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Constructing Success in the Electric Power Industry:

Flexibility and the Gas Turbine

Dr Jim Watson

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SPRU
Science and Technology Policy Research
Mantell Building
University of Sussex
Falmer, Brighton
BN1 9RF, UK

Tel: +44 (0) 1273 686758
Fax: +44 (0) 1273 685865
Email: M.E.Winder@sussex.ac.uk
http://www.sussex.ac.uk/spru/

Constructing Success in the Electric Power Industry: Flexibility and the Gas Turbine

**Dr. Jim Watson,
The Energy Programme,
SPRU - Science and Technology Policy Research,
University of Sussex,
Falmer, East Sussex, UK, BN1 9RF.**

**Tel. 01273 873539   Fax. 01273 685865
E-mail. w.j.watson@sussex.ac.uk**

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Constructing Success in the Electric Power Industry

Abstract

This paper explains the success and failure of two technologies that generate electricity from fossil fuels. Both the Combined Cycle Gas Turbine (CCGT) and fluidised bed boiler burn fossil fuels more cleanly than more traditional technologies. Whereas the CCGT has been used for an increasing number of new power plants during the past fifteen years, the latter has struggled to attract attention outside a small-scale niche. The paper draws on economic and social constructivist approaches to technical change. It shows how a combination of economic, institutional and political factors can be used to explain success and failure. It also demonstrates the importance of technological flexibility for the long term development of the CCGT and its acceptance as the power industry's current technology of choice.

Introduction

During the past decade, the UK power industry has undergone a technological transformation. Starting in the late 1980s, the phenomenon known as the 'dash for gas' has led to the construction of a large number of power stations fuelled by natural gas. These power stations are based on a new technology, the Combined Cycle Gas Turbine (CCGT), which was previously confined to the fringes of an industry fuelled by coal, oil and nuclear energy. The privatisation of the UK's electricity and gas industries changed the rules governing new investments and triggered a wholesale switch to cheaper, cleaner CCGTs.

Whilst the dash for gas represents a particularly powerful manifestation of a global trend towards the use of CCGTs, it is also important because of the severe effect on the UK's deep mine coal industry. For this industry, the replacement of traditional coal-fired power plants and the failure of newer cleaner coal technologies to attract the attention of private sector investors represents the latest stage in a long process of decline. Amongst these new technologies, the fluidised bed boiler had been regarded as the coal industry's best hope of survival. However, despite limited progress in some parts of the world, this technology has consistently failed to meet the expectations of its supporters.

The aim of this paper is to explain the success and failure of two fossil fuel power generation technologies that both produce cleaner electricity than their traditional counterparts. Whilst the reasons for the CCGT's global triumph and the failure of the fluidised bed appear to be relatively clear cut to current investors, this outcome was far from obvious just 15 years ago. The key question is how the CCGT came to be in the position to take advantage of a fortuitous combination of circumstances in a number of different countries. This question will be examined in the light of theories drawn from the evolutionary economic and social constructivist traditions. The conclusions of the paper will examine the wider implications of success and failure for governments wishing to aid the development of more sustainable energy technologies.

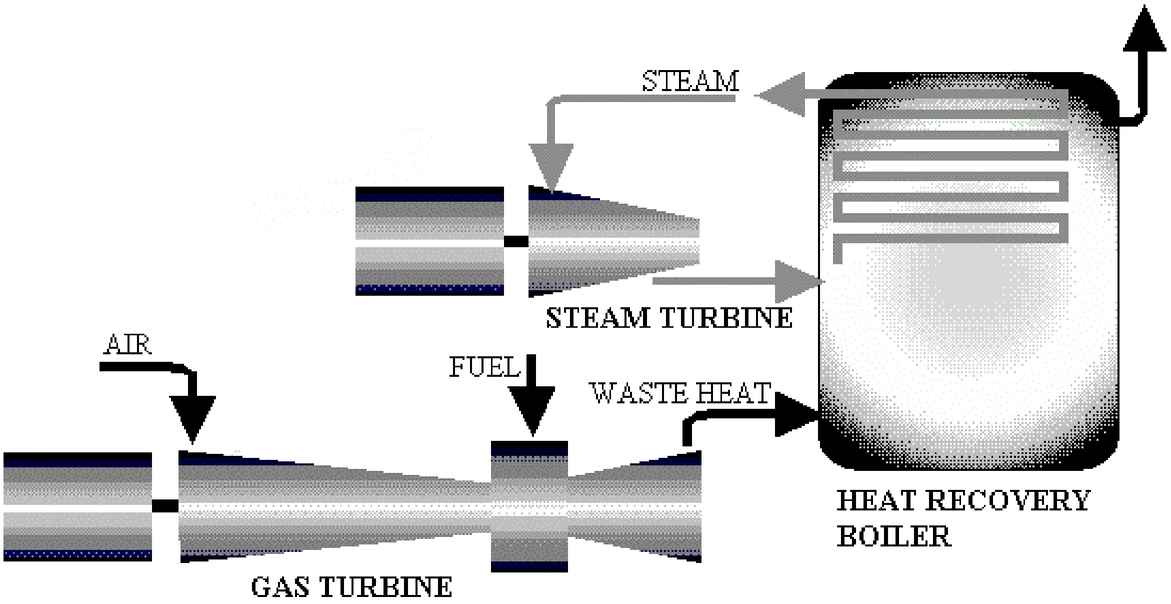
Inside Two Technologies

The Combined Cycle Gas Turbine (CCGT)

The Combined Cycle Gas Turbine (or CCGT) represents a radical departure from traditional power generation technologies. By combining two established building blocks - the gas turbine and the steam turbine - CCGT designers have achieved electrical efficiencies which are almost 50% higher than those of other fossil fuel power stations.

