23 January 1993 No1857 Weekly A$3·50

New Zealand NZ$5·80 (inc. GST) ISSN 1032 1233
Registered by Australia Post Publications NO. VBQ 8945

NewScientist

Why coal has a future

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In search of a better burn

(Coal could be the world's most attractive fuel in 20 years' time-clean and efficient to use, and in plentiful supply)

Dan Charles

COAL is nasty stuff. Extracting it from the ground involves tearing up landscapes with opencast mines, or risking human health and lives in deep mines. The traditional way to unleash coal's energy is by setting fire to it, a reaction that produces sulphur dioxide, nitrogen dioxide, carbon monoxide, a brew of aromatic hydrocarbons laced with toxic metals, to say nothing of carbon dioxide, the most notorious greenhouse gas. On top of all that, conventional power stations waste about two-thirds of the coal's energy.

Why bother? Because coal is the only fossil fuel available in quantities that for practical purposes are inexhaustible. It is the only fuel capable of providing the electricity needed for the economic development of central and south Asia-unless Japan and Korea succeed in persuading the region to go nuclear. Despite its drawbacks-and barring remarkable and unexpected breakthroughs in research on fusion-coal will be driving the world's power stations well into the next century. But the power stations needed to achieve these goals, and to replace those inefficiently belching out pollutants in the Americas, Europe and Asia, will look very different in the future.

Coal is a very versatile fuel. It can be burned as a solid, a liquid, or a gas. The hot gases that combustion releases drive steam generators in today's power stations, and they will probably power gas turbines in the next generation of station. Further into the future, the gases may produce electricity directly when they stream through a magnetic field, while hydrogen from coal could be generating electricity in battery-like fuel cells. Many of these technologies are far less polluting and capture coal's energy more efficiently than conventional power plants. But few are commercial yet.

Early progress

Despite the energy glut in the developed world since the mid-1980s, researchers around the world have made much progress on coal over the past decade, and are now beginning to demonstrate that their efforts are commercially viable. In the US, which has coal reserves second only to China, the government set up the Clean Coal Program five years ago with $2.75 billion for research on new coal technologies. These subsidies are supposed to promote a revolution in the way coal generates electricity. And although American power companies, like their· counterparts around the world, are notoriously reluctant to adopt what they see as risky new technology, tougher environmental laws may force them to change their ways.

Next month, the US Department of Energy will announce the fifth set of clean coal grants, amounting to $568 million. This latest round of federal funding is supposed to support the most advanced technologies available. Earlier grants helped build prototype power stations using well-established technology that industry has so far refused to adopt, for example, plants burning gas derived from coal, or which burn solid coal in a "fluidised bed", a cauldron of crushed coal and limestone. Other projects demonstrated ways to cut emissions of sulphur, the main cause of acid rain.

Last month, the department received 24 proposals for clean coal grants from industry; requesting a total of $2.3 billion in federal funds. One of the most ambitious proposals came from a group of eight companies who want $221 million to build a plant based on a process called magneto hydrodynamics, or MHD. the companies, including TRW; Textron, Westinghouse, Babcock and Wilcox, and Montana Power, would contribute another $300 million to the project. They spent about $1.5 million just preparing their proposal.

The idea behind an MHD plant goes back to 1831 when Michael Faraday discovered that moving an electrical conductor through a magnetic field creates an electric current. Conventional generators use this principle, too, spinning a coil of copper wiring in a magnetic field. In an MHD plant, however, hot, ionised exhaust gases from burning coal or gas act as the conductor. Superconducting magnets create a powerful magnetic field surrounding the exhaust channel (ordinary magnets would consume too much. power, thereby reducing the efficiency), and the stream of gases generates an electrical current as it passes electrodes in the walls of the channel.

Higher efficiencies

The MHD process bypasses many steps in conventional coal fired plants. Conventional plants take heat from burning coal to turn water into steam, which is used to spin turbines that in turn power a generator. Each step involves a loss of efficiency. Such plants convert only about 32 to 35 per cent of the heat from burning coal into electricity. A plant that includes an MHD generator can achieve an efficiency of 50 per cent, and perhaps up to 60 per cent, according to the DOE's calculations. To reach this level, however, an MHD system would need to work as part of an advanced form of combined-cycle plant. In this setup, a second cycle of power generation comprising traditional steam and turbine systems would extract energy from the hot exhaust gases that emerge from the MHD generator.

