimulate the development of new innovative energy conversion technologies and to create markets for them (section 4.5.6).

Many greenhouse gas emission related policies undertaken to date aim to achieve multiple policy objectives including market and subsidy reform, particularly in the energy sector (Table 4.5.1). In addition, governments are using a variety of approaches to overcome market barriers to energy efficiency improvements and other "win-win" actions.

Table 4.5.1: *General policy objectives and options used to reduce energy demand and hence greenhouse gas emissions from the energy supply sector.*

Policy options / Policy objectives	**Economic instruments**	**Technological development and diffusion**	**Regulatory instruments**	**Voluntary agreements**	**Information and other instruments**
Energy efficiency	• Higher energy taxes. • Lower energy subsidies. • Power plant emission charges. • Fiscal incentives. • Tradable emission permits.	• Cleaner power generation from fossil fuels.	• Power plant minimum efficient standards. • Best available technology prescriptions.	• Voluntary commitments to improve power plant efficiency.	• Information and education campaigns.
Energy source switching	• CO_2 and CH_4 taxes. • Emissions charges. • Tradable emission permits. • Fiscal incentives	• Increased power generation from renewable, nuclear and "clean" hydrogen sources.	• Power plant fuel portfolio standards.	• Voluntary commitments to fuel portfolio changes.	• Information and education campaigns.
Renewable energy	• Capital grants. • Feed-in tariffs. • Quota obligation. • CO_2 taxes. • Emissions charges. • Tradable emission permits.	• Increased power generation from renewable energy sources.	• Targets.	• Voluntary agreements to install renewable energy capacity.	• Information and education campaigns; • Green electricity validation.
Carbon capture and storage	• Emission charges; • Tradable emission permits.	• Chemical and biological sequestration. • Deep ocean sequestration.	• Emissions restrictions for major point source emitters.		• Information campaigns.

The choice of policies and measures is not an easy task. It depends on many factors including costs, potential capacity, the extent to which emissions must be reduced, environmental and economic impacts, rates at which the technology can be introduced, and social factors such as public acceptance. Also, in the implementation of policies and measures, governments could give consideration to actions to meet the specific needs and concerns of developing countries arising from the adverse effects of climate change and/or the impact of measures on countries whose economies are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels.

4.5.1.1 Emission reduction policies for energy supply

Subsidies and other incentives

The effects of various policies and subsidies that support fossil fuel use have been reviewed (IEA, 2001; OECD, 2002b; Saunders and Schneider, 2000). Government subsidies in the global energy sector are in the order of USD250 -300 billion /yr, of which around 2-3% supports renewable energy (De Moor, 2001). An OECD study showed global carbon dioxide emissions could be reduced by more than 6% and real income increased by 0.1% by 2010 if support mechanisms on fossil fuels used by industry and the power generation sector were removed (OECD, 2002b). However, subsidies are difficult to remove and reforms are usually conducted in a gradual and programmed fashion to soften any financial hardship.

Support for renewable energy, nuclear energy, and energy-efficient technologies depends on market conditions and how incentives are structured. For both environmental and energy security reasons, many industrialized countries have introduced, and later increased, grant support schemes for producing electricity, heat, and transport fuels based on nuclear or renewable energy resources, and on installing more energy-efficient power-generation plant. Some developing countries as China, Brazil, and India have also adopted policies.

Quantitative targets

Setting goals and quantitative targets for low-carbon energy at both national and regional levels increase the size of the markets, thereby providing greater policy stability for project developers. For example European Union 15 members agreed on targets to increase their share of renewable primary energy to 12% of total energy by 2010 including electricity to 22% and biofuels to 5.75% (EU, 2001; EU 2003). The Latin American and Caribbean Initiative, signed in May 2002 included a target of 10% renewable energy by 2010 (Goldemberg, 2004). The South African Government mandated an additional 10 TWh renewable energy contribution by 2013 (being 4% of final energy consumption) to the existing contribution of 115 TWh/yr mainly from fuel wood and waste (DME, 2003). Many other countries outlined similar targets at the major renewable energy conference in Bonn (Renewables, 2004) attended by 154 governments, but not to the extent that a sustainable energy future will result. Renewable quota obligations and feed-in tariffs have been used in many countries to accelerate the transition to renewable energy systems (Martinot *et al*., 2005). A strong case can be made for retaining both policies as although they essentially serve different purposes, they help promote renewable energy (Lauber, 2004). The United States has recently introduced federal loan guarantees, production tax credits, and risk coverage for investments in new nuclear plants (Energy Policy Act, 2005) that cover up to 80% of the project costs.

Feed-in tariffs/Quota obligations

Price-based, feed-in tariffs (permitting customers to receive favorable treatment) have been compared with quantity-based instruments, including quotas, green certificates, and competitive bidding (Sawin, 2003a; Menanteau *et al*., 2003; Lauber, 2004). In 2001, the total level of support provided for preferential power tariffs in EU-15, in particular Germany, Italy, and Spain, exceeded €1 billion (EEA, 2004).

Experience confirms that incentives to support the value of green power produced by rewarding performance are preferable to a capital investment grant (Neuhoff, 2004) since they encourage market deployment while promoting increases in production efficiency. Up to now in terms of installed renewable energy capacity, much better results have been obtained with price-based than quantity-based approaches (EC, 2005; Ragwitz *et al*., 2005; Fouquet *et al*., 2005). In theory, this difference should not exist as bidding prices that are set at the same level as feed-in tariffs should logically give rise to comparable capacities being installed. The discrepancy can be explained by the higher certainty of current feed-in tariff schemes and the stronger incentive effect of guaranteed prices.

The potential advantages offered by green certificate trading systems based on fixed quotas are encouraging a number of countries and states to introduce such schemes to meet ambitious renewable energy goals in an economically efficient way. Such systems can encourage more precise control over quotas, the creation of competition among producers, and incentives to lower costs (ECN, 2005; Menanteau *et al.*, 2003). The quota obligation systems are only beginning to have an effect on capacity additions, in part because they are still new. However, about 75% of the wind development installed in the US between 1998 and 2004 occurred in states with renewable energy standards. Experience in the US shows that if certificates are delivered under long-term agreements, the effectiveness of an obligation can be high and compliance levels can be reached (Linden *et al.*, 2005; UCS, 2005).