As shown in Figure 1, most CCGTs work in the following way: Fuel (usually natural gas) is burned in an industrial gas turbine, to generate electricity and waste heat. The waste heat is then passed into a heat recovery boiler which uses the gas turbine's hot exhaust gases to generate steam. This steam is then used to drive a small steam turbine and produce some more electricity. In some cases, more than one gas turbine is used (each with its own steam generator) in combination with a single steam turbine. However, in all modern CCGTs the steam turbine is designed so that it produces approximately one third of the total power output, with the remaining two thirds being met from the gas turbine(s).

Figure 1 : Schematic of a Combined Cycle Gas Turbine



Source: Author.

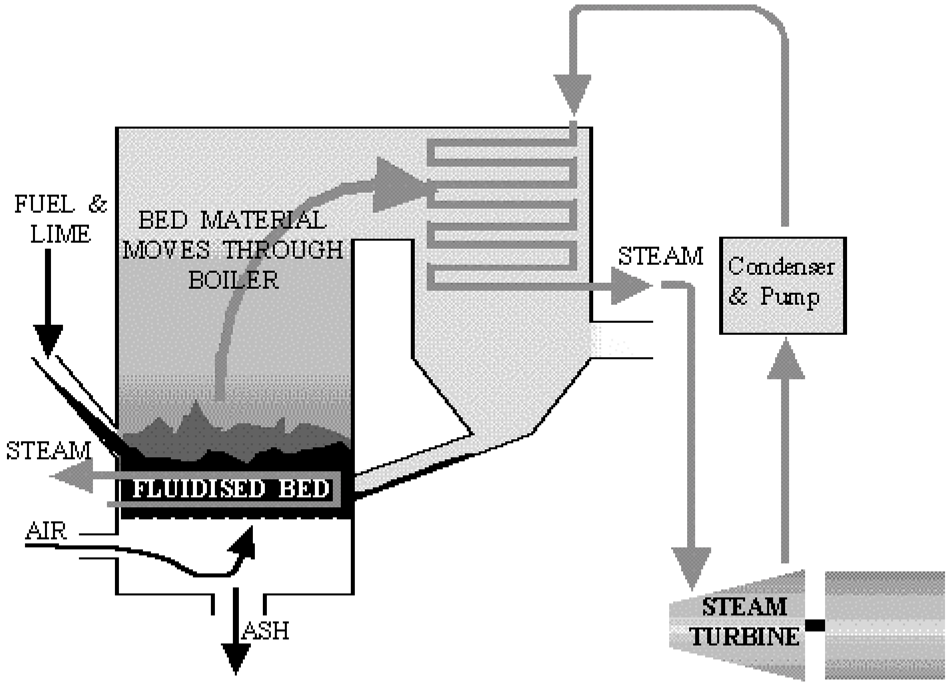
The most technologically advanced part of every CCGT is the industrial gas turbine. Most gas turbine designs have been developed steadily over the last 50 years from their roots in aircraft jet engines. Although the industrial gas turbines most frequently used in CCGTs are much larger than the aircraft variety, they still work on the same principle. For designers, there are a number of ways to increase the efficiency of a gas turbine and hence, the overall efficiency of a CCGT. The traditional approach is to raise the temperature at which the combustion gases enter the turbine. Achieving a temperature increase in this way is not difficult - the real challenge is to ensure that the metal blades which make up the turbine do not overheat the process. Turbine blade design is a sophisticated business requiring the use of the latest high temperature metal alloys. At the same time, advanced casting techniques are necessary to incorporate a network of tiny holes within the hottest blades for cooling air.

Until recently, many of these advanced materials, casting techniques and cooling technologies have been readily available. As one seasoned observer puts it, all the gas turbine manufacturers had to do was 'go shopping at the aero-engine technology supermarket'.[1] This supermarket is packed with products from the multi-billion dollar military jet engine programmes of the US Department of Defense and their European counterparts. The newest generations of CCGT have begun to depart from this established trajectory as designers search for further efficiency gains. As new products such as the *H System* from General Electric demonstrate (US Department of Energy, 1999), the move to efficiency levels beyond 60% will require an increasing amount of innovative thinking.

The Fluidised Bed Boiler

Figure 2 shows a simplified layout of a fluidised bed power plant. This technology gets its name from the way in which the combustion process is managed. The fuel, together with a sorbent for sulphur removal, is fed into a heated bed of inert material such as sand. The bed is 'fluidised' (i.e. made to behave as if it were a liquid) by a constant stream of air, pumped in from below. As a consequence of this, combustion of the fuel is much more uniform and occurs at a lower temperature than it would in a conventional boiler. The typical bed temperature of 900°C also maximises sulphur removal and minimises NO_x emissions.

