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Chapter 9: Clean Coal

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Coal is and will remain a major fuel worldwide. But the environmental impact of burning it will ensure ever stiffer controls. In conventional plant for electricity generation, this has led to the use of flue-gas desulphurization in boilers, and improved burners to reduce the emissions of nitrogen oxides. However, this has increased costs, and reduced efficiency - thereby increasing C02 emissions.

Emerging technologies for generating heat and electricity from coal offer greater fuel flexibility, higher efficiencies and lower environmental impact than conventional technologies. A wide variety of specific technologies, based on fluidized-bed combustion and gasification, are still developing rapidly, often cross-fertilizing from earlier designs and lessons. Existing and proven forms of bubbling and circulating fluidized-bed plants have been widely installed to take advantage of their fuel flexibility, smaller scale and reduced local environmental impacts, especiallyfor urban sites, often for applications which use both heat and electricity - cogeneration.

Second-generation technologies, especially those using pressurized fluidized beds or integrated gasification to power combined cycle and other advanced gas turbine systems, offer greater efficiency improvements and environmental benefits at potentially lower costs. These technologies are not yet commercially developed, but conceptual designs and some demonstration plants show a rapid trend towards reduced cost and better performance.

The progress of such 'clean coal' technologies will depend upon: the nature and timing of emissions constraints and penalties; the extent to which development and demonstration of more advanced systems receives financial support from governments and/or from coal industries seeking to diversify 'downstream'; aspects of utility regulation, for example with respect to cogeneration; and international support for technology transfer to encourage developing countries to use these cleaner and more efficient systems. Clean coal technologies appear destined to play a steadily increasing role in global energy supply, but the pace at which they penetrate the market will depend strongly upon such policy developments.

The world now uses more than 3,500 million tonnes of coal a year. Almost all of it is burned in plant using traditional technologies that date back at least sixty years - stoker-grate firing for small units, and pulverized-fuel firing for large units. The environmental impact of burning coal this way is now causing serious concern. It emits noxious combustion gases like sulphur and nitrogen oxides (SOx and NOx), precursors of acid precipitation; and international agreements and national standards in many countries now impose strict controls on these emissions. Moreover, carbon dioxide from fossil fuels is now recognized as a key factor in the 'greenhouse effect' of global warming and climate change; and coal releases more carbon dioxide per unit of energy than either oil or natural gas. Global negotiations are now seeking agreement on stringent control of carbon dioxide emissions; any effective agreement will have a significant impact on future use of coal.

In many countries a major use of coal is to raise steam to generate electricity, in traditional coal-fired power stations. But the efficiency of the steam cycle for pure electricity generation is low, usually well below 40%. Flue-gas desulphurization to control sulphur dioxide and selective catalytic reduction to control nitrogen oxides both reduce overall efficiency further; and this aggravates the emissions of carbon dioxide. Within the past decade, however, a widening range of new coal-use technologies has emerged. They can minimize emissions of sulphur and nitrogen oxides, while simultaneously achieving higher efficiencies to reduce emissions of carbon dioxide. Among the most promising concepts are 'fluidized-bed combustion' (FBC) and 'gasification', in a rapidly expanding variety of designs; some of the latest designs combine the advantages of both concepts.

(Except where referenced below, for a fuller description of and commentary on the concepts outlined here see Walter C Patterson, *Coal-use Technology in a Changing Environment*, Financial Times Business Information, 1990. For the latest information see, for instance, *Modern Power Systems*, and *Coal and Synfuels Technology*.)