Tradable permit systems

Domestic and international tradable permit systems, including for energy projects, are gaining recognition as a means of lowering the costs of meeting climate change targets. Creating new carbon markets can assist economies in locating and realizing economic ways to reduce GHG emissions and other energy related pollutants, or to improve efficiency of energy use. Modelling showed that with emission trading in an international regime, the cost of achieving the Kyoto Protocol targets in OECD regions could fall from 0.2% of GDP to 0.1% (Newman *et al.*, 2002).

Technology development

The need for further investments in R&D of all low-carbon emission technologies, tied with the efficient marketing of these products, is vital to climate policy. Programmes supporting "clean technology" development and diffusion are a traditional focus of energy and environmental policies because energy innovations face barriers all along the energy-supply chain (from R&D, to demonstration projects, to widespread deployment). Direct government support is often necessary to hasten deployment of radically new technologies due to a lack of industry investment. This suggests that there is a role for the public sector in increasing investment directly and in correcting market and regulatory obstacles that inhibit investment in new technology through a variety of fiscal instruments such as tax deduction incentives (Energy Policy Act, 2005).

After a steep increase in the 1970s related to oil crises, public expenditure for energy RD&D fell steadily in industrial countries from USD15 billion in 1980 to about USD7 billion in 2000. About 8% of this was for renewable energy, 6% for fossil fuel, 18% for energy efficiency, 47% for nuclear energy and 20% on other items (IEA, 2004b). About two-thirds of the reduced global expenditure occurred in the US but cuts also happened in Germany, United Kingdom and Italy. At the same time, public spending on energy RD&D increased in Japan, Switzerland, Denmark and Finland but remained stable in other OECD countries (Goldemberg and Johannson, 2004).

Information instruments

Education, technical training, and public awareness are an essential complement to GHG mitigation policies. They provide direct and continuous incentives to think, act, and buy "green" energy and to use energy wisely. Green power schemes, where consumers may choose to pay more for electricity generated primarily from renewable energy sources, are an example of combining information with real choice for the consumer (Newman *et al.*, 2002). Voluntary energy and emissions savings programmes, such as *Energy Star* (EPA, 2005a), *Gas Star* (EPA, 2005b) and *Coalbed Methane Outreach* (EPA, 2005c) serve to effectively disseminate relevant information and reduce barriers to the efficient and clean use of energy. These are not just public education programmes, but also industry/government partnership programmes.

4.5.1.2 Implementation

Technology deployment is a critical activity and learning from market experience is fundamental to the complicated process of advancing a technology toward economic efficiency while encouraging the development of a large scale, private sector infrastructure (IEA 2003i). This not only endorses the justification for new technology deployment support by governments, but also the challenge to determine *how much, for how long, and how to make investments most cost-efficient.* For these reasons in 2006 the IEA established a new collaborative Implementing Agreement on "Renewable Energy Technology Deployment" (www.iea-retd.org).

Experiences—successes and failures

The fast penetration of wind power in Denmark was due to a regulated, favourable feed-in tariff. A new energy act in 1999 changed the policy to one based on the trading of green certificates. This created considerable uncertainty for investors and has led to a significant reduction in annual investments in wind power plants during recent years (Johansson and Turkenburg, 2004).

A comprehensive renewable energy promotion approach launched at the beginning of the 1990s led to Germany becoming the world leader in terms of installed wind capacity, and second in terms of installed photovoltaic capacity. The basic elements of the German approach are a combination of policy instruments, favourable feed-in tariffs and security of support to reduce investment risks (Johansson and Turkenburg, 2004).

When Spain passed a feed-in law in 1994, relatively few wind turbines were in operation. By the end of 2002, the country ranked second in the world but had less success with solar PV in spite of having high solar radiation levels and setting PV tariffs similar to those in Germany. Little PV capacity was installed because no grid connection regulations were established until 2001 when national technical standards for grid connection were implemented. PV producers who sold electricity into the grid, even households, had to register as businesses in order to pay income tax on their sales (Sawin, 2003a). Significant growth in Spanish PV manufacturing in recent years has been mainly attributable to the neighbouring German market (Ristau, 2003).

In 1990, the UK government launched several rounds of competitive bidding for renewable energy contracts, known as the Non-Fossil Fuel Obligation (NFFO). The successive tendering procedures resulted in regular decreases in the prices for wind projects etc awarded to successful bids. The average price for project proposals, irrespective of the technology involved, decreased from €0.067/kWh in 1994 to €0.042/kWh by 1998, being only €0.015/kWh above the wholesale electricity pool reference purchase price for the corresponding period (Menanteau, 2001). Since this support mechanism only showed limited success, the government decided to implement a more market-driven support mechanism by placing an obligation on electricity suppliers to sell a minimum percentage of power from new renewable energy sources. The annual growth rate of electricity generation by eligible plant has significantly increased since the introduction of the obligation in April 2002 (OFGEM, 2006). However, the obligation has not yet been able to stimulate many new large- scale developments.

Swedish renewable energy policy during the 1970s and 1980s focused on strong efforts in technology RD&D. Market development took off during the 1990s when taxes and subsidies created favourable economic conditions for new investments and fuel switching. The use of biomass increased substantially during the 1990s (for example forest residues for district heating increased from 13 PJ in 1990 to 65 PJ in 2001). Increased carbon taxes for heating fuels (but not for fuels used for electricity production) created strong incentives for fuel switching in district heating other than for biomass-based cogeneration. The increase of biomass utilization in turn led to a development of the technology for biomass extraction from forests, production of short rotation coppice *Salix* and in the implementation of more efficient conversion technologies used in district heating system (Johansson, 2004).

Japan launched a "Solar Roofs" programme in 1994 to promote PV through low-interest loans, a comprehensive education and awareness program, and rebates for grid-connected residential systems. Government promotion of PV included publicity on television and in newspapers (IAE, 2003f). The rebates declined gradually over time, from 50% of installed cost in 1994 to 12% in 2002 when the programme ended. In 1997 the rebates were opened to owners and developers of housing complexes and Japan become the world's largest installer of PVs (Haas, 2002). Japan is now the world's leading manufacturer and user having surpassed the United States in the late 1990s. Total capacity increased at an average of more than 42% annually since 1992 to give more than 420 MW installed between 1994 and 2002 leading to a 75% cost reduction per Watt (Maycock, 2003; IEA, 2003f).

