Chapter 7

Technical Solutions

The main cause of environmental problems related to energy use, as identified in Chapter 5, is the use of fossil fuels (coal, oil and gas) either in power production, transportation or industry. The production of hydroelectricity and nuclear energy poses some special problems. The use of fuelwood in developing countries is also an important source of pollution.

The most obvious way of solving the problem is the removal of the causes, which is evidently a very difficult task, since fossil fuels account for more than 90 per cent of the present world energy consumption. However, it is not impossible, since renewable energy sources do exist and could, in time, replace most of the fossil fuels in use today.

Even with this solution in mind, energy consumption should be reduced wherever possible since this would relieve environmental problems as well as saving fossil fuel resources, of which the reserves are not infinite. In addition, we can shift away from very polluting fuels such as coal to cleaner fuels like natural gas. Increasing 'efficiency of energy use' or simply promoting 'energy efficiency', or 'energy conservation', is usually called a 'win–win' strategy because it is justified on grounds other than environmental protection: it is, in general, cost-effective, and also abates pollution.

Enormous progress has been made using technical methods in energy efficiency in many areas of industry and transportation as well as in power production in industrialized countries. Such progress was accelerated by the great increase of oil costs in the 1970s and fears of over-dependence on oil imports from the Middle East. However, long before that, the productive sector realized that costs can be reduced through technological change; in so doing, energy use is reduced and, as a by-product, environmentally damaging products, particularly SO_2 and CO_2, are reduced.

'Cost optimization' is the motto of industry, and energy efficiency is one component of economic efficiency but seldom the dominant one. For the overall manufacturing sectors of the US, capital and labor costs are roughly

20 times higher than energy costs. The strategy has been, therefore, ma one of trading capital for energy. While energy experts and engineers to think of energy as particularly unique, industry sees it as just ano item along with skilled labor, capital and raw materials. Despite this, changing preferences of the general public can have high costs for ind tries and lead to lengthy judicial disputes. For these reasons, the envi mental movement of the 1970s was highly instrumental in shifting strategies of industry into minimizing the emission of pollutants and ad ing energy-efficiency measures.

We shall discuss in this chapter the technical solutions to remove causes of environmental degradation in the sectors discussed in Chapter

- electricity production;
- transportation;
- industry;
- buildings; and
- carbon recapture.

Electricity Production

The environmental impacts of electricity production can be reduced by:

- improving the efficiency of fossil fuel generation technologies an reducing pollutants at source; and
- increasing the share of renewables in electricity generation.

The conventional systems for electricity generation (boilers and steam tur bines) rarely have efficiencies higher than 30 per cent and are significant con tributors to environmental degradation. Advanced fossil fuel-fired technologies are, however, becoming widely available.

New technology development is directed towards higher-efficiency technologies offering reduced unit generation costs, as well as reduced emissions. The trend appears to be away from the Rankine cycle (steam turbines) to combined Brayton (gas turbines) and Rankine cycles.

A number of highly efficient coal-based technologies are either available (eg circulating fluidized bed combustion plant) or are undergoing large-scale demonstration (eg integrated gasification combined cycle plant). These technologies will be available either for new plants, or in some cases as retrofit options to replace an existing fuel combustion stage.

The use of pressurized, fluidized bed units can reduce emissions from coal power generation while increasing efficiency, as indicated in Table 7.1.

Table 7.1 *Characteristics of pressurized fluidized bed thermal generating units*

Combustion efficiency	Higher than 99% with any type of coal
Sulphur removal	Higher than 90%
Nitrogen oxides removal	Higher than 50%
Overall efficiency	Higher than 42% (compared to 34% in conventional units)

Source: *The World Development Report, 1992 – Development and the Environment*, The World Bank, Washington DC, US.

Additional costs of this new technology, as well as electrostatic precipitators (and other filters) in conventional plants typically increase the capital cost of plants by 10–20 per cent. Even so, due to the present availability of coal and its low cost, this fuel will probably continue to play a very important role in the future, despite the advantages of natural gas.

In an integrated gasification combined cycle (IGCC) plant, the fossil fuel (eg coal or oil) is gasified, producing a fuel gas which is cleaned and then burned with compressed air in the combustor of a gas turbine to produce hot gases at high pressure. These hot gases are then expanded through a gas turbine, driving an air compressor and a generator which produces electrical power. The hot exhaust gases from the gas turbine are subsequently used to raise steam, which is then expanded through a steam turbine, driving a generator to produce more electrical power. These improvements are projected to increase system efficiency from an initial level of 43 per cent to 47 per cent by 2010.

Highly efficient combined cycle gas turbines (CCGT) plants are very popular at this time, not only because they use natural gas, which is cleaner than coal, but also because they produce less CO_2 for the same amount of electricity produced: 0.086 kg of C per kWh for coal, 0.071 kg of C for oil and 0.049 kg of C for gas, which reflects the calorific content of coal, oil and gas per kg of fuel.

Several other schemes are in an advanced R&D stage, including magnetohydrodynamics in which an electrically charged plasma moves through an intense magnetic field inducing an electric current.

Renewables

There is a broad range of technologies for producing electricity from renewable sources. The main ones are listed in Table 7.2, together with their current technological and commercial status and estimates of their current contribution to world energy production. We shall discuss here the present status of:

- biomass;
- wind;
- solar thermal; and
- photovoltaics.

Table 7.2 *Summary of renewable power generation technologies*

Technology		*Technical status*	*Current commercial status*	*Current exploited capacity (M*
Biomass	Agricultural residues	R–D	A	50,000
	Energy crops	R–D	A	500
	Urban wastes	R–D	A	1,000
	Biogas	D	A	1,000
Geothermal	Hydrothermal	M	E	10,000
	Geopressurized	R	U	0
	Hot dry rocks	R–D	U	0
	Magma	R	U	0
Hydroelectric	Small scale	M	A	19,500
	Large scale	M	A	627,000
Ocean	Tidal	M	A?	263
	Tidal stream	R	U	0
	Shoreline wave	R–D	A?	<1
	Offshore wave	R	U	<1
	Ocean thermal (OTEC)	R–D	A	0
	Salinity gradient	R	U	0
Solar	Solar thermal electrical	R–D	U	>350
	Solar thermal	M	E	
	Solar architecture	D–M	E	
	Photovoltaics	D–M	A	380
	Thermochemical	R–M	A?	
	Photochemical	R	U	
Wind	Onshore	D–M	A	2,000
	Offshore	D	A?	5
	Wind pumps	M	A	

Notes: Technical status: R = Research, D = Demonstrated, M = Mature.
Commercial status: U = Uneconomic, A = Economic in certain areas or niche markets, E = Economic

Source: 'Energy and Environment Technology to Respond to Global Climate Concerns', *Scoping Study 1994*, IEA/OECD, Paris, France (1994).

Biomass

Burning fuelwood, bagasse and other agricultural residues is a well-known technology in use in many countries but particularly in the US where approximately 8000 MW of electricity are thus generated per year.