9.1 Coal-use technologies

In FBC, the combustion chamber contains a bed of inert particles like sand or ash, which is 'fluidized' by combustion air blown in from below, and heated to incandescence. Coal or other fuel injected into this turbulent glowing bed ignites and bums. Because the bed acts as a heat reservoir, FBC can burn almost any combustible material, including very low-grade fuel. Coal, of course, is not one substance but a wide range of substances, with widely varying characteristics; but an FBC unit with appropriate fuel-handling equipment can burn the entire range, from lignite to anthracite. It can also burn pit spoil, heavy oil, peat, wood, wood waste, refuse, sewage sludge - the list grows steadily longer. With fuel prices and supplies ever harder to predict, this fuel flexibility is one of FBC's most attractive attributes. The operating temperature of FBC, about 850 C, is low enough to minimize NOx formation; staged injection of combustion air can reduce it yet further. If a 'sorbent' like limestone or dolomite is injected, most of the sulphur in the fuel reacts with the calcium in the sorbent and is retained in the bed as solid calcium sulphate.

FBC designs can be classified into three modes: *bubbling* (BFBC), *circulating* (CFBC), and *pressurized* (PFBC). BFBC is simple and compact, suitable for units of output up to some tens of megawatts of heat. MC is more complex, requiring a tall combustion chamber and heavy-duty cyclone; but it offers greater fuel flexibility and better control of

S0x and NOx, and is suitable for units with outputs from tens to hundreds of megawatts. MC is the most complex of all, requiring a pressure shell and equipment for feeding fuel and sorbent and removing ash under pressure; but it offers good control of S0x and NO, and its pressurized combustion gas can be fed directly into a gas turbine. Instead of requiring a premium fuel like natural gas, a combined cycle (CC) plant based on PFBC can burn cheap low-grade coal, with an overall generating efficiency above 40%.

FBC of any kind requires sorbent for sulphur-trapping; a large unit, for instance, may require tens of thousands of tonnes of limestone per year. Extracting and transporting the sorbent may pose an environmental problem; so may disposing of the even larger quantity of sulphated sorbent. Tests indicate that the material is generally benign, and indeed that it may be usable as an analogue for light-weight concrete, or even gravel; but the specifications must be established for each particular fuel and sorbent at each particular site.

Coal gasification is another route to coal-fired CC, as 'integrated gasification combined cycles' or IGCC. Modem gasifiers can be classified into three types: *stationary bed, fluidized bed* and *entrained flow.* Each produces a fuel gas of moderate calorific value, lower than that of pipeline-quality natural gas, but entirely satisfactory as a fuel provided it does not have to be transported any considerable distance. Its sulphur content, mostly hydrogen sulphide, can be removed by conventional chemical clean-up, emerging as either elemental sulphur or sulphuric acid. Both are commercially marketable by-products. The fuel gas is then burned directly in a gas turbine, as the first stage of a CC plant, with an overall generating efficiency of more than 40%.

Different gasifiers offer different advantages and disadvantages. Some feed the fuel dry, others as a water slurry, affecting fuel flexibility and efficiency. Some require a large and costly 'radiant boiler' to recover heat from the gasification reaction. Those that do not recover this heat for use have lower efficiency. Some discharge ash as coarse agglomerate, some as granular slag. Both appear to be benign, and the slag can be used directly as aggregate, for instance for roadways. Current gasifier designs are mostly based on gasifiers originally intended to convert coal completely into 'synthesis gas' for manufacturing chemicals. Complete conversion of coal usually requires an oxygen plant, entailing extra capital cost and a significant fraction of the electrical output of the CC plant, effectively lowering the overall efficiency. Some recent gasifiers, specifically intended for power generation, use ordinary air, eliminating this efficiency penalty; the unconverted coal is burned to raise steam for the steam cycle in the CC plant.

Table 9.1 Comparative performance of coal-use technologies for electricity generation: indicative estimates

	Thermal efficiency %	**Unit capital cost**	**Generating cost**
Technology		(1990 £/kW)	(1990 p/kWh)
PF+FGD	37	950	3.7

CFBC	38	885	3.5
PFBC	40	760	3.1
IGCC	42	780	3.1
Topping cycle	45	715	2.8
Natural gas CC	47	370	2.0-2.4

Note: conventional pulverized fuel and flue gas desulphurization.
Assumption: 10% discount rate; coal at £l.7/GJ; natural gas at 24p/therm.
Source: J.Harrison, Coal Research Establishment, in presentation to British Institute of Energy Economists, London, meeting spring 1991, Chatham House.