In late 2001, China's State Development and Planning Commission launched an ambitious renewable energy "Township Electrification Program" for rural areas. This was the first program on such a large scale aimed at providing electricity to remote rural areas by means of stand-alone renewable energy power systems. During 2002–2004, almost 700 townships received village-scale solar PV stations of approximately 30–150 kW (about 20 MW total). A few of these were hybrid systems with wind power (about 800 kW of wind total). The government provided $240 million to subsidize the capital costs of equipment. From 2002–2004 1 million people in rural areas were provided with electricity from PV, wind-PV hybrid, and small hydropower systems (Martinot *et al.*, 2005).

4.5.2 Air quality and pollution

The Johannesburg Plan of Implementation (UNDESA, 2002) called on all countries to develop more sustainable consumption and production patterns. Policies and measures to promote such pathways will automatically result in a reduction in greenhouse gas emissions and also be useful in controlling air pollution. Climate change is largely associated with the emissions of non-toxic CO_2 from combustion processes, with no detrimental effects on a local or regional scale. On the other hand, air pollution concerns the impacts from toxic emissions such as SO_2 and particulates that can have local health impacts as well as potentially detrimental environmental impacts.

The need for uncontaminated food and clean water to maintain general health have been recognized and addressed for a long time. However, only in recent decades has the importance of clean air to health been seriously noted (WHO, 2003). Major health problems suffered by women and children in the developing world (acute respiratory infection, chronic obstructive lung disease, cancer and pulmonary diseases) have been attributed to a lack of access to high quality modern energy for cooking (Smith, 2002; Smith *et al.*, 2000; Lang *et al.*, 2002; Bruce *et al.*, 2000). WHO (2002) ranked indoor air pollution from solid fuels as the fourth most important health risk factor in least developed countries where 40% of the world's population lives. Up to one billion of the world's population are exposed to pollution at levels of up to 100 times higher than World Health Organization guidelines (BBC World Service, 2001). It has been estimated that half a million children and women die in India annually from indoor air pollution (Smith *et al.*, 2000a). Acute respiratory infections are the leading causes of deaths of children under 5 years old with 75% caused by pneumonia (Fig 4.5.1). A study of indoor smoke levels conducted in Kenya revealed 24 hour average respirable particulate concentrations as high as 5526 $\mu g/m^3$ compared with the EPA standards for acceptable annual levels of 50 $\mu g/m^3$ (ITDG, 2003) and the EU standard for PM_{10} of 40 $\mu g/m^3$ (European Council Directive 99/30/EC). Another comprehensive study in Zimbabwe showed that those who came from households using wood, dung, or straw for cooking were more than twice as likely to have suffered from acute respiratory disease than those from households using LPG/natural gas or electricity (Mishra, 2003).

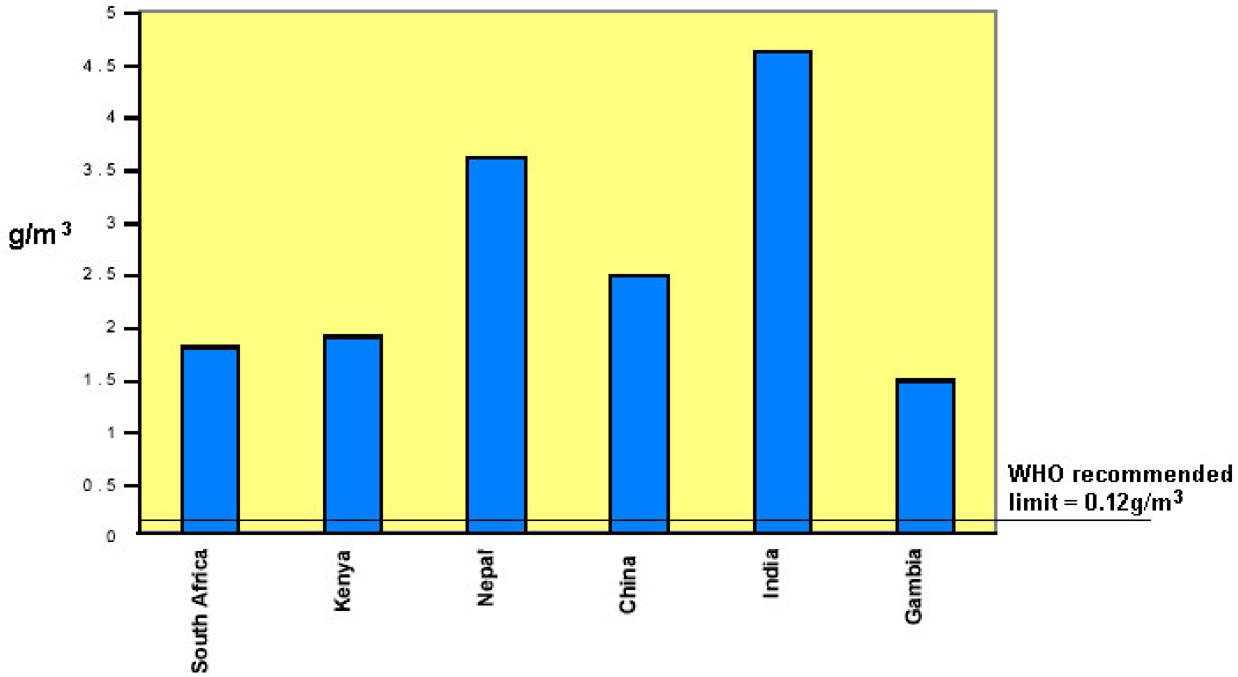


***Figure 4.5.1**: Indoor levels of particulate concentrations emitted from wood fuel combustion in selected developing countries (Karekezi and Kithyoma, 2003)*

Feasible and cost effective solutions to poor air quality in both urban and rural areas need to be urgently identified and implemented (World Bank, 1998). Increasing access to modern energy services can have a double benefit. The use of such services can help alleviate air quality problems but also realize a decreases in GHG emissions as greater overall efficiency is often achieved over the entire domestic energy cycle, starting from the provision of primary energy up to the eventual end-use. For instance, a shift from crop residues to LPG, kerosene, ethanol gel, or biogas could decrease indoor air pollution by approximately 95% and GHG emissions by 75% (Smith *et al.*, 2000).