MHD plants offer environmental benefits, too. The more efficient a plant, the less carbon dioxide it emits per watt of electricity generated. The MHD process also removes sulphur from coal: by a happy coincidence, the most convenient agent to ionise combustion gases, potassium carbonate, reacts with sulphur from the coal to form potassium sulphate, which can easily be collected and recycled. On the other hand, because of its high operating temperatures, an MHD plant produces high levels of polluting nitrogen oxides, or NO_x. These can be reduced, however, by carefully managing how the coal is burned.

If the DOE decides to back the MHD proposal, the eight-strong consortium will build the world's largest MHD plant by 1999 near Billings, Montana. The plant would have a capacity of about 80 megawatts (about one-tenth the capacity of a large thermal power station) and about a third of its electricity would come from the MHD generator. Traditional gas and· steam turbines would provide the rest.

Because of its size, the Billings plant will be no more efficient than a conventional power plant. Between 30 and 35 per cent of the heat will be turned into electricity, says Gerry Funk, manager of the technical development and engineering division at MSE, another of the industrial partners in the project. But he says it would show that the technology is reliable, preparing the way for larger, more efficient plants.

The Soviet Union, China, India, and Japan have also dabbled with MHD technology. During the late 1980s, the Soviet Union planned to build a large MHD plant powered by natural gas, rated at 580 megawatts. But the magnets turned out to be too difficult and costly to produce and the MHD part of the plant was never built. "Their programme ground to a halt about three or four years ago," says Funk. The only fully integrated MHD plant is in China, just outside Shanghai, rated at just 5 megawatts of power.

America's largest MHD plant so far, in Butte, Montana, began tests in February last year. The generator has a capacity of 1.5 megawatts of electricity; its purpose is to test the system's reliability through years of bombardment with a blast of corrosive gases heated to 2700 °C.

MHD is an attractive idea, but government-funded projects to develop it have more to do with political expediency than technological objectivity. The trouble with MHD is that, while the idea works well in theory and in small pilot plants, developing such power plants commercially will take a lot of money-and may not be worthwhile. Much of the research so far, in the US and the former Soviet Union, was driven by military interest in the behaviour of high-temperature plasmas in rockets rather than a serious effort to develop power sources.

Many countries that showed an early interest in the technology, such as Britain and Australia, have now dropped it. An MHD power station would pose serious technical difficulties, says Ian Smith, research manager of the coal utilisation programme at CSIRO, Australia's national research organisation. The difficulties include burning coal at well over 2000 °C, and passing the products through a duct at supersonic speeds. Not least of the problems are the engineering difficulty of passing very hot gases just a few centimetres from superconducting magnets operating at only a few degrees above absolute zero. This adds up to a process that looks exciting on paper, but tricky to turn into reality; says Smith. "It's one of those technologies that people sniff at because of its potential attractiveness and then back away from because of the practical difficulties."

Much better, he says, is to concentrate on developing plants in which gasified coal drives turbines connected directly to generators, with a secondary steam system running off the waste heat. Such combined cycle gas turbines are as efficient as MHD plants are ever likely to be - and are based on better established technologies. Several tried and tested processes are available for turning coal into gas, by making it react with oxygen, steam, carbon dioxide or hydrogen. The product consists of hydrogen, carbon monoxide, carbon dioxide, hydrogen sulphide, methane and other hydrocarbons, in proportions that vary according to the technology used. The problem comes in removing the substances in coal that create ash when the fuel is burnt; flying ash damages turbine blades and is one of the reasons behind the British power industry's "dash for gas". So far, efforts to clean the gases from coal combustion before they hit turbines have not been successful.

At the DOE in Washington, the MHD proposal must compete for funding with many other ideas for generating electricity from coal. Most involve more familiar technologies. Several groups propose to build small power plants that convert coal into gas, which can be burned to generate power more cleanly. Similar DOE-funded plants are already under construction. Other companies want DOE funding for advanced methods of removing sulphur dioxide and nitrogen oxides from flue gases at existing power plants, or to remove sulphur from coal before it is burnt.

Ways of cleaning up coal are attracting particular interest in Australia, which has large reserves of black coal. These bituminous coals produce more heat per tonne than brown coals but contain more potential pollutants (see "Where the power lies", this issue). A team at CSIRO has discovered that agitating bituminous coals in a hot aqueous solution of caustic soda softens potential pollutants in the coal. A dilute acid wash removes them. The process leaches out many of the substances that form ash. The Australian Coal Industry Research Laboratories are testing the process at a pilot plant at Maitland, New South Wales. ACIRL will decide within the next year whether to go ahead with a demonstration plant to assess the technique's economic viability.