All these technologies are evolving with remarkable speed, often cross-breeding between concepts to form hybrids that promise yet higher efficiency, lower environmental impact and lower unit costs. CFBC, for instance, does not of itself much increase generating efficiency, although it avoids the loss of efficiency involved in flue-gas desulphurization (FGD). But a gasifier and gas turbine 'topping cycle' can be added, converting the plant to CC, burning the solid 'char' residue from the gasifier in the CFBC unit. Again, PFBC efficiency is limited because the fluidized bed operates at only 850 C, whereas a modem gas turbine can accept an inlet temperature of 1,260 C. Accordingly, fuel gas - perhaps from a gasifier - can be blended with PFBC combustion gas and burned in the gas turbine inlet, raising the temperature and the overall efficiency (see Table 9.1 for generic performance data). These technological permutations and combinations suggest that the potential for FBC and gasification can be extended significantly further.

Because the applications for both FBC and gasification vary widely, as will be described below, costs also vary widely from unit to unit. CFBC is already a commercial technology, in a hotly competitive international context; and manufacturers are reluctant to provide much financial detail. Recent turnkey plant, including steam-raising equipment, turbo-alternator and ancillaries, have been ordered at contract prices ranging from less than $1,400/kW to more than $2,000/kW. The wide disparity of costs arises from the particular plant configuration chosen, including the number of individual boilers and turbines. If the plant is to burn cheap waste fuel, the fuel-handling gear may be correspondingly expensive, to cope with awkward materials. Other features may likewise be particular to the given design.

Neither PFBC nor IGCC is yet fully commercial; cost data are thus at best indicative. The Tidd PFBC project in Ohio, replacing an existing steam system but retaining the existing steam boiler, had an estimated cost of $185 million, for an output of 80 megawatts of electricity, or about $2,300/kWe. The follow-up project, now in the design stage, is a 330 megawatt PFBC at the nearby Sporn plant, at a cost estimated to be $579 million, or $1,750/kWe. These are of course demonstration plants, conservatively designed and heavily instrumented; commercial units would be less expensive. On the other hand these prices are for repowering projects, retaining some of the original plant; a complete turnkey PFBC plant would cost correspondingly more. Shell has estimated that the unit capital cost of a 250 megawatt European IGCC plant like the one now under construction at Buggenum in the Netherlands would be some $1,910/kWe; they add that scaling up to

400 megawatts would reduce this to some $1,400-1,500/kWe.

The capital cost of these coal-use technologies is, and always win be, higher than that of plant of equivalent capacity burning oil or natural gas, simply because coal is a solid fuel and produces a solid waste. What matters, however, is the cost of the electricity and/or heat delivered. At the present low price of natural gas, coal-fired generating plant is hard-pressed to compete. Nevertheless, coal reserves remain much greater than natural gas reserves worldwide. The current enthusiasm for natural gas CC seems likely to accelerate depletion of natural gas reserves and exert strong upward pressure on prices, especially if supplies from politically volatile areas like the former Soviet Union and the Middle East are jeopardized. Coal prices are unlikely to rise so much; coal reserves are too large, suppliers too numerous and reserves too widely distributed. As natural gas prices rise, advanced coal technologies will look increasingly attractive.

9.2 Primary market areas

Advanced coal-use technologies may be retrofitted to existing boilers and furnaces, or may serve as the basis for new greenfield installations. Some dozens of FBC retrofits are now in operation, mostly BFBC but also including a few large CFBC units and three demonstration PFBC units. An FBC retrofit can replace the bottom of the combustion chamber alone, or the whole of the combustion chamber, or the whole steam-raising plant including heat-exchange surfaces. Experience suggests that attention to site-specific details is essential: otherwise the nominal capital savings from retaining part of the original steam-raising plant may be offset by operating and maintenance problems arising from the difficulty of matching the original plant - fuel-handling gear in particular - to the retrofit.