Present systems frequently use low-pressure boilers and their efficiency is usually less than 10 per cent. The simple improvements of using condensing-extraction steam turbines and higher temperatures could increase efficiencies to 20 per cent.

Advanced technologies have been proposed to convert solid biomass into a low BTU gas through gasification, and the use of this gas to power gas turbines. Efficiencies higher than 40 per cent could be expected from a biomass integrated gasifier/gas turbine (BIG/GT) system. This efficiency is not surprising since large combined-cycle plants are in operation, running with natural gas, and producing efficiencies equal to, or even above, this value. The merit of BIG/GT systems would be the ability to provide such high efficiencies in small units, in a range suitable for the economical use of biomass (20–100 MW).

The BIG/GT technology is still under development;[1] it is not yet clear whether higher pressurized gasification will dominate BIG/GT power generation in all circumstances or whether atmospheric pressure systems could retain an economic edge. A project in progress in Brazil for a 25 MW, full-scale demonstration plant, with the financial support of the Global Environment Facility (GEF), is trying both approaches with General Electric's aeroderivative gas turbines.

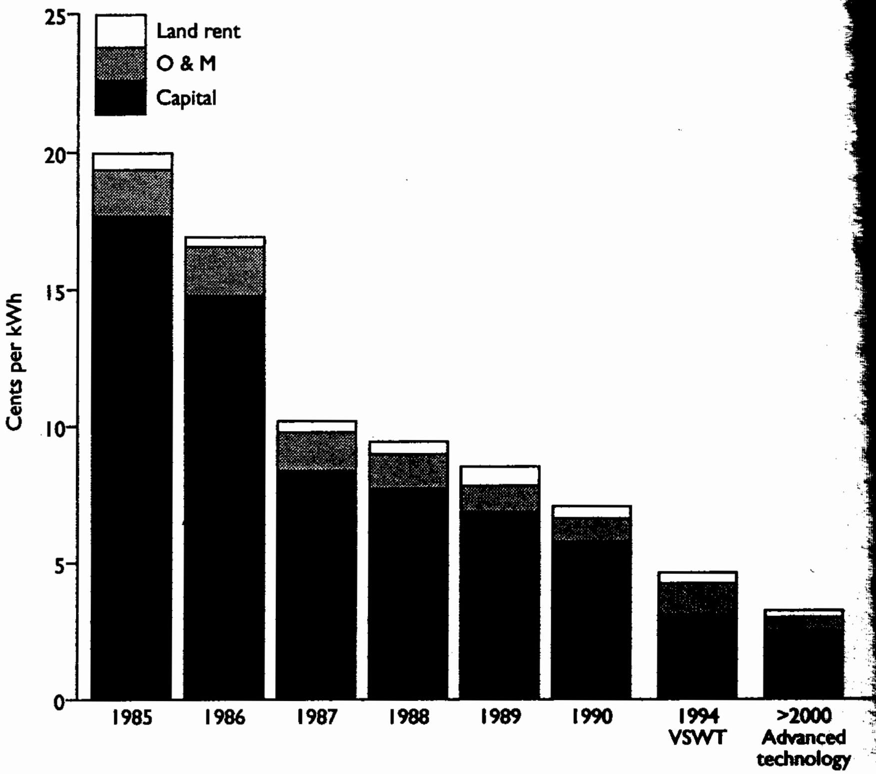
If the technology meets expectations, the global implications could be significant, with biomass possibly contributing to power supplies on a scale similar to nuclear and hydroelectric by the middle of the 21st century. Once developed, the same technology could be used worldwide. Fuelwood grown in large 'energy farms', and the handling of it, would be particularly significant for providing a basis for rural development and employment in developing countries. This is a case in which multinational companies have either developed, or are developing, the necessary technologies to open developing-country markets for their products.

Wind

Wind energy for electricity generation has been deployed in many countries, particularly in the US (California) and Denmark. In the past decade costs of the electricity produced fell significantly, largely as a result of organizational learning. Manufacturers have learned how to exploit the economies of mass-produced, standardized wind turbines, and, by improved measurements of local wind resources, wind-farm developers have enhanced 'micrositing techniques' for extracting more energy from the wind with the same technology.

1 Elliot, P and Booth, R, 'Brazilian Biomass Demonstration Project', Shell Special Project Brief, London, UK (1993).

Trends in the cost of the electricity generated are given in Figure 7.1.



Source: Johansson, T B, Kelly, H, Reddy, A K N and Williams, R H (eds), *Renewable Energy – Sources for Fuels and Electricity*, Island Press, Washington DC, US (1993).

Figure 7.1 Trend in the cost of electricity from wind

In 1994, a new variable-speed wind turbine (VSWT) was commercialized that permits the rotor to turn at optimal speed under a wide range of wind conditions, thereby increasing wind energy capture, while also reducing material fatigue and maintenance costs. Further technological improvements are expected to reduce the cost of wind power to 4 US cents per kWh or less over the next decade or so.

Solar Thermal

With solar thermal electrical technologies, sunlight is focused into a receiving station to heat a fluid to a few hundred degrees centigrade which produces steam for electricity generation. Existing designs are marginally competitive and continuing R&D (especially on the heat engines for generating electricity and improvements in the costs and reliability of tracking systems) together with the potential for economies of scale, are improving the competitiveness of this technology. A large 300 MW electric plant using parabolic mirrors is operating in California, and a number of other plants are planned in Mexico and Morocco.

Photovoltaics (PV)

Annual PV module production currently runs at about 60 MW but, at present, PV is uneconomic except for small-scale decentralized applications. There has, however, been a steady increase in PV efficiency through continuing R&D. A number of national technology development programs are underway to improve the economics of photovoltaic technology and its application. The aim is to produce large amounts of electricity that could be fed into the grid, thus eliminating storage problems. As an example, in places of high insolation (typically 5 kWh/m^2/day) 5000 kWh per day of electricity could be generated with one hectare covered with photocells with 10 per cent efficiency.

PV has been used successfully in satellites, telecommunication in isolated places and is now becoming popular in remote rural areas where it is used in modules of one battery, a charge controller and an inverter, together with the desired electrical output of lighting, communication, refrigeration, water pumping, etc. It requires little maintenance, is well suited for remote locations and costs approximately US$ 0.75 per kWh. PV systems are less expensive than rechargeable batteries and they can provide an energy source to areas that are not, or cannot be, reached by a grid service.