Cleaned-up coal has several attractions. Mixed with water as a slurry it could substitute for heavy fuel oil, an idea that Australia, the world's largest coal exporter, is investigating with a view to exporting fuel in this form to Japan. Coal-water mixtures could also fuel gas turbines in advanced power generation, run diesel engines, or provide clean carbon for aluminium and steel smelters. Meanwhile, the State Electricity Commission of Victoria hopes to obtain enough clean coal from the Maitland pilot plant to test the feasibility of using coal gas to drive a turbine directly. The commission will use a turbine simulator to gather information about how the technique performs. The main purpose of the simulator is not to test black coal, however, but to help develop a way of using brown coal in coal-fired turbines.

This technology, known as hydrothermal drying (HTD), aims to increase the energy efficiency of brown coals by reducing their moisture by as much as 50 per cent. This is done by heating the coal under pressure in an HTD plant to reduce its capacity to hold moisture-by weight, brown coal can contain more than two-thirds water. The turbine simulator; which operates at pressures of 10 atmospheres and temperatures of 1350 °C, can then be used to determine the combustion behaviour of the resulting coal-water slurries, and to evaluate corrosion, erosion and deposition of contaminants on the turbine blades.

Working with a West German company, Lurgi, the commission is also investigating another technique for reducing the moisture content of brown coals, known as steam-fluidised bed drying. Lurgi has set up a steam-drying plant in Victoria's Latrobe Valley where finely crushed coal is dried in a fluidised bed using superheated steam at about 110°C as the fluidising medium. The technique was invented 10 years ago by Owen Potter, a chemical engineer at Monash University in Melbourne. When he failed to interest Australian companies in the technology, he sold the licence to develop it to Lurgi. While Lurgi wants to pulverise the dry coal and use it in conventional generating technology, the commission is keen to see how suitable the dry coal is for turning into a gas for driving turbines.

There is another developing technology that offers a way to convert the energy in coal directly to electricity without wasteful mechanical processes and without the formidable engineering of MHD. This is the fuel cell, essentially a battery running on a continuous flow of chemicals, usually gases. Fuel cells consume hydrogen as fuel, oxidising it to create a flow of electrons from cathode to anode, producing electricity and heat while giving off water and carbon dioxide. The hydrogen fuel usually comes from natural gas but it could come from gasified coal.

Fuel cells emerged from the need for compact, silent and efficient sources of power for special jobs, for example, inside spacecraft or military gadgets. The different types are named according to their electrolyte, the material at the cell's core. NASA's spacecraft, most famously the Apollo missions, have carried phosphoric acid cells since the 1960s. More powerful "molten carbonate" cells, with an electrolyte of lithium and potassium carbonates, were developed during the 1980s. These operate at higher temperatures of about 650°C. The third generation of cells, solid-oxide fuel cells with zirconia as an electrolyte, operate at even higher temperatures, around 1000 °C.

This technology; combined with coal gasification, seems to offer an efficient way of producing electricity from coal with virtually none of the environmental damage that thermal power stations cause. Fuel cells do produce carbon dioxide, but at less than half the rate of thermal power stations.

Cell power

Researchers from the University of Wollongong in New South Wales described the concept of such a plant to the Fifth Australian Coal Science Conference, organised by the Australian Institute of Energy in Melbourne last month. The raw coal enters a conventional gasifying plant, which produces a fuel gas at between 650°C and 1000 °C. This gas passes through a cleanup process, removing extraneous particles, sulphur, nitrous oxide and other substances. The cleaned-up gas then passes to the anodes of a stack of fuel cells, which also consume air, to produce DC electricity. Hot exhaust gas, mainly carbon dioxide and water, from the fuel cells' cathodes creates steam to drive a turbine, producing more electricity. The overall efficiency could be more than 45 per cent.

There are snags. Although engineers have accumulated a lot of experience with small fuel cells, no one has yet built a commercial-sized plant. Tokyo Electric Power Company operates the world's largest fuel-cell power station on the shores of Tokyo Bay, but it is a first-generation phosphoric acid plant, producing just 11 megawatts. The long-term reliability of fuel cells is also still in question.

According to Ron Wolk, director of the advanced fossil power systems department at the Electric Power Research Institute (EPRI) in Palo Alto, California, such technical problems will be solved with "grunt-work engineering". He says a more important hurdle on the way to commercial success is making them cheaper. At the moment, two American companies build molten carbonate fuel cells in small prototype manufacturing facilities, at a maximum rate of about 2 megawatts of capacity per year. Without the benefit of mass production, their fuel cells are far too expensive for the commercial market. "It's a classic case of how you establish a market," he says.