Until recently, the size range of FBC units available made them suitable primarily for industrial boilers and furnaces and for combined heat and power. In the late 1970s and early 1980s, hundreds of small BFBC boilers and furnaces came into service, both new plants and retrofits of existing plants. Since the early 1980s, however, the focus has shifted to CFBC, in ever-increasing sizes. CFBC allows greater fuel flexibility and better control of SOx and NOx. The low emissions allow CFBC plants to be sited in urban areas without major detriment to the environment. Accordingly, many of the more than 100 CFBC units now in service worldwide, in sizes from tens to more than 400 megawatts thermal, are cogeneration plants. They raise steam to generate electricity with back-pressure or pass-out turbines that also supply process steam for local industry, or steam or hot water for local district heating. Such applications also achieve overall fuel efficiencies better than 80%. Some of the latest CFBC units, however, are for pure electricity generation, in capacities of 150 megawatts of electricity and above, with reheat steam cycles; Electricite de France is involved in design studies for a CFBC unit with a capacity of 250 megawatts of electricity. Such plant can use cheap low-grade fuel of a wide range of specifications with minimal preparation, while meeting prevailing standards for SOx and NOx. Nevertheless, using a pure steam cycle means that their efficiencies, albeit better than those of traditional coal-fired plant with flue-gas desulphurization (FGD), are still likely to be less than 40%.

Higher efficiencies for pure electricity generation using coal can be achieved only by combined-cycle operation - that is, by PFBC or IGCC - or by technologies still at the laboratory stage, like coal-fired fuel cells and magnetohydrodynamics (MHD). The 330 megawatt Sporn PFBC plant may get the go-ahead in the US by 1993. The first utility-scale IGCC plant, the 250-megawatt Buggenum unit, is now under construction in the Netherlands; and at least two others of comparable size have been ordered in the US, in Massachusetts and Florida. Progress will be studied closely. A number of utilities are carrying out feasibility studies of utility-scale PFBC and IGCC units, with a view to ordering plant later in the 1990s. Companies in Britain, Germany, France and the US are also pursuing the possibility of adding a coal gasifier, gas cleanup and gas turbine - a 'topping cycle' - to existing coal-fired steam plant, whether traditional, CFBC or PFBC. This will increase its efficiency and reduce both SOx and CO2 emissions per unit of electricity sent out.

Until recent years utilities sought higher efficiency simply by increasing the size of steam plant, to 1,000 megawatts or larger. This trend has run its course; and utilities are now more interested in plant of moderate size, up to perhaps 400 megawatts. Such plant is easier to site; much of it can be shop-built, reducing site problems; it is likely to be more reliable in operation, and require less backup capacity; and it can be built and brought on stream in three years or less, alleviating problems of forecasting for system planning. Advanced coal-use technologies fit well into this new utility philosophy.

A recent census by IEA Coal Research catalogued more than 1,300 coal-fired electricity plants around the world.

(*A. Mannini et al, *World Coal-fired Power Stations,* IEA Coal Research, HMSO, September 1990.)

Many of these will be candidates for retrofitting or replacement within the coming fifteen years; advanced coal technologies will undoubtedly figure prominently in the plans. Several developing countries, among them China, India and Brazil, have major coal reserves and are striving to expand their electricity systems. Commentators stress the need for cooperation, to enable such countries to install the cleanest and most efficient coal-firing technology available; but problems of technology transfer remain challenging. For most developing countries shortage of capital for investment is a daunting problem. The major engineering firms now active in advanced combustion technology cannot hope to sell plant on straightforward commercial terms; developing countries simply cannot afford them. Opportunities for joint ventures, licensing on 'soft' terms, or even 'build-operate-transfer' deals will need to be explored. International aid and development agencies like the World Bank will have a crucial role to play. Forthcoming global environmental agreements like a carbon dioxide convention may have to incorporate suitable measures to offer technical assistance to developing countries.