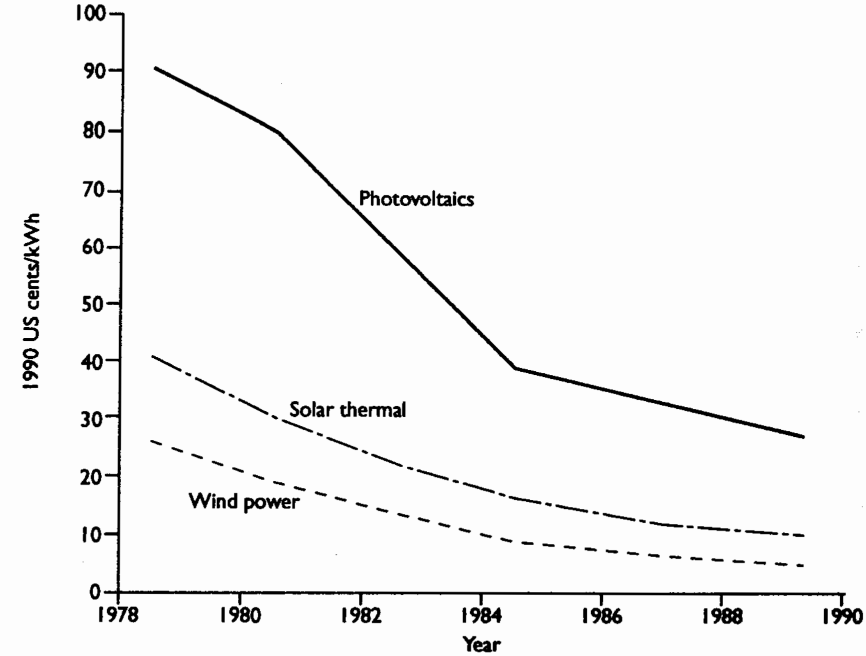
Although the initial cost of each system per household is high (about US$ 600), financing schemes have been started in Central America and elsewhere to repay the equipment with monthly instalments of US$ 12–24, which permits a rapid payback time.

The problem with niches is that they are usually small and, as is the case for renewables, larger-scale production is needed to push prices down.

Japan established an early lead in amorphous silicon PV technology by focusing on the consumer electronic product market niche (hand calculators, watches, etc). US industry (which traditionally has focused on potential electric utility applications rather than niche market development) is now pulling ahead because it has developed the capability of making large amorphous-silicon PV modules (approximately 1–2 m^2). Amoco/Enron plans to build a large-scale (10 MWp/year) amorphous-silicon PV module factory and a 100 MW peak power plant in Nevada, US.

Present installed costs for grid-connected PV systems (without storage) of US$ 7–8 thousand per kW (corresponding to more than 25 cents/kWh) can be expected to reach much lower values of 5–6 cents/kWh early next century (see Accelerated development in Chapter 8, p. 131).

Figure 7.2 shows the evolution of the cost of electricity produced by wind power, solar thermal and photovoltaics in the past few years, indicating very substantial decreases for all of them.



Source: Johansson, T B, Kelly, H, Reddy, A K N and Williams, R H (eds), *Renewable Energy – Sources for Fuels and Electricity*, Island Press, Washington DC, US (1993).

Figure 7.2 Renewable energy costs (1979–1990) – electricity in the US

Recent estimates of costs of electricity generated by a variety of sources made by the World Bank are given in Table 7.3.

Table 7.3 *Costs of electricity generation*

Source of power	*US cents/kWh*	*Long-term expectations*
Coal	5.0	
Oil	6.0	May rise gradually with fuel prices
Gas (combined cycle)	4.5	
Nuclear	5.5	Rises with environmental concerns
Photovoltaics	30–50	7.0
Thermal solar	15.0	7.0
Biomass	9.0	4.0–6.0

Source: Anderson, D, 'Cost Effectiveness in Addressing the "CO_2 Problem"', *Annual Review of Energy and Environment*, 19, 423 (1994).

Transportation

Transport represents 22 per cent of total energy consumption in industrialized countries, mainly in the form of automobiles. Although this is the fastest growth sector in such countries, the rate of increase in road transport energy demand has slowed in most developed countries since the late 1960s. This has reflected both improved vehicle efficiency and a slowing down in the level of acquisition of automobiles by households (although, by contrast, the number of households with two or more automobiles has risen steadily for much of the past two decades). These developments have encouraged hopes that saturation levels may operate at lower levels than sometimes projected.

In developing countries, transport represents 14 per cent of total energy consumption but the number of automobiles is approximately 20/1000 people, compared to 600/1000 people in industrialized countries, as indicated in Table 5.5. If the use of automobiles were to reach OECD-country levels all around the world, environmental problems would become insoluble. Urban congestion and the use of land for roads would impose additional strains in a number of countries, for example, China.

In addition to strictly technical improvements that can be made to automobiles and trucks, as discussed below, there is another important area of action which could help in the solution of the problems, namely system operation. In this category there is a variety of actions that could be performed more efficiently such as shifting passengers and freight to modes that would result in lower energy consumption and, therefore, lower emissions. Table 7.4 gives the average energy intensity of current modes of transportation for passengers and freight. Energy intensity is measured in Mjoules/passenger-km for passenger travel and Mjoules/ton-km for freight.

Table 7.4 *Average energy intensity of transport modes in the OECD*

Passenger travel	
Travel mode	*Intensity (MJ/passenger-km)*
Automobile	2.3–2.6
Bus	0.6–0.8
Rail (excluding US)	0.6–1.5
Air	2.7–2.9
Freight	
Mode	*Intensity (MJ/ton-km)*
Road	3.4–4.2
Rail	0.4 (delivered energy)

Source: Schipper, L and Meyers, S, *Energy Efficiency and Human Activity: Past Trends, Future Prospects*, Cambridge University Press, Cambridge, UK (1992).

As shown in Table 7.4, rail is the most efficient mode for freight trans and comparable to bus for passenger travel.

The technical approaches to reduce emissions from transportation are:

- Engine efficiency improvement – increasing effectiveness with which energy in the fuel is converted into useful work for powering the au mobile. Engine efficiency is the product of two factors: *thermal efficien* expressing how much of the fuel energy is converted into work to dri the engine and vehicle; and *mechanical efficiency*, the fraction of that wo which is delivered by the engine to the vehicle.
- Alternative fuels – presently represented by gasoline for Otto-cycle au mobiles and diesel for Diesel-cycle trucks (ethanol as a fuel is treat separately below, p. 99).

An example of transportation related environmental problems is di cussed in the box on p. 99.

Engine Efficiency

Thermal efficiency could, in principle, be improved by increasing compressio ratios from today's typical value of 9 towards the best value of, perhaps 15 – resulting in a nominal thermal efficiency improvement of approximately 15 per cent. In practice, gains are smaller, not only because friction increases with the compression ratio, but also wall effects (cooling and unburnt fuel associated with the surfaces) increase.

Lean burning is advantageous in terms of efficiency as it increases the air/fuel ratio. Increasing this ratio by a factor of 2.5 (above the chemically correct stoichiometric value) for example, would increase efficiency by approximately 1.15.

The recovery of energy from the exhaust could be significant. Exhaust gases carry away about 40 per cent of the fuel energy from the vehicle but the quality of this energy is low because the temperature is low.

Gas turbines have been proposed for road vehicles because of their light weight, low noise and exhaust emissions (except NO_x), multi-fuel capability and high efficiency. Below 100 kW, however, they are currently too expensive and inefficient, thus making them unsuitable for use in most automobiles.