In an attempt to get the fuel cell industry on its feet, the DOE is contributing $16·5 million towards a 2-megawatt fuel cell plant in Santa Clara, California, which is due to open by early 1995. The rest of the $47 million cost will come from the local electricity company; EPRI, and Energy Research Corporation (ERC) in Danbury; Connecticut, which is building the fuel cells. If the plant works well, ERC says it will offer similar plants to other electricity companies. The cost to the first customers will still be high, but as an incentive, ERC will offer them a share of the revenue from all future sales. If enough customers sign up, ERC will build a large-scale manufacturing base, bringing the price down from around $5000 per kilowatt of capacity to about $1200, which is about the same as the cost of building a coal-fired power station.

Meanwhile in Australia, a consortium of public and private enterprises, brought together by the CSIRO and including BHP, the country's largest company, and the state power authorities of New South Wales and Victoria, has enough faith in fuel cells to set up Ceramic Fuel Cells to develop third generation cells commercially. These cells, which could have efficiencies of up to 60 per cent, have electrolytes of solid ceramic made from zirconia and yttrium oxide. One reason for Australia's interest is that it supplies 70 per cent of the world's zircon.

Commercial success for fuel cells will not necessarily help the coal industry immediately. All these fuel cell projects use natural gas, not gas from coal. But if natural gas prices rise, as seems likely when exploitable resources run short over the next few decades, fuel cells might switch over to coal gas (see "A very dirty business", this issue). Running fuel cells on coal gas would mean· more efficient use of coal, while eliminating most of the emissions of sulphur dioxide and nitrogen oxides that now pour from conventional power stations.

This month, in an effort to kick-start development of the technology, the ERC and EPRI plan to hook up a 20-kilowatt stack of fuel cells to a coal gasification plant in Louisiana. In the past, simulated coal gas has tended to be used to test the performance of fuel cells. M-C Power, the main competitor to ERC in the fuel cell business, has applied for government funding to conduct a similar experiment in Indiana.

The increased efficiencies of combined-cycle gas turbines, fuel cells and MHD will all reduce the amount of carbon dioxide that . power stations produce per unit of electricity generated. But no known technology will eliminate it. The Japanese government has chosen the area as a target for its Research Institute for Innovative Technology for the Earth, which is due to begin work in earnest this year. One team of genetic engineers will be trying to improve the photosynthetic properties of a new breed of microorganisms, which could then be used to fix carbon dioxide in industrial exhaust gases. Another team of researchers will look for new catalysts to help turn carbon dioxide into useful chemicals. Another idea under investigation is to pump carbon dioxide to the seabed where it would lie in store-the gas becomes denser than sea water at 3000 metres below sea level. The cost, however, would be colossal.

This type of research is worlds away from the realities of today's electricity industry. The most modern technology in place at a current coal plant might be an assembly of thousands of huge bags to capture fine particles of fly ash from exhaust emissions. Some plants still use electrostatic precipitators, a technology developed early this century; to do the same thing.

In the US, most coal-fired plants built before the Clean Air Act of 1978 do not even have "scrubbers" to remove sulphur dioxide. Technologies that would minimise pollution by changing the combustion process itself, such as fluidised-bed combustion, are still almost unknown among commercial energy generators. Even coal gasification, which most scientists describe as a proven technology, has yet to catch on commercially. Robert Lumpkin, director of coal utilisation projects at Amoco Corporation, a member of the National Coal Council, says most electricity companies "are scared of gasification plants" because the chemical processes are unfamiliar.

Wolk of EPRl says that American generating companies are a conservative breed, unlikely to adopt unproven technologies such as MHD or fuel cells. There is little reward for an electricity company that takes a risk because regulations require it to pass any savings on to consumers, he says. Joseph Goffman, a lawyer specialising in pollution control at the Environmental Defense Fund, an environmental pressure group based in Washington DC, says many environmentalists have come to share Wolk's views. He says that a utility and its shareholders should be allowed to profit financially for taking risks that cut the environmental costs of generating energy.

The law that will force the US's power companies to try some of these technologies was passed by Congress in 1990, as an amendment to the 1978 Clean Air Act. It will require the country's largest coal-burning companies to halve their emissions of sulphur by 1995, and by half again by 2000. Emissions of sulphur will then be capped at the level set for 2000. If an electricity company wants to build a new plant to meet rising demand, it will have to cut back sulphur emissions in its existing plants by an equal amount, or buy the right to emit a certain amount of sulphur from other power companies. These "emissions credits" are likely to become very expensive as such companies fight for the right to pollute.

Although, even with these incentives, the era of truly clean coal, whether driving MHD, fuel cells or super-efficient gas turbines, is at least one generation of technology in the future, those countries developing the new technologies now will be the ones that will benefit later.