Climate change and air quality are linked through the physical and chemical processes that take place in the atmosphere (Borrego *et al*., 2000; Shackleton *et al*., 1996; Chen *et al*., 2004). Although there remains an incomplete understanding (Grambsch, 2001), the International Global Atmospheric Chemistry programme has provided major insights into the roles of nitrogen, ozone, aerosols and other gases when defining the interactions that take place between atmospheric chemistry, climate change, and its impacts (Brasseur *et al*., 2003). West and Fiore (2005) showed that mitigation of methane emissions for global warming purposes would also have beneficial impacts on the background concentrations of toxic tropospheric ozone. Further, controls on methane emissions beyond those likely to be taken for climate change purposes could have even greater benefits. They concluded that air quality planning should consider reducing methane emissions alongside NO_x and NMVOCs and industrialized nations should consider emphasizing methane in the further development of climate change and ozone policies.

Policies and measures aimed at increasing sustainability through energy efficiency improvements, switching from the use of fossil fuels, and reducing the production of process wastes, will result in a simultaneous lowering of GHG emissions and reduced air pollution. Conversely, there are cases where measures taken to improve air quality can result in a simultaneous increase in the quantity of GHGs emitted. This is most likely to occur in those developing countries experiencing a phase of strong economic growth but where it may not be economically feasible or desirable to move rapidly away from the use of an indigenous primary energy source such as oil or coal (Brendow, 2004).

Most legislative mechanisms for air quality rely on limiting emissions of pollutants, often incorporating linkages to ambient air quality guidelines or standards (Sloss *et al*., 2003). Although regulations to limit CO_2 emissions could be incorporated as command and control clauses in most of the existing legislative schemes, no country has so far attempted to do so. Rather, emissions trading has emerged as the preferred method of effecting global GHG mitigation, both within and outside the auspices of the Kyoto Protocol (Sloss *et al*., 2003).

Ambient air quality standards or guidelines are usually set in terms of protecting health. They are thus applicable only at or near ground level where acceptable concentrations of gaseous emissions such as SO_2 can often be achieved through atmospheric dispersion, using a tall stack, as opposed to physical removal by scrubbers. Although abatement can also be effected by adopting technologies that intrinsically give lower emissions, such as efficient IGCC generating plant, tall stacks are still in use at the majority of existing industrial installations and power plants around the world to avoid excessive ground level concentrations of gaseous pollutants. If the use of tall stacks is precluded due to either stringent limits being set for ambient SO_2 concentrations or if regulations directly mandate the use of SO_2 scrubbers or other end-of-pipe removal system, then the equipment used for removing the SO_2 will require energy for its operation and thus divert it away from the production process leading to an overall decrease in cycle efficiency with a concomitant increase in CO_2 emissions. Sorbent extraction or other processes necessary to support scrubber operations will also have GHG emissions associated with them. This effectively amounts to trading off a potential local or regional acid rain problem against a much larger global climate problem. The overall costs of damage due to unmitigated CO_2 emissions has been estimated to greatly exceed those from regional acidification impacts arising from insufficient control of SO_2 emissions (Chae and Hope, 2003).

Air quality legislation needs to be approached using the principles of integrated pollution prevention and control if unexpected and unwanted climate impacts on a global scale are to be avoided (Nalbandian, 2002). Adopting a multi-parameter approach could be useful. A US proposal calls for a cap and trade scheme for the power sector, simultaneously covering SO_2, NO_x, mercury and CO_2 that would specifically avoid conflicts with conventional regulations. Facilities would be required to optimize control strategies across all four pollutants (Burtraw and Toman, 2000). An approach developed for Mexico City showed that linear programming, applied to a database comprising emission reduction information derived separately for air pollutants and GHGs, could provide a useful decision support tool to analyze least-cost strategies for meeting co-control targets for multiple pollutants (West *et al*., 2004).

4.5.3 Co-benefits of mitigation policies

Energy source switching from fossil fuels to renewable energy and nuclear sources and the growth of energy efficiency programs can lead to air quality improvements and economic benefits as well as reduced GHG emissions (Beg, 2002). Co-benefits of mitigation policies are explored in Chapter 11. Therefore this section only covers aspects specifically related to energy supply.

The variety of co-benefits stemming from the utilization of new energy technologies should be seen as an integral part of economic policies that strive to facilitate sustainable development. The co-benefits of GHG mitigation policies include improved health, employment, and industrial development. In most cases the co-benefits of GHG mitigation are defined from the macro-economic point of view or as social welfare improvements. Quantitative information about co-benefits primarily remains limited to health effects and many co-effects are still not quantified due to a lack of information. Climate change mitigation policies in the energy-supply sector including energy efficiency of plant, fuel switching, renewable energy uptake and nuclear power, may have several objectives that implies a diverse range of co-benefits. These include the mitigation of pollution impacts, energy-supply security, energy diversity, technological innovation and economic benefits such as reduced fuel cost and employment. Reducing GHG emissions in the energy sector yields a global impact but the co-benefits are typically experienced on a local or regional level.

Benefits of GHG mitigation may only be expected by future generations but co-benefits are often detectable to the current generation such as fewer health impacts due to a reduction in local air pollution. Energy-efficient technologies leading to energy demand reduction results in less dependence on imported fuels, lower energy costs to the economy, slower resource depletion and less pollution (Swart *et al*., 2003). Reduced imports of energy resources have a positive effect on the balance of payments, while optimised use of a country's power stations will delay the need for investment in increased generating and distribution capacity. This is particularly relevant where installed capacity is lagging behind demand for electricity (Bennett, 2001).

The co-benefits of renewable and non-carbon emitting energy resources can be divided into energy security and diversity, reduction of air pollution and economic growth. While there are relatively high capital costs for most renewable energy technologies, the fuel input has minimal cost. This means that electricity or heat supplied is not prone to price fluctuations, as is the case with fossil fuels (Janssen, 2002). Nuclear energy shares many of the same market co-benefits as renewables (Hagen *et al*., 2005).

Co-benefits of mitigation are important decision criteria for policy makers, but often neglected (Jochem and Madlener, 2002). There are many cases where the net co-benefits are not monetised, quantified or even identified by decision-makers and businesses. Co-benefits can include local environmental effects such as reduced emissions of fine particulates, job creation, less dependence on imported energy and associated trade-balance effects, enhanced energy security, and others. Due consideration of co-benefits can significantly influence policy decisions concerning the level and timing of GHG mitigation action. There may be significant economic advantages to the national stimulation of technical innovation and possible spill-over effects, with developing countries benefiting from innovation stimulated by GHG mitigation in industrialized countries. Most aspects of co-benefits have short-term effects but they support long-term mitigation policies by creating a central link to sustainable development objectives (Kessels and Bakker, 2005). To date, most analyses have calculated GHG mitigation costs by dividing the incremental costs of "mitigation technologies" by the amount of GHG avoided. This implicitly attributes all the costs to GHG emission reduction, and the co-benefits are seen as ancillary. Ideally, one would attribute the incremental costs to the various co-benefits by attempting to weight them. This could lead to significantly lower costs of GHG reductions since the other co-benefits would carry a share of the costs together with a change in the cost ranking of mitigation options. The absolute costs could be significantly reduced (Schlamadinger *et al*. 2006).