Increased *mechanical efficiency* could be achieved by decreasing the power required of the engine by reducing air drag, rolling resistance, weight, drivetrain friction and vehicle accessory loads. Unlike thermal efficiency, for which, due to limitations of thermodynamic cycles, it is not practical to aim at efficiencies higher than about 50 per cent, it is a practical goal to increase the actual average mechanical efficiency of 40 per cent to approximately 65 per cent.

The mechanical efficiency of typical US automobiles is roughly 35 per cent when averaged over the urban driving cycle and about 50 per cent in the highway driving cycle. The overall mechanical efficiency averages about 40 per cent. It is lower for high-powered automobiles and higher for low-powered automobiles.

Improving mechanical efficiency at a given load requires that the power necessary to operate the engine be reduced – in particular, the energy used for pumping, overcoming friction and driving engine accessories. There are many strategies for achieving this: engine size, sources of friction themselves and engine speed. The Otto spark ignition gasoline engines in use today have a low cost and high power-to-weight ratio and are, therefore, difficult to replace with other types of engines.

Working against improvements in the present transportation system is the fact that advances in designing better automobile engines and vehicles to guarantee higher energy efficiency are inhibited by other factors of customer acceptance. These include visual attractiveness, safety, capacity, performance and comfort (even luxury). Safety is also one of the key features that must be taken into account in energy-efficient designs, and it has been repeatedly argued that smaller and more efficient automobiles increase highway fatalities.

For such reasons, the maximum power of new automobiles has increased in recent years: the average new-automobile power/weight ratio has risen from a low 70 HP/1000 kg to 90 HP/1000 kg, although high power is only required in unusual driving conditions, such as acceleration at high speed and on mountainous roads. Some governments have tried to counteract such trends by imposing taxes on gas suppliers, but manufacturers have systematically opposed such taxes by adopting the strategy of improving fuel economy rather than pay even a small 'gas-guzzler' tax.

Developing countries present some special problems in improving the effeciency of transportation systems. In many countries the leading world automotive manufacturers such as General Motors, Chevrolet, Renault, Volkswagen, Fiat, Mercedes Benz and Scania have established subsidiaries where cars and trucks are either assembled or entirely built locally. Despite this, cars and trucks have lower fuel efficiency in developing countries, mainly because of bad maintenance practices, low quality fuels and bad roads. Generally speaking cars and trucks have fuel efficiencies which are 20–50 per cent lower than their counterparts in industrialized countries.

Alternative Fuels

Liquified petroleum gas (LPG) and compressed natural gas (CNG) have a higher hydrogen to carbon ratio than gasoline, thereby emitting less CO_2 per unit of energy. They have a higher octane number than gasoline, permitting use of higher compression ratio engines. No major infrastructure changes are required for LPG or CNG use.

Hydrogen can fuel ultra-low-emission vehicles. Storage is a problem due to its low energy density. Compressed hydrogen storage is the most probable scheme, though liquid hydrogen or metal hydride storage is also possible. While proponents claim it is no more dangerous than gasoline, safety concerns need to be addressed before it will obtain public acceptance. In terms of its compatibility with existing infrastructure, hydrogen would require very significant changes. Today, the most probable source of hydrogen would be natural gas. In the future, it could be produced from biomass.

Biofuels include ethanol produced from sugars and starch by fermentation with yeasts. Ethanol can be used pure or as a gasoline extender in spark-ignition engines. In addition, lignocellulose – from energy forestry, agricultural and forest industry residues, and the carbohydrate fraction of municipal solid waste (MSW) – is a further source of biomass liquids. Such a resource is 20 times more plentiful in the US than maize, and does not compete with food production.

A number of plant-derived oils have also been considered for possible use as fuels in diesel engines including sunflower, soya, groundnut, cottonseed, rapeseed, palm oil and castor oil. Vegetable oils have been tried unsuccessfully in the past, raising problems of carbon deposits in the engine, clogged injection systems, high particulate emissions, reduced efficiency and high maintenance needs. Diesel engines operating on these fuels have reduced efficiency and higher maintenance requirements.

Biodiesel oil is a potentially important enhancer or replacer of conventional diesel fuel. It can be prepared from many renewable raw materials that include soybean, rapeseed and palm oils. The viscous, high-boiling triglycerides are processed to obtain more volatile methyl esters of the straight-chain fatty acids. Biodiesel oil is in the early stages of development but specimens of it have undergone many successful long-term tests in buses, trucks and tractors. In some of the tests, a mixture containing 80 per cent conventional fuel and 20 per cent biodiesel oil has been employed. Tests using 100 per cent renewable fuel have also been successful. In both instances, the results were superior in many ways to those noted when conventional diesel fuel was employed. The renewable fuel is practically sulphur-free. It is non-toxic and quickly biodegradable if spilled. On combustion it produces less toxic particulate matter. Only minor adjustments of existing engines are required to attain optimum performance.

Electric vehicles, using batteries, are of great current interest, especially as 'urban vehicles'. If the electricity that fuels them comes from a non-fossil source, they can yield a significant greenhouse gas emission reduction. The key barrier to their implementation is the current state of chemical battery technology, resulting in high costs, heavy automobiles and limited range. Also, while a gasoline automobile can be fueled in a few minutes, electric automobiles are generally fueled much more slowly over a time span of hours. Large-scale introduction of electric vehicles could require major infrastructure changes, not only in the energy distribution system and the automobile itself, but also in the electric power generation industry.

Fuel cells produce power electrochemically, as opposed to combustion processes in conventional engines, and can potentially reach significantly higher conversion efficiencies – perhaps by a factor of 2–3 – compared to today's internal combustion engine. Fuel cells come in several varieties but the proton-exchange-membrane (also called solid polymer) fuel cell is the leading candidate for automobiles because of cost, size, simple design and low temperature (<120°C) operation. The technology was originally used in the US space program. The fuel cell requires hydrogen fuel which may be generated on-board the automobile by reforming methanol or natural gas.

Air pollution in Mexico City

Mexico City is notoriously one of the most polluted cities of the world, and transport (chiefly automobiles and taxis) is mainly responsible because it generates:

- 97 per cent of the carbon monoxide;
- 66 per cent of the nitrogen oxides, and
- 54 per cent of related organic compounds.

The strategies to be followed to reduce them are:

- decreasing the overall demand for travel;
- shifting travel demand towards less polluting or less fuel-intensive modes of transport, such as micro, minibuses and large buses, and
- reducing emissions per kilometer driven.

The US has focused almost exclusively on the third option, primarily by imposing emission standards on all new vehicles and requiring vehicle inspections, which would be difficult to conduct in Mexico.