The fuel flexibility of many of the advanced combustion technologies offers a way to overcome the often low or unpredictable quality of fuels available in developing countries. In the longer term, and perhaps especially in developing countries, this same fuel flexibility will allow a gradual transition away from fossil fuels like coal, to the use of non-fossil fuels like biomass - wood and wood waste, bagasse from sugar cane, and similar cellulose materials - whose combustion does not add fossil carbon to the atmosphere. Biomass gasification combined cycles, for instance, could become an increasingly important generating technology, utilizing plant originally installed to bum fossil fuel.

(* Eric Larsen et al, 'Biomass Gasification for Gas Turbine Power Generation', in T.Johanssonetal (eds), *Electricity: Efficient End-use and New Generation Technologies and their Planning Implications,* Lund University Press, Lund, Sweden, 1989.)

Biomass can be gasified more easily than coal, often in the same gasifier; indeed some modern gasifiers were designed initially for biomass. The concept is already technically feasible; but its economic status and environmental impact will depend on organizing a sustainable and environmentally acceptable supply of suitable biomass fuel. In the meantime, coal will continue to be an essential component of the evolving fuel mix.

9.3 History

Until the mid-1970s almost nobody was interested in technological alternatives to stoker-grate and pulverized-fuel firing for coal. From the 1950s onwards coal itself had faced increasing competition from cheap oil and natural gas. Energy research and development, especially that funded by governments, was devoted almost exclusively to nuclear power. Early efforts to develop coal-firing for gas turbines failed. The engineering development that did affect coal-fired power plant was mainly on the steam cycle itself, scaling up unit size and increasing steam conditions in pursuit of higher steam-cycle efficiency.

The concept of FBC emerged in Britain and the US at the beginning of the 1960s, but attracted essentially no interest from electricity suppliers. The ability of FBC to trap fuel-borne sulphur during the combustion process itself had been identified by 1967. In 1968 Britain's National Coal Board proposed to build a coal-fired FBC demonstration power station at Grimethorpe, in Yorkshire; but the then Central Electricity Generating Board instead opted for a nuclear station now known as Hartlepool. In 1968 British engineers proposed the concept of PFBC, and the following year built a test rig that remained the world's largest through the following decade, carrying out much of the fundamental research that proved the feasibility of the concept. They worked, however, mainly under contract to clients in Sweden and the US, as successive British governments ignored the technology in pursuit of ever more trouble-prone nuclear power.

The first FBC power plant was a BFBC retrofit to a small old coal-fired station at Rivesville, West Virginia in the early 1970s. It was done on a shoestring, and the cost-cutting led to endless problems that culminated in shutdown before the end of the 1970s. Other early units experienced erosion and corrosion of boiler tubes, clogging of air distributors and frequent difficulties with coal feed. From the mid-1970s onwards, however, a series of industrial demonstration boilers and furnaces in the US and Britain confirmed technical feasibility; some are still operating today.

Meanwhile, however, CFBC emerged, initially from private industry in Scandinavia and with government support in Germany. The first demonstration plants were operating by 1980, and the technology thereafter took off with remarkable speed with scarcely a technical hitch, evolving virtually from plant to plant, increasing in size and versatility while meeting stringent emissions standards. Within a decade CFBC industrial boilers and cogeneration plants, district heating plants, and even utility-scale power plants have come into service in more than a dozen countries, from a lengthening roster of major engineering manufacturers. Questions of longer-term maintenance and reliability of course remain to be answered; occasional tube leaks and problems with refractory are being closely watched. But CFBC is already clearly a commercial technology, with a number of manufacturers competing hotly for new contracts across the world.