New energy technologies are inevitably expensive during their market introduction phase but substantial learning experience can usually be achieved to reduce costs (Barreto, 2001; Herzog *et al*., 2001; IEA, 2000; McDonald and Schrattenholzer, 2001; NCOE, 2004). The reduced cost of new technologies due to technology learning and the incentives for further technological improvement due to technological competition are co-benefits of climate change policy (Jochem and Madlener, 2002). Increased net employment and increased trade of technologies and services are useful co-benefits given high unemployment in many countries. Employment is created at different levels, from research and manufacturing to distribution, installation and maintenance. Renewable energy technologies are more labour intensive than conventional technologies for the same energy output (Kamman *et al*., 2004). Solar PV generates 5.65 person-years of employment per $1 million investment (over 10 years) and the wind energy industry 5.7 person-years. In contrast, every million dollars invested in the coal industry generates only 3.96 person-years of employment over the same time period (Singh & Fehrs., 2001). In South Africa, the development of renewable energy technologies could lead to the creation of 36,400 direct jobs by 2020 (Austin *et al*., 2003) whilst more than 900,000 new jobs could be created across Europe by 2020 as a result of the increased use of renewable energy (EUFORES, 2004).

Low-carbon-emitting energy technology manufacturing and related services can be stimulated by both local and international demand growth. Many technologies are taking advantage of economies of scale to expand manufacturing capability oriented to export markets. For example, Danish manufacturers of wind turbines had a world market share of approximately 38% in 2003 (Danish Wind Industry Association, 2003).

4.5.4 Implications of energy supply on sustainable development

The connection between climate change mitigation and sustainable development is covered extensively in Chapter 12. The impact of the mitigation efforts from the energy-supply sector can be illustrated using the taxonomy of sustainability criteria and the indicators behind it. A text analysis of the sustainability indicators mentioned in 750 project design documents submitted for validation under the Clean Development Mechanism up to the end of 2005 (Olsen and Fenhann, 2006) showed renewable energy projects provide the most sustainable impacts.

Project examples include biomass energy to create employment; geothermal and hydro to give a positive balance of payment; fossil fuel switching to reduce emissions of SO_2 and NO_x; coal bed methane capture to reduce the number of explosions/accidents; and solar PV to create improved and increased access to electricity, employment, welfare and better learning possibilities.

4.5.4.1 Health and environment

Energy interlinks with health in two contradictory ways. It is essential to support the provision of health services but energy conversion and consumption can have negative health impacts. For example, in the UK a lack of insufficient home heating has been identified as a principal cause of high levels of winter deaths (London Health Commission, 2003) but emissions from oil, gas, wood and coal combustion can add to reduced air quality and respiratory diseases.

The historical dilemma between energy supply and health can be demonstrated for various sectors, although it should be noted that recent times have seen major improvements. For instance, whereas epidemiological studies have shown that oil production in developed countries is not accompanied by significant health risks due to application of effective abatement technology, a Kazakhstan study compared the health costs between the city of Atyrau (with a high rate of pollution from oil extraction) and Astana (without). Health costs per household in Atyrau were twice as high as in Astana. The study also showed that the annual benefits of investments in abatement technologies were at least five times higher than the virtual annual abatement costs. A key barrier to investment in abatement technologies was the differentiated responsibility as household health costs are borne by individuals while the earnings from oil extraction accrue to the local authorities and governments do not always act in the immediate interests of their citizens, whatever the motive (Netalieva *et al*., 2005).

Another study conducted in San Carlos in Ecuador, found that males faced a 2.3 times higher risk of getting cancer compared to those living in Quito. Analysis of the water in San Carlos showed levels of polycyclic aromatic hydrocarbons to be 40,000 times greater than that allowed by the USEPA (Sebastian and Cordoba, 2000).

Accidental spills during oil product transportation are damaging to the environment and health. There have been many spills at sea resulting in the destruction of fauna and flora. However, the frequency of such incidents has declined sharply in recent times (Huijer, 2005). There are also spills originating from cracks in pipelines. For example, it was estimated that the trans-Ecuadorian pipeline alone has resulted in the spilling of 400,000 litres of crude oil since the pipeline opened in 1972. Spills at oil refineries are also not uncommon. Verweij (2003) reported that in South Africa more than one million litres of petrol leaked from the refinery pipeline systems into the soil in 2001 hence contaminating ground water. One of the most recent spills occurred in Nanchital, Mexico in December 2004, where it was estimated that 5000 barrels of crude oil spilled from the pipeline with much of it going into the Coatzacoalcos River. Pemex, the company owning the pipeline, indicated a willingness to compensate the more than 250 local fishermen and the owners of 200 hardest-hit homes. China sustained 3,413 coal mining accidents during the first 11 months of 2004, which claimed the lives of 5,286 miners (People's Daily On-line, 2004). Exposure to coal dust has also been associated with accelerated loss of lung function (Beeckman *et al*., 2001).

4.5.4.2 *Equity and shared responsibility*

Studies have suggested that the greater the dependence of a country on oil, the poorer the economic performance (Leite and Weidmann, 1999). Inadequate returns to the energy resource-rich communities have resulted in organized resistance against oil extraction companies. The local energy needs of the host countries may be overlooked by their governments in the quest for foreign earnings from energy exports. Insecurities associated with oil supplies also result in high military expenditure. From 1984-94, military expenditure in OPEC countries was three times as much as in developed countries and two to ten times that of non-oil producing countries (Karl and Gary, 2004). The advent of reform in the energy sector is intensifying inequalities as multi-nationals benefit at the expense of local companies and the poor. Notably electricity tariffs have generally shifted upwards after commencement of reforms (Wamukonya, 2003; Dubash, 2003) making power supply even more inaccessible to the lower-income earners.

There are many genuine efforts to address such injustices (World Bank, 2005), although, much still needs to be done (Lort-Phillips and Herrigshaw, 2006). Companies whose origin countries have stringent mandatory disclosure requirements are reported to be those with the best track records on transparency. The advent of public private partnerships in developing countries is also starting to make inroads into the issue of inequity and to harmonize practices in the developed and developing world. One such example is the Global Gas Flaring Reduction Partnership (World Bank, 2004a) aimed at reducing wasteful flaring and conserving the hydrocarbon resources for utilization by the host country.