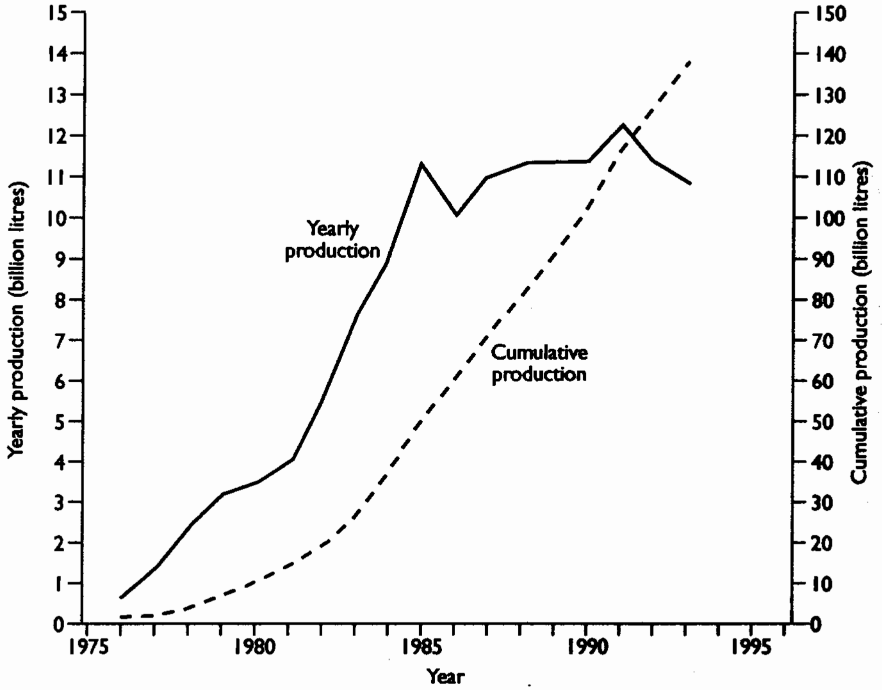
By using technical measures to decrease emission per km, Mexico City could reduce current emissions from transport by 1.2 million tons (more than 50 per cent) at a cost of US$ 560 million. Adding a gasoline tax would achieve the same reduction with a cost saving of about 20 per cent. The tax would also generate about US$ 300 million in public revenue within the metropolitan area alone, which could be used to reduce other, more distortionary taxes.

Mexico City has already begun to implement several of these measures, including gas retrofits for high-use vehicles, emissions standards and inspection programs for all vehicles, and replacement of older taxis by newer, catalyst-equipped models. In addition, unleaded gasoline has been introduced, and prices of leaded and unleaded gasoline have been increased by about 50 per cent.

Source: *The World Development Report*, The World Bank, Washington DC, US (1992).

Ethanol in Brazil

Hard-pressed by the rising cost of oil imports that seriously threatened its balance of payments in the 1970s, the Brazilian Government encouraged the production of ethanol from sugarcane and the adaptation of Otto-cycle engines to work either on 'neat ethanol' (96 per cent ethanol, 4 per cent water) or 'gasohol' (78 per cent gasoline, 22 per cent ethanol). The program started in 1976 and rapidly reached a yearly production of 12×10^6 m^3 (about 200,000 barrels a day) of ethanol, replacing one-half of the gasoline that would have otherwise been used in automobiles in Brazil (Figure 7.3). At one time, one-half of all automobiles in the country were running on gasohol and the remaining on 'neat ethanol'. More recently that percentage has declined.



Source: Goldemberg, J, Monaco, L C, and Macedo, I C, 'The Brazilian Fuel-Alcohol Program', in Johansson, T B, Kelly, H, Reddy, A K N and Williams, R H (eds), *Renewable Energy – Sources for Fuels and Electricity*, Island Press, Washington DC, US (1993).

Figure 7.3 Evolution of ethanol production in Brazil

The program was established to reduce the country's dependence on imported oil and to help stabilize sugar production in the context of cyclic variations of international prices. An important consideration has always been the contribution to increase direct job opportunities for both skilled and unskilled workers. Also, the program was almost entirely based on locally manufactured equipment, helping to establish a strong agro-industrial system, and generating a significant number of jobs (700,000, of which 75 per cent were direct jobs).

The cost of alcohol is not yet competitive with the international selling price of gasoline of about US$ 25 a barrel. Most countries, however, have established heavy taxes (100 per cent or higher) on gasoline to discourage unnecessary driving and/or as a method of reinforcing Treasury funds. The difference between the price paid by drivers and the real cost is redistributed to lower the cost of other petroleum derivatives such as diesel or LPG, or to help social programs. In the case of ethanol in Brazil, the extra cost is not available for redistribution and goes to the producers. The justifications for such policy are the positive environmental and social consequences of the program.

The local benefits of using ethanol as a fuel are evident in the city of São Paulo where the quality of the air has improved while the number of automobiles has increased (alcohol fuel does not emit sulphur oxides). In addition, there are the global benefits of a reduction in net CO_2 emissions, since ethanol is a renewable resource. This is not entirely true because fossil fuels are used in alcohol production but the balance is very positive.

Table 7.5 shows that the emission of 9.45 x 10^6 tons per year of carbon (approximately 15 per cent of total emissions of Brazil due to the use of fossil fuels) is avoided by the use of ethanol as a replacement of gasoline.

Table 7.5 *Net CO_2 emissions due to sugarcane production and use in Brazil*

	10^6 t C/year
Ethanol substitution for gasoline	−7.41
Bagasse substitution for fuel oil (chemical and food industry)	−3.24
Fossil fuel utilization in agro-industry	+1.20
Net contribution (uptake)	−9.45

Source: Macedo, I C, 'The Sugar Cane Agro-Industry: Its Contribution to Reducing CO_2 Emissions in Brazil', *Biomass and Energy*, 3 (2) (1992).

The program has led to technological developments, both in agriculture production and sugarcane processing, leading to lower ethanol costs and the possibility of a large surplus in biomass-based (bagasse and agricultural residues) electricity. This would further improve its advantages in promoting a 'CO_2-free' energy source.

The investments in job creation have ranged from US$ 11,000 (in the northeast) to a maximum of US$ 45,000 in the southern part of the country. As a comparison, the average investment needed for job creation in the 35 main sectors of the Brazilian economy, according to estimates made in 1991, varies from US$ 10,000 to US$ 125,000, averaging US$ 41,000. Selected agro-industrial activities (food, beverages and tobacco, farming, and paper and pulp) average investments of US$ 50,000/job; services (trade, supermarkets, communications, hotels and public services) average US$ 44,000/job, and the chemical industry, including petrochemicals, averages US$ 125,000/job.

Even with the inclusion of land costs, only 14 sectors would provide jobs with lower investment than the ethanol industry.

The cost of ethanol has been going down as production increases in recent years, declining by 30 per cent for each doubling of production (see Figure 7.4). The present cost ranges from US$ 0.208–0.229 per liter, or US$ 33–37 per barrel. The technical equivalence of ethanol per liter of gasoline (in a neat ethanol engine) is 1.20 and, therefore, the replacement cost of gasoline by alcohol is about US$ 40–44.