Cleaning up with cheap technology

(The perfectly clean coal-fired generator may lie far in the future, but technologies that could be excellent stopgaps already exist. The biggest obstacle appears to be the generating companies.)

Mat Ridley

Even sulphurous clouds have silver linings. Britain's deserved reputation for dragging its feet over European environmental regulations could ironically be the saviour of its coal industry. If in the 1980s Britain had followed Germany's lead and installed expensive scrubbers and catalysts in its power stations to reduce emissions of sulphur dioxide and oxides of nitrogen, its coal would have been priced out of the domestic electricity market years ago.

It is because Britain has barely begun cleaning up fumes that the power generators can take advantage of new technologies that were not available to the Germans but which dramatically reduce the price of pollution control. On their own they might not be enough to make coal-fired power competitive with gas fired power, but go a long way towards that goal.

Before the privatisation of the electricity industry; the British government estimated that to meet emissions standards laid down by the European Commission it would have to spend £1 billion on its coal-fired power stations. This would have enabled it to reduce emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) to well below the 1980 levels by 2003. Powergen and National Power, the power generation companies due to be privatised, immediately saw that it would be less expensive, given the coal-fired plants' remaining useful life, to close them and build gas-fired power stations instead. Their reluctance to commit themselves to greater purchases of coal led inevitably to the pit-closure proposal and subsequently to Michael Heseltine's review of energy policy.

But the £1 billion estimate was based on conventional technologies-flue-gas desulphurisation (FGD) for sulphur dioxide, and selective catalytic reduction (SCR) and low-NO_x burners for NO_x. All three are expensive. FGD requires the installation of a piece of equipment about 20 metres high between the boiler and the stack. Inside it wet calcium salts react with the sulphur dioxide to make calcium sulphate, which can be precipitated out of the smoke and removed (to be dumped somewhere). Low-NO_x burners involve replacing the entire bed of the furnace with a design that allows the flame to burn at a lower temperature through controlled ventilation of the fuel, so that less nitrogen in the air is oxidised. SCR entails setting up equipment between the boiler and chimney stack incorporating catalysts based on platinum group metals to help break down NO_x into nitrogen and oxygen.

On average, FGD alone increases the cost of generating electricity from coal by about 10 to 15 per cent. The other technologies are only marginally cheaper: SCR costs about £1000 per tonne of NO_x removed. Although 10w-NO_x burners can cost as little as £150 per tonne removed on fairly new plants, they can only achieve a 20 to 50 per cent reduction in emissions, and can cost much more-up to £1000 per tonne-on plants with only a few years' useful life left.

A far cheaper technology is now available for the first time.

In the 1970s, Exxon experimented with injecting ammonia into a furnace flame and found that it reduced the nitrogen oxide in the flame to nitrogen. It never developed the idea much further, but scientists at the Electric Power Research Institute (EPRI), a research arm of the electricity generating industry in the US, picked up on the idea and tried injecting other chemicals. They discovered that urea worked even better than ammonia. It was also a safer chemical and more practical: it could be dissolved in water and injected as a liquid. The reaction was:

$2CO(NH_2)_2 + 4NO + O_2 \sim 4N_2 + 2CO_2 + 4H_2O$

A shot in the boiler

The idea of injecting a solution of urea-in effect, concentrated urine-into coal-fired boilers became a sort of joke in the industry. But one company took it seriously. In 1986 a small firm called Fuel Tech, funded largely by British investors, noticed the EPRI idea, bought the right to manage the patents and began a series of experiments to improve the efficiency of the chemical reaction. There were two problems. First, if the urea solution touches the steam-carrying heating tubes in the boiler, they burst, and the whole plant has to be shut down. Secondly, if the chemical meets the flame at the wrong temperature, the results are counterproductive. Above 1100 °C, more NO_x is formed. Below 900°C, ammonia-another pollutant-is created.

But by 1989 Fuel Tech, with offices in London and Connecticut, had perfected a way of spraying liquid into the furnace so that a fine chemical mist met the rising flame at the right temperature and for just the right length of time before evaporating. In small-scale trials, NO_x emissions were cut by up to 80 per cent. The company then proved its case by installing the system, dubbed Noxout, in 25 industrial boilers throughout Europe and the US. But the research and development had cost $60 million, and Fuel Tech needed a partner with access to the market. So it formed a joint venture with a large American chemicals company called Nalco, based in Naperville, Illinois.

Nalco-Fuel Tech (NFT) still had to persuade the power industry to buy its technology. Paradoxically, cheaper pollution control can be bad news for generating companies. Emissions controls are always politically imposed; if meeting them is expensive, the generating companies can argue that they will have to increase electricity costs, so hurting economic growth, jobs, and political popularity. But cheap systems that meet the standards mean inconvenience, rather than expense, to the generators and so are harder to argue against.