4.5.4.3 *Barriers to providing energy sources for sustainable development*

The high investment cost required to build energy system infrastructure is a major barrier to sustainable development. The IEA (2004a) estimates that US$5 trillion will be needed to meet electricity demand in developing countries by 2030. The UN Millennium project study calculated that to me*et al*l the eight Millennium Development Goals will require an annual average investment of US$20 billion to develop energy infrastructure and deliver energy services (UNDP, 2004a). Yet access to finance for investment in energy systems, especially in developing countries, has been declining.

Available infrastructure also dictates energy types and use patterns. For instance, in a study on Peruvian household demand for clean fuels, Jack (2004) found that urban dwellers were more likely to use clean fuels than rural householders, largely due to the availability of the necessary infrastructure. Investment costs necessary to capture natural gas and divert it into energy systems and curb flaring and venting are also a barrier, even though efforts are being made to overcome this problem World Bank, 2004a). It is estimated that over 110 billion m^3 is flared and vented worldwide annually, equivalent to the annual gas consumption of both France and Germany (ESMAP, 2004).

Levels of investment vary across regions, with the most needy receiving the least resources. Between 1990 and 2001 private investments to developing and transition countries for power projects were about USD207 billion. Nearly 43% went to Latin America and the Caribbean, 33% to East Asia and the Pacific and approximately 1.5% to sub-Saharan Africa (Kessides, 2004). This pattern persists such that accessibility and affordability of clean fuels remains a major barrier in many developing countries. This is exacerbated when complex supply systems are required that lead to high transaction costs.

Corruption, together with bureaucracy and mismanagement of energy resources, has often prevented the use of proceeds emanating from extraction of energy resources from being used to provide energy systems to meet sustainable development needs. Forms of corruption have encompassed such schemes as the granting of lucrative power purchase agreements with politicians benefiting from receiving a share of guaranteed prices considerably higher than the international market price (Shorrock, 2002; Vallete and Wysham, 2002). Suspending plant operations, thereby compromising access to electricity and persuading government agencies to pay high premiums for political risk insurance (Hall and Lobina, 2004), and granting of lucrative sole supplier trading rights for gas supplies (Lovei and McKechnie, 2000) are other forms. Oil backed loans have contributed to high foreign debts in many oil producing countries at the expense of the poor majority (IMF, 2001; Global Witness, 2004). Despite heavy debts such countries continue to sign for oil backed loans (AEI, 2003) and potential revenues are used as collateral to finance government external debt rather than to promote sustainable development. These loans are typically provided at higher interest rates than conventional concessionary loans (World Bank, 2004b) and thus the majority of the local population can fail to benefit from high oil prices (IRIN, 2004). The problem could be overcome by legal frameworks that enable the channelling of revenue into investments that provide energy systems and promote sustainable development in communities affected by energy resource extraction. This remains a key barrier to sustainable development and, although several countries including Peru, Nigeria and Gabon have mandated enabling mechanisms for such transfers, progress in implementing these measures has been slow (Gary and Karl, 2003).

Poor policies in the international financing sector also hinder the establishment of energy systems for sustainable development. A review of the extractive industries (World Bank, 2004b) for example revealed that the World Bank group and the International Finance Corporation (IFC) have been investing in oil and gas extractive activities that have negative impacts on poverty alleviation and sustainable development. The review, somewhat controversially, recommended that the banks should pull out of oil, gas, and coal projects by 2008.

Population growth and higher per capita energy demand are forcing the transition of supply patterns from potentially sustainable systems to unsustainable ones. Efficient use of biomass fuels can reduce CO_2 emissions if they replace fossil fuels. These benefits can only be sustained however, if biomass supplies are adequate to satisfy demand without depleting biomass carbon stocks by deforestation. If supplies are inadequate, it may be necessary to shift demand to fossil fuels to prevent over harvesting. In Niger for example, despite the concerted efforts through a long-term World Bank funded project, it is not possible to provide sufficient woody biomass on a sustainable basis. As a result the government has launched a campaign to encourage consumers, particularly industry, to shift from wood to coal and has re-launched a 3000 t/yr production unit, distributed 300 t of coal to Niamey, and produced 3800 coal burning stoves (ISNA, 2004). Further, in the electricity sector, power purchase agreements (PPAs) that are not favourable to the establishment of generation plants that promote sustainable development are increasingly common. These include long term PPAs with payments made in foreign currency denominations, leaving the power sector extremely vulnerable to macro-economic shocks as demonstrated in the 1998 Asian crisis (Wamukonya, 2003).

4.5.4.4 Strategies for providing energy for sustainable development

Although the provision of improved energy services is not mentioned specifically in the formal Millennium Development Goals (MDGs) framework, it is a vital factor to achieve these goals. Electrification and other energy-supply strategies should target income generation if they are to be economically sustainable. It is important to focus on improving productive uses of energy as a way of contributing to income generation. They should be seen as a way to provide services and not as an end in themselves. The traditional top-down approaches to reform the power sector—motivated by macroeconomic factors and not aimed at improving access for the poor—should be replaced by bottom-up ones with communities at the centre of the decision process. Improving energy access for the poor should be accompanied by other measures to promote use of energy for development (GNESD, 2006).

4.5.5 Vulnerability and adaptation

Energy issues are vitally important to sustainable development and it is essential to look at how the various components of the energy-supply chain might be affected by climate change. At the same time it is desirable to assess current adaptation measures and their adequacy to handle potential vulnerability while a robust predictive skill is required to ensure that any mitigation programmes that are adopted now will still function adequately under the altered climatic conditions prevailing in the future.

Assessing the vulnerability of energy supply to climatic events and longer-term climate change needs to be country or regional specific. The magnitude and frequency of extreme weather events such as ice storms, tornadoes and cyclones is predicted to change, as may annual rainfall, cloud cover and sunshine hours. This is likely to increase the vulnerability of the various components of the energy-supply infrastructure such as transmission lines and control systems. Further, many developing countries are particularly vulnerable to extremes of normal climatic variability that are expected to be exacerbated by climate change. Investments in developing countries are more focused on recovery from disaster than on the creation of adaptive capacity. Lending agencies and donors will need to reform their investment policies accordingly to mitigate this problem (Monirul, 2004).