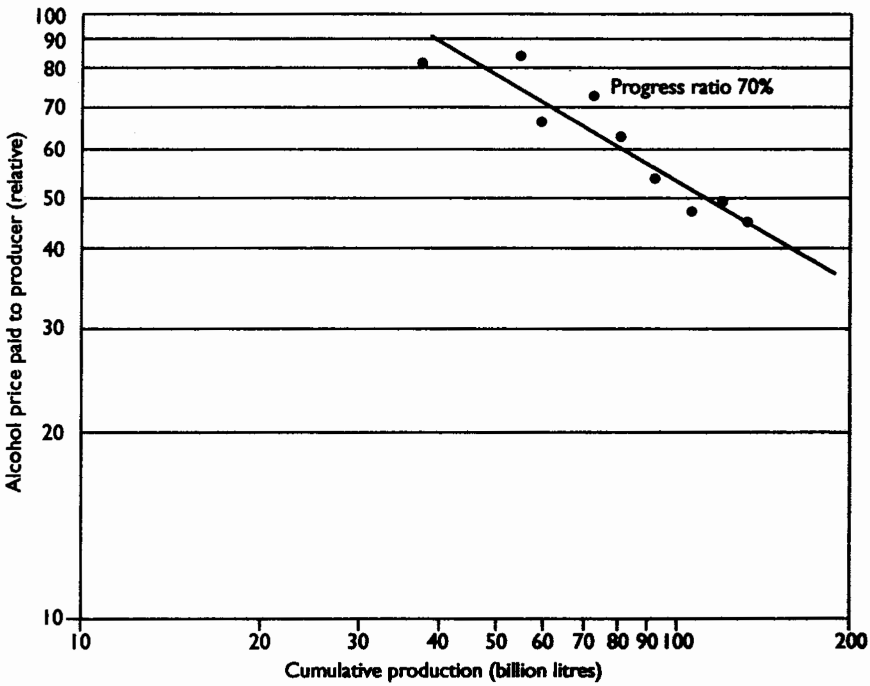


Figure 7.4 Market penetration of alcohol in Brazil

Industry

The aggregate energy intensity in the OECD manufacturing sector decreased by 3.1 per cent a year from 1973–1988. The decrease in energy intensity, during this period, was 43 per cent in the US and 45 per cent in Japan. Industry is, therefore, a very dynamic sector in which energy and the resulting emission of pollutants can be greatly reduced.

There are a number of energy conserving 'horizontal technologies' which are used in many industries. These can be of two types:

- Components on basic items of equipment in all areas of industry; and
- Technologies for individual applications.

In the first category are included:

- motors/drives: development of faster and more intelligent motor controllers (eg with new power electronic systems);
- boilers for steam or hot water production (eg low emission burners);
- compressors with super-insulation against noise for direct use at work sites (no network for compressed air, no losses); and
- energy management systems for industrial processes and buildings.

In the second category of horizontal technologies, with broadly varied individual application, can be included:

- process control (new sensors, microelectronics);
- separation of substances at low temperatures (eg via membranes);
- freeze concentration (replacing more energy-expensive evaporation);
- laser processing (steel hardening, cutting, hole drilling);
- infrared heating, drying, and
- solar process heat for industry (especially in warmer climates).

In addition, there are numerous advances in specialized technologies for the production of steel, chemical products, non-ferrous metals (such as aluminum), pulp and paper, and food, beverages and tobacco.

Most of the processes in use today were developed at a time of abundant, cheap energy and when environmental concerns were either non-existent, or little understood, which is why there are so many opportunities for energy-saving improvements either to increase competitiveness or to improve the public image of formerly polluting industries.

In the developing countries, industry was established very late in the development process: in the former colonies most of the manufactured products were imported from Europe or the US except for some goods produced locally, mainly by artisanal methods. Over the years, as local markets grew, whole factories or machines were transferred to developing countries and served as the basis for local development. Usually the equipment was second hand or obsolete but still served the purpose of producing low quality consumer goods. The equipment is, however, quite inefficient and only recently have the improvements made in the industrialized countries been reaching developing countries. The integration of many of them in the international economy, and increased trade and exports are leading to a strong modernization of the industrial development of many of these countries.

Buildings

About 20 per cent of all end-use energy in the European Union is consumed in houses and apartments, and the situation is not very different around the world. In industrialized countries, where the housing problem of the population has been largely solved, the task is mainly to retrofit existing buildings: appreciable energy savings can be achieved that way. In developing countries, the problem is different because there is an enormous 'deficit' in housing, so great savings can be achieved by improving design and construction of new buildings. This is a very promising area, since experience shows that to construct an improved building costs only a small percentage more than a conventional one. On the regulatory side, important actions that can be taken are:

- building codes for existing buildings;
- building codes for new buildings (even stricter, because it would be more expensive to delay and add comparable improvements to existing buildings);
- energy certificates for buildings; and
- financial incentives (tax reductions, grants) for energy-efficient buildings.

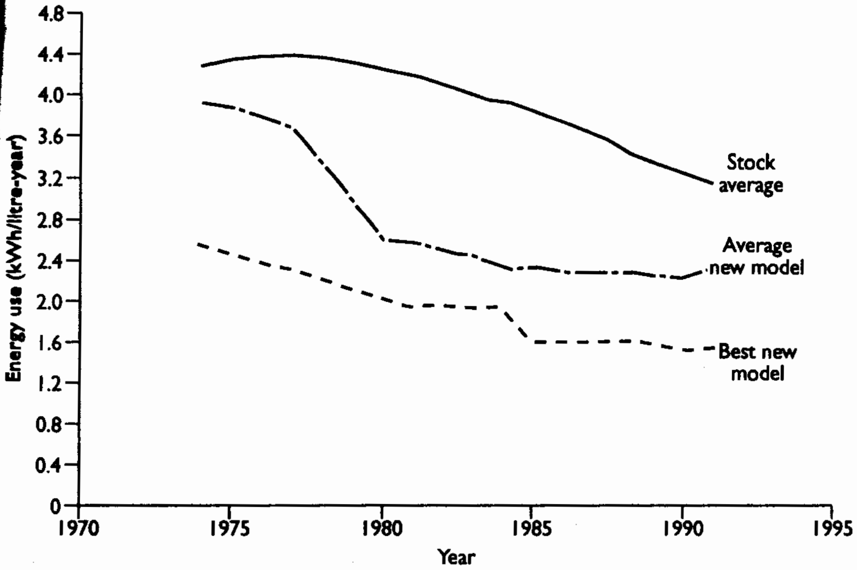
In Switzerland, for example, just by making building codes stricter, commercial buildings built today consume, per square meter, only one-half of the energy consumed 20 years ago.

As far as specific technolgies are concerned, there are three main areas of action: domestic appliances, lighting and space heating.

Domestic appliances, especially electrical appliances, are being used increasingly all over the world. There are, therefore, ample opportunities for technological improvements in each of the following areas:

- refrigeration (eg incorporating CFC-free insulation that is more effective, using aerogels, gas-filled panels and vacuum plates; high-efficiency refrigerators, especially equipped with better compressors);
- new types of cookers (eg advanced microwaves, electromagnetic induction) and improved stove insulation;
- efficient wood heaters (primarily outside OECD);
- washing machines employing a range of improvements (requiring less water to heat, lower washing temperatures and mechanical drying at higher spin-speeds which reduces thermal needs);
- television sets and computers (flat screens and low-energy consumption in stand-by mode); and
- office equipment (eg fax machines and copiers that feature power management and reduced stand-by losses).