A tripartite agreement between Britain, Germany and the US in 1975 led to construction of the first large PFBC rig, at Grimethorpe in Britain. Many technical problems were encountered, especially relating to erosion of in-bed tubing; but many of them were solved, contributing substantially to advanced testing of PFBC configurations. Work in Sweden confirmed the feasibility of the concept; and three demonstration plants - at Tidd in the US, Escatron in Spain and a two-unit plant in Stockholm - are now in the commissioning stage and appear to be performing well. At least three engineering manufacturers now have significant PFBC programmes.

Gasification has a much longer history than FBC. But modem high-throughput, high-conversion gasifiers have been around for less than two decades. Most of the work in the early 1970s was carried out by oil and chemical companies seeking a way to produce coal-based chemical feedstocks or pipeline-quality 'synthetic natural gas'. Active interest in IGCC for electricity generation dates back only to the beginning of the 1980s, after the first prototype and demonstration gasifiers for feedstocks were already coming into service. The Cool Water project, a 100 megawatt IGCC plant in California, was a remarkable engineering success, starting up in 1984 ahead of schedule and under budget, and performing even better than expected - both more flexibly and more reliably. The Deer Park and Plaquemine demonstration plants both started up in 1987, and have likewise performed very well, spurring interest not only in the particular gasifiers involved, but also in IGCC itself. Quasi-commercial IGCC plants are now under construction in the Netherlands and the US; further units are planned, and more gasifier designs are under active development. A related concept, the gasifier topping cycle, is also reaching prototype stage in Germany and the US. Britain's topping cycle project was granted a modicum of government funding in 1991; but coal technology research remains the poor relation in Britain.

9.4 Pressures for increased uptake

The future use of coal itself faces many uncertainties. In recent history, coal has been used mainly to supply industrial process heat and steam, electricity, and district heating. In the industrial world all of these markets are under threat from both ends. Higher end-use efficiency of buildings and process plant will reduce the need for fuel of any kind to deliver the final comfort, light, process output and other 'energy services'. Governments around the world enthusiastically endorse the concept of increased efficiency; but many are laggard in implementing the practical measures already available, as described elsewhere in this book. Because coal is a comparatively awkward fuel to use, it must compete on price and availability against oil and gas in its traditional markets in the industrial world, and also in the expanding fuel markets of the developing countries. The advanced coal-use technologies, with their flexibility, higher efficiency and lower environmental impact, will help to reduce the gap between coal and competing fuels that have hitherto been more convenient.

The size of this gap of course depends on the actual and anticipated price of oil and natural gas where they can be used as alternative fuels to coal. In the present climate of uncertainty about future oil and gas prices, with dramatic changes not only year by year but week by week, no confident prediction is possible. Plant operators can seek long-term fuel supply contracts whose price structure includes appropriate escalation clauses; but the present volatility of the market suggests that long-term contracts may routinely link one winner and one loser. Against this background, the relative stability of coal prices is itself an attraction, especially if it can be coupled with coal-use technology whose fuel-specifications are undemanding and flexible. Moreover, in many countries coal is a domestic resource, whose security of supply may enhance its attractions against imports - provided the coal can be burned cleanly.

In general, current standards for emissions of SOx and NOx and for efficiency, where they are imposed, will enhance the attraction of advanced coal-use technologies compared to traditional technologies. To be sure, a move to these technologies will entail major investment in new plant, although as the technologies mature their unit capital costs are already declining, and this decline will probably continue.

But some standards - for instance those for NOx in Japan - are already so stringent that even FBC and IGCC plant may need to incorporate additional NOx control such as selective catalytic reduction (SCR). Depending on the particular fuel used and the standard in effect, SO2 control may be easier for IGCC than for CFBC and PFBC. FBC and PFBC require sorbent extraction and generate solid waste of limited economic value at best, whereas IGCC does not require sorbent extraction and generates marketable sulphur or sulphuric acid.