Moreover, power companies are understandably wary of radical inventions, especially those which entail shutting down their power stations at huge cost, and particularly those which add equipment that could fracture those precious heating tubes.

This conservatism discourages innovation through a catch-22. New ideas for reducing pollutants simply do not get tested on full-scale plants; but the industry distrusts anybody whose technology has not had full-scale tests.

NFT eventually got around this problem by developing a computer program to predict the temperature at any point in a furnace. The program models the flow of air and flame from the burning coal up through the boiler over the so-called bull nose inside the furnace and past the heating tubes. Given the specifications and blueprint of any boiler, NFT's complex model can identify exactly where the temperature drops to the critical level at which the urea reaction will take place at any load of power production. Per Christiansen, NFT's president, boasts that the company will guarantee exactly how much NO_x reduction, by-product formation and chemical use can be achieved in a given boiler on the basis of the computer predictions alone.

Eventually in 1992 one power generator, WEPCO in Wisconsin, agreed to test Noxout in its Valley power plant in Milwaukee, with four 70-megawatt coal-fired boilers. The results of the two-week test enabled NFT to show the process's realistic costs: it can remove 70 per cent of NO_x from the flame for a cost of about £250 per tonne of NO_x removed. That makes it four times cheaper than SCR and more effective (for a comparable price) than a low-NO_x burner, which would anyway only be economic in a new plant.

Flexible friend

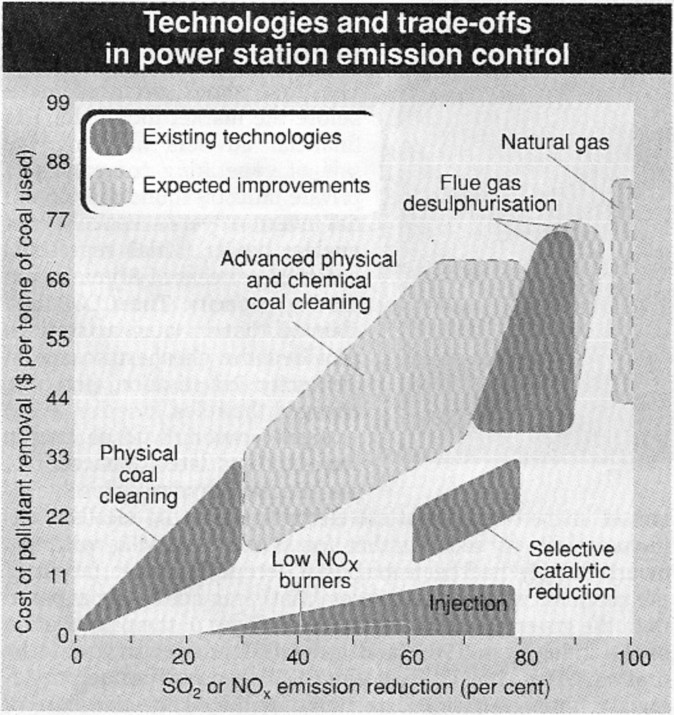
Furnace injection also has other advantages. The equipment required is small and can easily be fitted into a crowded old power plant: it consists of some storage tanks (about the size of a petrol tanker lorry), pumps, control valves and computers to adjust the volume of liquid spraying through the nozzle. It is also flexible-it can be adjusted as the plant's power output varies. Compared to FGD, SCR or a low-NO_x burner, most of Noxout's cost is for the chemicals, so it is a running rather than a capital cost-like the difference between changing to unleaded petrol and replacing the car engine.

NFT is the only company working that has reached the stage of full-scale tests. It now has over 50 systems installed and 60 commercial orders from Germany, Sweden, Switzerland, the former Czechoslovakia, Taiwan and the US. Noxout's only significant drawback is that it creates a little nitrous oxide (N_20), a greenhouse gas. But NFT says that a new version of Noxout solves this problem by converting the urea into a chemical that overcomes this, but it is keeping details confidential.

What about sulphur dioxide? EPRI's scientists have been experimenting with injecting dry lime for some time, but the results are disappointing. Acurex, an American company based in Mountain View, California, invented a device for injecting an emulsion of wet lime into the furnace of a coal-fired boiler, instead of into the exhaust stream. Then a Canadian power generator, Ontario Hydro, patented the use of a combination of calcium carbonate and urea. Meanwhile NFT has adapted Noxout to use a slurry of urea and calcium hydroxide, and claims that the hydroxide works better than carbonate because it reacts with the urea to improve the efficiency of both.