An example of the advances in energy efficiency in freezers in Sweden is given in Figure 7.5.



Source: Swischer, J C, Hedenström, J C and Lewald, A, 'Dynamics of Energy Efficiency in Swedish Buildings', ACEEE Summer Study on Energy Efficiency in Buildings, Copenhagen, Denmark (1993).

Figure 7.5 Historical progress of energy efficiency of freezers in Sweden

Lighting, particularly, is a field in which the potential for electricity saving through retrofitting older systems is of the order of 60 per cent. Even higher savings are possible if 'passive solar architecture' is incorporated into the design of new buildings.

Specific areas of action are:

- high efficiency lamps and reflectors;
- automatic control of artificial light as a function of daylight;
- sensors that control room lighting according to occupancy; and
- advanced light-control systems providing individual availability of light only in immediate work areas, etc.

Space heating and hot water are frequently produced in conjunction, so techniques to improve efficiency can be applied to both of them simultaneously. Examples are:

- condensing water heaters;
- solar water heaters;
- district heating;
- advanced cost-competitive heat pumps to provide heating and cooling; and
- recovery of waste heat for local water heating from air conditioners, refrigeration systems, etc.

In developing countries most buildings present characteristics quite distinct from those in industrialized countries. First, they almost exclusively use local materials. There is thus scope for local advances in this area and this has already happened in India in the production of low cost, less energy-intensive methods for producing bricks, which is one important component of the energy 'sunk' into buildings. Secondly, buildings in developing countries do not usually require space and water heating, thus saving significant amounts of energy in operating costs (see Table 5.6). An interesting rule of thumb is that in industrialized countries the energy used per year in the use and maintenance of a building is 20 times smaller than the energy 'sunk' into the building. In developing countries use and maintenance is closer to 50 times smaller than the energy 'sunk' into the building.

Carbon Recapture

There are three approaches to a solution of the problem of deforestation and other carbon emissions:

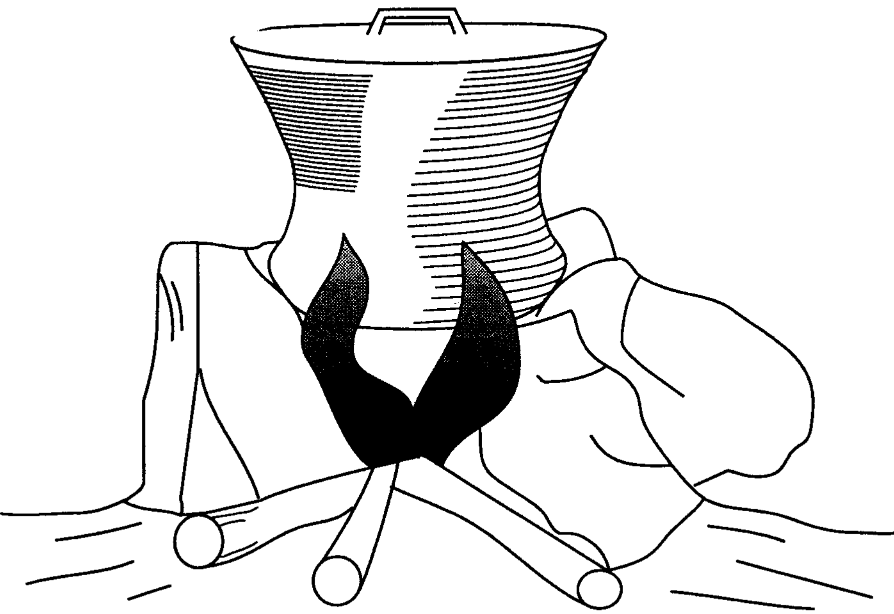
- improvement of the efficiency of the use of fuelwood for cooking which is directly energy related;
- capturing CO_2 emissions (which are closely related to global warming) at source; and
- afforestation.

Improvement of the Efficiency of the Use of Fuelwood

The basic problem of the use of fuelwood for cooking is its dismally low efficiency which converts only about 10 per cent of the energy contained in the fuelwood into useful energy in the pot. This is the case of the three-stone cooking fireplace (Figure 7.6) which is in wide use among the rural poor in developing countries since it costs almost nothing, and also provides light and heat, repels insects and serves as a social meeting place.

On the other hand, these fireplaces are often dirty and dangerous: dirty because smoke and soot settles on utensils, walls, ceiling and people; dangerous because the fire is open and the pots can easily tip over. The smoke irritates and is a well-known danger to health.

With increasing affluence, people move from simple, primitive stoves using dung or crop residues, to wood or charcoal used in metal or insulated stoves, and finally to propane, liquid petroleum and electrical appliances, climbing an 'energy ladder' which characterizes cooking (Figure 7.7).



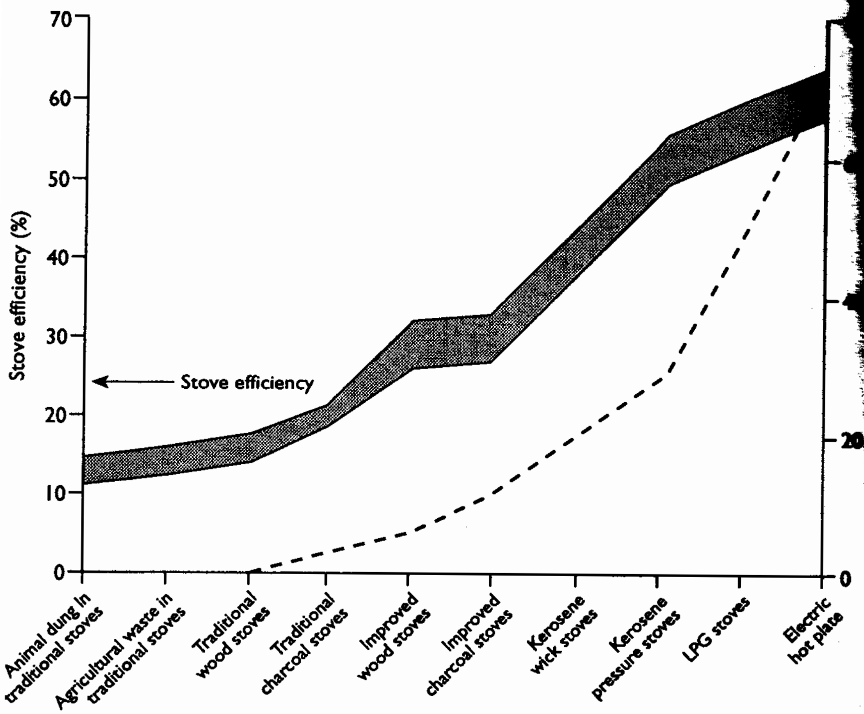
Source: Kammen, D M, 'Cookstoves for the Developing World', *Scientific American*, 273, 64–67 (1995).