Possible structural damage by a combination of factors including sea level rise, tropical cyclones and large ocean waves may hamper offshore oil and gas exploration and extraction of these fossil fuels. Higher ambient temperatures expected from global warming may affect the efficiency and capacity ratings of fossil fuel powered combustion turbines. In addition, electricity transmission losses may increase due to higher ambient temperatures.

Renewable energy systems may be negatively affected by future climate changes (Sims, 2003). For example solar power generation and water heating will be impacted where increased cloud cover occurs. Lower precipitation and higher evaporation due to higher ambient temperatures may cause lower water levels in storage lakes or rivers that will affect the outputs of hydro electric power stations. Energy crop yields could be reduced due to new pests and weather changes and more extreme storm events could damage wind turbines and ocean energy devices.

Although many technologies already exist to combat the threat of climate change, there is no single solution to the problem, but rather a choice of technologies, some more robust than before, that will be gradually implemented over a period of several decades (Pacala and Socolow, 2004). Thus the need to take measures to lessen the impacts on energy systems resulting from their intrinsic vulnerability to climate change will remain a very real challenge for the foreseeable future.

4.6 Technology Research, Development, Demonstration, plus Deployment (RD^3)

Technology can play an important role in reducing the energy intensity of an economy (He *et al.*, 2006). In addition to new and improved energy conversion technologies, such concepts as novel supply structures, distributed energy systems, grid optimization techniques, energy transport and storage methods, load management, co-generation and community based services will have to be developed and improved (Luther, 2004). Then, the knowledge base required to transform the energy supply and utilization system will need to be created and expanded.

The major innovations of the future that will shape society will require a foundation of strong basic research (Friedman, 2003). Areas of generic scientific research in material-, chemical-, bio-, and geo-sciences that could be particularly important to energy supply need to be undertaken and reviewed. Progress in basic research should lead to new materials and technologies that can radically reduce costs or reveal new approaches to providing energy services. For example, the development of fibre optics from generic research investment resulted in their current use to extract greater volumes of oil or gas from a reservoir than had been previously possible.

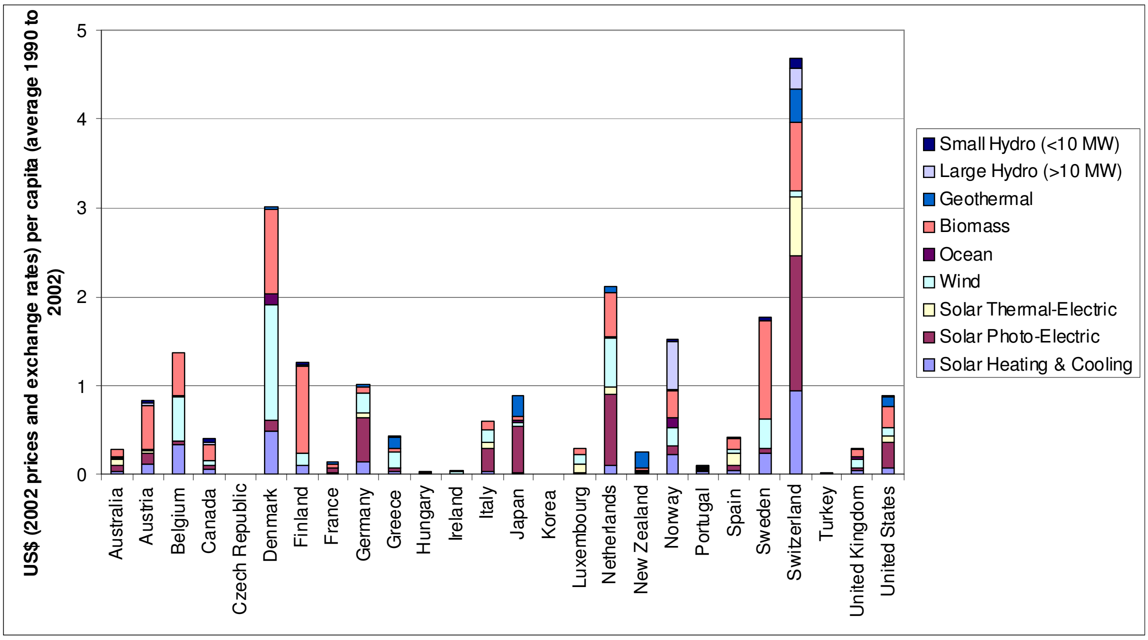
Cross-disciplinary collaborations between many scientific areas, including applied research and social science, are needed for successful introduction of new energy supply and end-use technologies necessary to combat the unprecedented challenge of supporting human growth and progress whilst protecting global and local environments.

Integrating scientific progress into energy and environmental policies is difficult and has not received the attention it deserves (IEA, 2003a). Successful introduction of new technologies into the market requires careful coordination with governments to encourage, or at the least not to hinder, their introduction.

There is no single area of research that will secure a reliable future supply of energy. A diverse range of energy sources will be utilized and hence a broad range of fundamental research will be needed. Setting global priorities for technology development should be based on quantitative assessments of possible emissions and their abatement paths, but guidelines would first need to be developed (OECD, 2006).

4.6.1 Public and private funding

Ninety-eight percent of total OECD energy R&D investment has been by only 10 IEA member countries (Margolis and Kammen, 1999; World Energy Council, 2001) and this declined by 50% between the peak of 1980 (following the oil price shocks) and 2002 in real terms (Figure 4.6.1). Expenditure on nuclear technologies, integrated over time, was many times higher than investment in renewable energies. The end of the cold war and lower fossil fuel prices decreased the level of public attention focused on energy planning in the 1980s and global energy R&D investment has yet to return to these levels in spite of the concerns about energy security and climate change.