NFT's process has recently been tested for the first time on a solid-waste incinerator in Pennsylvania. It looks impressive in trials. The company claims it can remove up to 80 per cent of the sulphur dioxide for a lower capital cost than FGD, which removes 90 per cent.

Germany and Japan, the first countries to install pollution control equipment on power stations in the early 1980s insisted on the proven technologies of FGD for sulphur dioxide removal and SCR to catch NO_x' Nobody would order SCR now. And if furnace injection lives up to its promise, FGD may soon be a thing of the past too. Britain is therefore well placed to get the work done cheaper-a strange reward for its procrastination over pollution.



Technologies and trade-offs
in power station emission control
Existing technologies
Expected improvements
Natural gas
Flue gas
desulphurisation
Advanced physical
and chemical
coal cleaning
Physical
coal
cleaning
Low NOx
burners
Injection
Selective
catalytic
reduction
99
88
77
66
55
44
33
22
11
0
0
20
40
60
80
100
Cost of pollutant removal ($ per tonne of coal used)
SO2 or NOx emission reduction (per cent)

A very dirty business

(No one can calculate the real cost of generating electricity. But all the suppliers of power claim they can provide it more cheaply than anyone else)

Michael Cross

Two hundred years ago, the Scottish economist and philosopher Adam Smith drew on a self-evident truth about energy prices to make a fundamental point about economics: “Coals are a less agreeable fuel than wood: they are said, too, to be less wholesome. The expense of coals, therefore, at the place where they are consumed, must generally be somewhat less than that of wood."

But if Smith were to investigate the electricity industry for a 1993 edition of The Wealth of Nations, he would find his view rather off the mark. Power stations burn "less wholesome" fuels even when alternatives are cheaper. Rather than recast his entire economic theory; he would undoubtedly look for evidence that the market was distorted.

He would very quickly find it because every country in the world, to a greater or lesser extent, rigs the market in energy. The motive for doing so may be to safeguard national security, to protect employment, to stop abuses of monopolies, to nurture high-technology industry or, although no government would admit it, to prevent revolution. And the energy market is particularly prone to manipulation.

"Since the Second World War, the electricity industry, however organised in each European country, has shown all the characteristics of a monopoly supplier: subsidisation, protectionism and no differentiation of user needs," concludes an investment report on European power trends published in 1991 by Arthur Andersen, a firm of management consultants. In lay terms, this means that organisations which produce electricity decide how they will do it, who they will sell it to, and the price at which they will sell it. But without a truly free market, it is difficult to calculate the true costs of generating electricity, and thus to judge the effectiveness of different ways of doing it.

In 1988, however, the British government set in motion a bold programme to create a free market in energy. It broke up the Central Electricity Generating Board the state authority that had until then generated and distributed power in England and Wales. Instead came a collection of companies that compete with each other in supplying electricity (via an independently owned national grid) to regional electricity companies, which in turn sell it to customers.

The new market came into effect in 1990. This meant, for the first time, that the marketplace, rather than government policy, would decide the mixture of technologies that would generate Britain's electricity. The effects of this shift were more than the government had bargained for.

Nuclear expose

The first shock occurred even before the market took hold. The financial advisers handling the sale of generating companies to private industry found that potential investors were sceptical about nuclear power, which represents about 23 per cent of Britain's generating capacity. The CEGB had claimed that its nuclear stations provided the cheapest source of electricity. Privatisation, however, changed the rules.

Nigel Lawson, who as energy secretary and later Chancellor of the Exchequer was closely involved in the break-up of the electricity industry, recalls in his memoirs: "It turned out that for years the CEGB, wittingly or unwittingly, had been making a deceptive case in favour of the economics of nuclear power (that) was not finally exposed until the government was in the final stages of the privatisation of the industry in 1989, and a detailed prospectus had to be drafted." This showed that "the CEGB had been underproviding for, and greatly underestimating the likely true cost of decommissioning a nuclear power station at the end of its life". The CEGB had estimated its liability at £3.7 billion. The government decided that a more realistic figure would be £15 billion.

Dash for gas

The second shock followed privatization. Since the discovery of large resources of gas under the North Sea, Britain, like its continental neighbours, had considered the new fuel too precious to burn for electricity. Instead, the government decided, gas should be used only for direct heating and as a raw material in the production of chemicals. But since the free market was created in 1990, private companies have financed the construction of 16 large gas-fired power stations in Britain, encouraged by an offer from British Gas; a privately owned monopoly, to supply fuel at prices that undercut those of coal from Britain's deep mines. This so-called "dash for gas" was the immediate reason for the government's decision last October to close 31 of Britain's 50 coal mines.