Figure 7.6 The three-stone cooking fireplace

Moving up the 'ladder', improvement in pollution reduction is dramatic: a gas stove emits 50 times less pollutants and is 5 times more efficient than a primitive stove. With higher efficiencies, capital costs also increase, posing severe problems for the very poor. This is, however, the direction in which to move and a large number of programs in Africa, Asia and Central America have been successful in disseminating many millions of more efficient stoves used in rural areas and cities.

Experience has shown that very simple improvements to primitive cooking stoves cost little and can improve their efficiency considerably. This is particularly the case for the Kenya Ceramic Jiko (KCJ), 700,000 of which are in use today in East Africa, as well as some of its variants. Over 13,000 KCJ stoves are sold in Kenya each month.

Improved fuelwood cookstove programs succeeded in China but not so well in India. Jiko stoves, so successful in Kenya, did not fare well in Rwanda. The reason why programs for dissemination of better stoves succeeded in some countries and not in others is difficult to understand but seems to depend heavily on education and grassroot involvement rather than government action alone.



Source: Baldwin, S F, *Biomass Stoves: Engineering Design, Development and Dissemination*, VITA, Arlington, VA, US (1987).

Figure 7.7 Efficiency of stoves with commercial and non-commercial fuels

Capture of CO_2 at Source

Removal and recapture of CO_2, after it has been produced, is another technical option to be considered when the main concern is the greenhouse effect. Two approaches to the problem have been developed:

- direct capture at the source before it spreads out into the atmosphere; and
- indirect capture from the atmosphere through afforestation.

About one-third of all CO_2 emissions from fossil-fuel energy sources comes from electric power plants, which therefore provide an appropriate focus as a control target.

The idea of capturing CO_2 from the flue gas of power plants did not start with concerns about the greenhouse effect but as a possible economic source of commercial CO_2. Several commercial CO_2 recovery plants have been built and operated in the US but most of them have been closed for economic reasons caused by the drop in crude oil prices. A few smaller capture plants are operating to provide food-grade CO_2, used in dry ice production for freezing food.

In general, CO_2 capture processes have significant energy requirements, which reduce the plant's conversion efficiency and net power output, thereby increasing the amount of CO_2 produced per net kWh of electricity generated.

Table 7.6 compares a number of CO_2 capture technologies and their energy penalties.

Table 7.6 *Comparison of CO_2 capture technologies for existing coal-fired plants*

Process	*Energy penalty*[1] *(%)* *(c)*	*Nominal CO_2 recovery (%)* *(d)*	*Net reduction of CO_2 emissions*[2] *(% of base case)*
Base case – no CO_2 removal	0	0	0
Air separation fuel gas recycling	30	100	100
Molecular sieves	80	90	50
Cryogenic fractionation	75	90	60
Membrane separation	63	80	46

Notes: [1] 100 per cent × $(a{-}b)/a$, where a = net power plant output with no CO_2 controls and b = net power plant output with CO_2 controls. Includes CO_2 compression to about 130 atm for the CO_2 capture plant.

[2] 100 per cent × $[1{-}e(1{-}d)]$, where e is the ratio of fossil fuel burned in the capture case to that burned in the no capture base case for equivalent net power output (calculated as $1/(1{-}c)$, where c is the energy penalty expressed as a fraction) and d is the nominal recovery expressed as a fraction.

Source: 'Energy and Environment Technology to Respond to Global Climate Concerns'. *Scoping Study 1994*, IEA/OECD, Paris, France.

The most interesting method seems to be the removal of nitrogen from the air prior to the combustion process since it has the lowest energy penalty: a cryogenic air separation plant installed next to the power plant could produce a fairly pure oxygen stream for combustion; the flue gas would then only contain CO_2 and water, with some nitrogen among the trace components. Once the CO_2 is captured, there is still the problem of sequestering it or using it for commercial purposes. In the US alone over 1.6 Gt of CO_2 is produced each year from power plants and the commercial use of CO_2 – for example for dry-ice production – is only 40 million tons per year, equivalent to about 2 per cent of the CO_2 produced; therefore, there is no incentive to capture CO_2.

Afforestation

As discussed in Chapter 5, land changes and deforestation contribu icantly to total carbon emissions: fossil fuel use contributes 6 Gtons of per year and deforestation approximately 1.6 Gtons.

There are a number of forest practices that could be used to se carbon:

- afforestation of agricultural land;
- reforestation of harvested or burned timberland;
- preservation of forestland from conversion;
- adoption of agroforestry practices;
- establishment of short-rotation woody biomass plantations;
- lengthening forest rotation cycles;
- modification of forestry management practices to emphasize ca storage; and
- adoption of low-impact harvesting methods to decrease carbon rel

A strategy of afforestation, ie immobilizing land as a carbon sink, se more attractive in temperate or boreal forests, but a strategy of agrofore ie growing forests for energy (or other) uses, seems more appropriat tropical areas because of the rapid rotation of forest growth that can achieved. Typical capture rates of approximately 5 tons of carbon per y per hectare can be achieved in temperate forests while approximately 20 t of carbon per year per hectare can be captured in tropical areas.

The advantage of agroforestry for sequestering carbon on land is that i compatible with, and may even enhance the productivity of, existing ag cultural land. The withdrawal of carbon from the atmosphere into woo biomass, whether through reforestation or agroforestry, only takes pla while the trees or forests are growing. Reforestation contributes, therefo only temporarily to the stabilization of atmospheric concentrations of CO On the other hand, one of the greatest benefits from reforestation might be lessening of pressures on undisturbed forests. If reforestation with agro forestry provided a source of local fuel and income, degradation and defor estation of nearby forests might be reduced.

In trying to quantify the potential for carbon sequestration, a wide array o estimates on land availability, growth rates and costs are found.

A detailed analysis of the existing literature has been conducted by Working Group III of IPCC and the rough figures that can be considered as representative, within a factor of 2, are:

- Reforestation of 500 million hectares of degraded lands in the tropics and 100 million in Europe and the US appears to be possible.
- If all these lands were reforested, 50–150 x 10^9 Gtons of carbon might be withdrawn from the atmosphere over a period of several decades or

0.5–1.5 Gtons/per year contributing, therefore, significantly to a postponement of greenhouse warming.

- In North America, costs for carbon absorption range from US$ 9–65 per ton of C and sometimes higher. Costs as low as US$ 7/ton C are commonly found in the literature. However, it is most likely that costs in tropical forests are much lower than in boreal forests.

In the light of the above figures, it is reasonable to accept the possibility of withdrawing 1 Gton of C per year (approximately 20 per cent of present fossil fuel emissions) through reforestation of 500 million hectares at a cost of US$ 10/ton of C, ie a total expenditure of US$ 10 billion a year or less than 0.1 per cent of the world's GNP. As we will see later (in Chapter 8) most other strategies are an order of magnitude more expensive.