Carbon dioxide emissions limits will pose a much more serious problem for all fossil-fuel technologies, coal most of all. So long as fossil fuels are used at all, higher overall efficiency will become crucial. This implies, for instance, a steady expansion of cogeneration - for which the advanced technologies are especially well suited. Their fuel flexibility will also open the way to a progressive shift from fossil to biomass fuels with no net carbon emissions, in the same or similar plant.

For coal suppliers, this presents an important corollary. Higher efficiency means using a lower quantity of coal to deliver the same service. Coal suppliers may find their markets smaller than expected, and intense competition may reduce profit margins on coal sales even further - especially once biomass fuels become significant. One way for suppliers to counter this threat to their business will be for suppliers themselves to diversify downstream. Some coal suppliers are already actively involved in developing technologies to use their coal. They could expand these activities, for example, by building and even operating the power stations that use their coal. Profits from selling electricity could be substantially higher than those from selling coal; and the higher efficiency and lower environmental impact of the new technologies could make them the key to successful downstream diversification. If coal suppliers themselves seize this opportunity, the role of the new technologies could expand rapidly.

9.5 Constraints on uptake

The worldwide recession in industrial countries has created an unpropitious climate for investment by manufacturing industries and utilities. Demand for goods and services, and for the electricity and heat needed to provide them, is low, and interest rates are high. Orders for new plant of any kind, including advanced combustion plant, are unlikely to pick up until the world economy recovers significantly. Developing countries likewise face continuing acute difficulty with access to capital for industrialization. They also lack skilled people to build and operate new plant.

Even if new plant is contemplated, buyers are likely to look sceptically at advanced coal-use technologies if they are confident about future supplies and prices of oil or gas. Their scepticism may be reinforced by doubts about the long-term reliability and performance of the new technologies, and by questions about further tightening of environmental constraints on the use of coal.

9.6 Policy mechanisms and options

As indicated above, in sum, policy measures that will affect the rate and scale of moves to new coal-use technologies include:

- emission controls and standards;
- carbon dioxide protocols and emissions targets;
- the extent and focus of government financial support for demonstration plants;
- downstream diversification by coal suppliers;
- the impact of local planning controls;
- fiscal incentives;
- electrical utility regulation, especially concerning the role of cogeneration, district heating and independent power production;

• steps towards effective technology transfer arrangements between industrial and developing countries.

9.7 **Likely and potential impact**

The impact of emerging coal-use technologies in the 1990s will be determined by the implementation or otherwise of policy measures like those outlined in the preceding section. The likelihood of this differs markedly from country to country. Some national governments, notably the US and Japan, already have active and substantial programmes of support for new coal technologies. Curiously enough, although the US of course is a major coal producer, Japan's domestic coal industry has almost disappeared. Other countries - of which Britain is a prime example - have domestic coal industries but give them little if any support, in either policy or finances. Still others, like Denmark, are actively hostile to coal in general, for environmental reasons, regardless of the technology employed. Developing countries with major coal industries, notably China, India and Brazil, are aiming for rapid expansion of their energy systems, and have some interest in the new coal technologies; China in particular has some 2,000 small and basic FBC units, built between the mid-1960s and the early 1980s. But these countries continue to focus on traditional coal-use technologies, abetted by engineering firms in the industrial world and by international funding agencies like the World Bank.

The prospects for the new coal technologies are thus widely disparate in different places. But the rate of development over the past decade, against a generally unpromising economic and environmental background, has been remarkable. Historically, coal has played a central role in the evolution of industrial society. It continues to be abundant and widely available, from many suppliers, including domestic suppliers in many countries that use coal. Unlike oil, coal is not subject to the vagaries of an international cartel; unlike natural gas, coal is not dependent on supplies from areas that may be politically volatile. In these important respects coal is therefore a more reliable fuel than either oil or gas. From now on, however, the world seems bound to insist that coal clean up its act. In the next decade FBC and gasification, especially for cogeneration and combined cycles, will offer a burgeoning catalogue of opportunities to do so. They will also help to build essential bridges towards a future of high efficiency and low emissions, whatever the fuel.