British Coal, the public authority that runs almost all of Britain's mines, blames distortions in the market for the lack of demand for coal. In fact, the only change is the arrival of the cost of capital as the main factor in energy economics. Under the old rules, the Treasury funded investments on power stations over 40 years, and required a return under normal public sector rules, which was usually about 5 per cent. It was, in effect, giving the money away.

Calculating real returns

Private investors, usually consortia of banks, need to show real returns, which means that they must get their money back in roughly half the time, plus interest at perhaps two percentage points above base rates. Most private ventures to build power stations assume a financing cost of 12 per cent.

In Britain, over the past two years, these arrangements have favoured gas. First, gas-fired stations are cheaper to build than coal-fired ones, mainly because coal-fired plants need a separate steam-generating circuit while gas drives a turbine directly. The cost of a gas-fired station in Britain is less than half that of an equivalent coal-fired station, which, in turn, costs less than half that of a nuclear power plant. Secondly, the cost of capital represents less than a quarter of the cost of running a gas-powered generator over its useful life. Most of the rest is the cost of gas, paid for as the plant generates income.

With a coal-fired plant, however, the cost of capital is closer to half the plant's total running costs. So, even if coal turns out to be cheaper per unit of energy produced than natural gas-as the British coal industry claims it might still make business sense for a power company in an unrestricted market to choose the more expensive fuel

The picture is even grimmer for non-fossil fuels. The cost of generating electricity from a nuclear plant, a wind farm or a tidal barrage is almost all in the capital cost, which is also greater than that of building a fossil fuel plant. The wind is free and the amount of uranium needed to supply a nuclear power station during its working life is less than 10 per cent of the overall cost of the station. The result is an unlikely alliance between supporters of nuclear and renewable energies, hitherto at opposite ends of the energy debate. "Since privatisation, the cost of finance has rigged the economics heavily in favour of gas at the expense of renewables," says Catherine Mitchell, a research student in the Science Policy Research Unit at the University of Sussex. Mitchell's research into the costs of renewable energy has shown that power stations based on new technologies, such as wind, must endure a double blow: financing is usually available only over five years, largely because of investors' suspicions about "new" technology, as against a usual 18 years for gas-fired plants.

Forced to intervene

The British government faces a dilemma. It has vowed repeatedly that it has no energy policy beyond allowing a free market. As Nigel Lawson put it: "I did not-and still do not think that it makes sense to have an 'Energy Policy' over and above the government's overall supply-side policy to the energy sector of the economy." Prime Minister John Major took this philosophy even further last year by abolishing the government's Department of Energy.

In practice, however, the realities of politics have repeatedly forced the government to intervene. One example is the Non Fossil Fuel Obligation, a levy on the operators of fossil-fuelled power stations in the cause of "diversity of supply". Income from the levy, which adds about 10 per cent to the average electricity bill, was designed to help fund the decommissioning of nuclear power stations and to encourage the exploitation of renewable energy, mainly in the form of wind farms.

Under pressure from the European Commission, which does not allow such subsidies to nuclear power, the levy is due to be phased out in 1998. British Coal complains that the levy has substantially reduced demand for its coal as electricity suppliers have compensated for shortfalls by making use of imported power from France rather than by drawing more power from local fossil-fuelled stations.

In the long run, the free market in electricity will work only if generating companies pay the real costs of the technology they use. This opens a new can of worms. There are the obvious costs of building and dismantling a power station, plus the costs of fuel, staff and insurance involved in running the plant, and the costs of financing the project. It is harder to put a figure on the environmental and sociopolitical costs. These fall into two categories. Internal costs fall on the producers and users of the electricity; external costs fall on everyone else-for example, farmers whose land is less productive because of pollution from power stations. These costs would tilt the equation against coal: equipping a large power station with equipment to remove sulphur from its flue gases costs around £250 million.

Favouring conventional generation

Enthusiasts for renewable energy, on the other hand, say that their pet technologies would benefit. The European Wind Energy Association, in its report A Plan of Action, published last year, says: "The pricing policy which controls today's power supply industry favours conventional means of electricity generation. It demands that electricity be provided at the lowest cash cost and not at the lowest total cost. The external, or environmental, costs of power production are not passed on to the end consumer, thus prices are being held down artificially. The economic disadvantage to renewable energy caused by the price distortion forms a major barrier to the development of a market for wind power."

But calculating these external costs, and ensuring that they are paid, is likely to drag the government-whatever its "free market" intentions-even further into the business of controlling the electricity market.