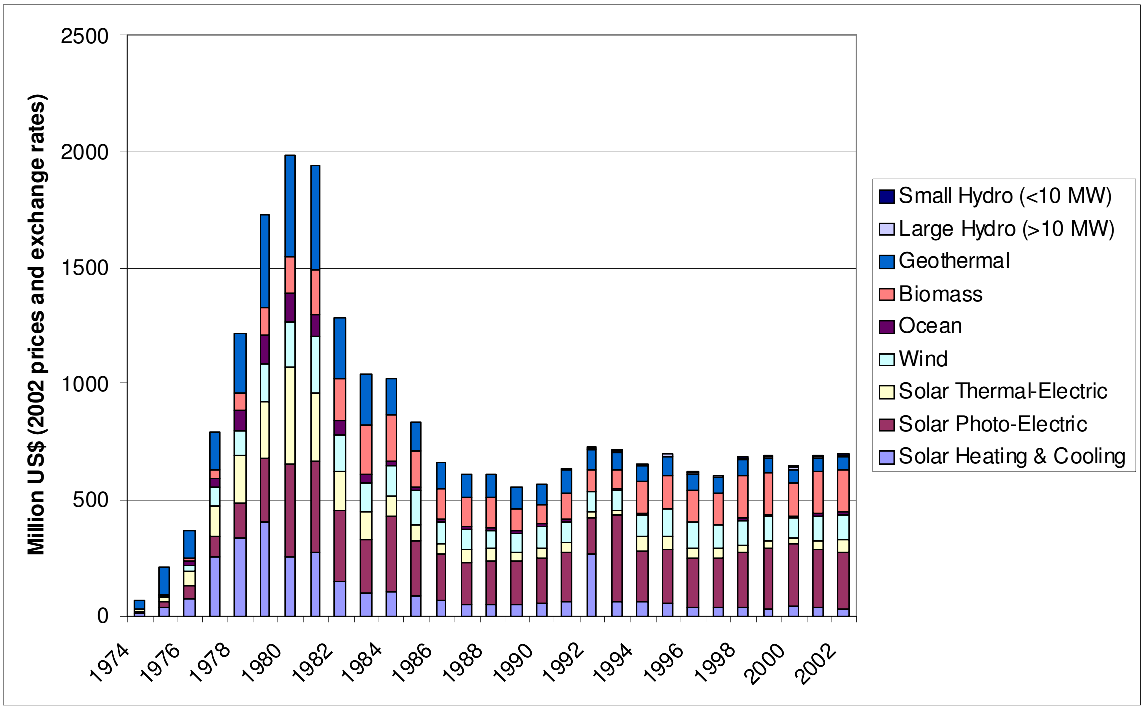


Figure 4.6.1: *IEA member government budgets for total renewable energy R&D annual investments for 1974–2003 and investment per capita (averaged between 1990 and 2002) (IEA, 2006b).*

Ultimately, it is only by creating a demand-pull market (rather than supply-push) that technological development, learning from experience, economies of scale in production and related cost reductions can result. As markets expand and new industries grow (the wind industry for example) more private investment in R&D results, which is often more successful than public research (Sawin, 2003b).

The private sector invests a significant amount in energy RD[3] to seek competitive advantage relevant to risk avoidance. However firms tend to invest in RD[3] at less than socially optimal levels and, for business reasons, focus on incremental technology improvements to gain profits in the short term. R&D spending by firms in the energy industry is particularly low with utilities investing only 1% of total sales in US, UK and Netherlands compared with the 3% R&D-to-sales ratio for manufacturing, and up to 8% for pharmaceutical, computer and communication industries (Battelle, 2002). Even in Japan and USA, private sector energy R&D investment has declined significantly, partly as a result of the more competitive energy market. Programmes designed to create new lower carbon-emitting electricity generation technologies in Europe are also suffering from insufficient R&D investment.

If government policies can ensure long-term markets for new technologies, then industries can see their potential, perform their own R&D, and complement public research institutions (Luther, 2004). Although fixed pricing laws to encourage the uptake of new energy-supply technologies do not usually result in novel concepts, further innovation is encouraged once manufacturers and utilities begin to generate profits from a new technology as they then invest more in R&D to lower costs and further increase profit margins (Menanteau *et al.*, 2003). Under government mandatory quota systems (as used to stimulate renewable energy projects in several countries—section 4.5.1), consumers tend to benefit the most and hence producers receive insufficient profit to invest in R&D.

Recent trends in both public and private energy RD[3] funding indicate that the role of technology in reducing GHG emissions is often overlooked and may not be fully understood. Subsidies and externalities (both social and environmental) affect energy markets and tend to support conventional sources of energy. Intervention to encourage R&D and adoption of renewable energy technologies, together with private investment and the more intelligent use of natural and social sciences is warranted (Hall and Lobina, 2004). Obtaining a useful balance between public and private research investment can be achieved by using partnerships between government, research institutions and firms.

Current low levels of public and private energy-supply R&D investment are unlikely to be adequate to reduce global GHG emissions while supplying the world with the energy needs of the developing nations (Edmonds and Smith, 2006). Success in long-term energy-supply R&D is associated with near-term investments to ensure future energy services are delivered cost-effectively and barriers to implementation are identified and removed. Sustainable development and providing access to modern energy services for the poor have added challenges from R&D investment in order to make markets work better, reduce energy subsidies, provide energy security, mobility and energy efficiency and provide greater support for renewable energy in ways that safeguard health, safety and the environment, (IEA, 2004a and 2006a).

4.7 Concluding Statement

Energy supply is dominated by fossil fuels and this situation is unlikely to change rapidly. The trend of increasing GHG emissions will continue over the next several decades and possibly throughout the 21st century, especially for CO_2 from the energy-supply sector. The current technological adoption path will not come close to meeting the goal of Article 2 of the UNFCCC to stabilize concentrations in the atmosphere at a level that will avoid anthropogenic damage to the climate system. The adoption of new supply technologies and fuels enhances the potential for slowing and eventually lowering emissions and reaching a sustainable concentration in the atmosphere.

A wide range of energy-supply technologies are available to help reverse this trend, but their deployment will not be rapid unless new policies and incentives are put in place. Many of these technologies are already economically competitive or would be if it were not for government support and structural advantages for fossil fuels. If the costs of fossil fuels continue to rise either because of scarcity or geopolitical unavailability, more low-carbon alternatives will become market competitive. Reducing the carbon intensity of electric power generation, heating, and the production of transport fuels (together with improving the end-use efficiency of appliances and vehicles) could achieve the goal of lowering GHG emissions through the adoption of new supply technologies. Other higher-carbon alternatives such as tar sands, oil shales, heavy oils, and synfuels from coal are also becoming more widely available and unless they are combined with CCS, GHG emission reductions from non-fossil sources will be negated.

No single energy-supply technology or fuel option can bring about the desired carbon intensity reduction alone. A combination of modern, highly efficient fossil-fuel production technologies with CCS, biofuels, renewables, distributed energy, combined heat and power, and nuclear power will all be required. These supply options will be most effective if demand reductions simultaneously take place through improved efficiency of end-use technologies and practices.

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