Figure 2 : Schematic of a Fluidised Bed Power Plant



Source: Author.

Although the fluidised bed process is complex, the basic differences from a conventional fossil fuel boiler are the low combustion, the fluidising air and the removal of sulphur during

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[1] This phrase was coined by Al Dolbec, Managing Executive, Electric Power Research Institute European Office during an interview with the author in Birmingham, UK in November 1995.

combustion. The latter property, together with its ability to burn a wide variety of difficult fuels (e.g. coal processing wastes), is what really sets this technology apart from its predecessors. The basic layout of Figure 2 shows what is known as a bubbling fluidised bed (BFB). It is characterised by relatively low air velocities which give the bed a discernible upper surface. Later varieties, known as circulating fluidised beds (CFBs), use higher air velocities to propel the bed material into the upper portion of the boiler. CFB designs normally feature an additional component, known as a cyclone, which recycles unburned fuel back into the bed. The effect of this greater movement of the bed material is to enhance fuel mixing and combustion efficiency.

A final development in fluidised bed technology, which has yet to be fully demonstrated commercially, is the pressurised fluidised bed (PFB). This particular variant works in much the same way as the others. However, the boiler is now pressurised in order to produce exhaust gas at sufficient temperature and pressure to drive a small gas turbine. This gas turbine is then used to generate extra electrical power. Whereas CFBs and BFBs yield maximum efficiencies of around 38%, PFB plants offer the possibility of efficiencies of up to 42%. For all types of fluidised bed, unit sizes are limited, with maximum power outputs of around 250MW.

An Open and Shut Case ?

There is a stark contrast between the commercial success of the CCGT and the limited interest in fluidised bed technology. At present, 300 Gigawatts (GW) of CCGT capacity is in operation or under construction world-wide[2], whilst installations that use fluidised bed technology have an equivalent combined output of less than 20GW[3]. Whilst there are large numbers of CCGTs in many countries in Europe, Asia and North America, fluidised bed plants are concentrated in a small number of countries. A simple economic comparison of these two technologies using typical UK fuel prices reveals why this is the case (see Table 1).

Table 1: The Economics of New CCGT and Fluidised Bed Power Plants in the UK

	CCGT (gas-fired)	**Fluidised Bed (coal-fired)**
Capital Cost	£300/kW (0.7p per kWh)	£650/kW (1.6p per kWh)
Fuel Cost	18p per therm (1.1p per kWh)	£28 per tonne (1.0p per kWh)
Operations & Maintenance	0.3p per kWh	0.6p per kWh
Cost of Electricity	**2.1p per kWh**	**3.2p per kWh**

Note: Figures assume 15 year payback of capital and a real discount rate of 12%.

Source: Fuel prices from Department of Trade and Industry (2000), other figures from author's own calculations. For further elaboration, see Watson (1997).

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[2] This compares to over 3000GW of installed electric power capacity world-wide (Energy Information Administration, 2000). CCGT figures from author's world-wide database of CCGT power plants.

[3] Based on Simbeck et al, 1994 and subsequent plant orders announced in trade journals.

Although fuel prices vary considerably between countries, Table 1 indicates that the fluidised bed will only be economically preferable if natural gas is much more expensive than coal. This is not often the case at present since low international coal prices are accompanied by relatively cheap natural gas in many areas of the world (BP Amoco, 2000). Even if coal prices are sufficiently cheap, experience shows that it is far more likely for coal-fired power plants to use traditional boiler technology (Financial Times, 2000).

The main reason for the CCGT's economic advantage is that the capital equipment is very cheap to buy in comparison with most other generating options. This characteristic is particularly appealing for the new breed of private power developers since they finance new projects through high interest bank loans rather than their own balance sheets or State funds. This built-in economic advantage is reinforced by the fact that CCGT construction times are very short. New plants can be completed in under two years rather than the four to ten years that characterise other large scale technologies. For many private investors, this further accelerates the repayment of bank loans since their only source of revenue is the sale of electricity.

The CCGT also has important environmental advantages that are attractive for governments as well as investors. CCGT emissions are lower than those from other fossil fuel technologies. A typical CCGT emits around 65% less carbon dioxide than a traditional coal-fired power plant for each unit of electricity generated, almost no sulphur dioxide and relatively small quantities of oxides of nitrogen (PowerGen 2000). In addition, CCGTs create a small visual impact[4], and may be sited nearer to population centres than large coal or nuclear plants. This makes it easier for developers to secure planning permission.

Whilst these advantages provide clear evidence for the CCGT's current popularity, they do not explain how this technology came to be in such a dominant position. As Donald MacKenzie (1996: 7) has argued, although hindsight may suggest that a particular technology is intrinsically superior, it is more important to determine how this state of superiority has come about. Therefore the search for an explanation of success needs to take in historical perspectives on technology development.

A New Gas Turbine Paradigm ?

Jorge Islas has argued that the rise of the industrial gas turbine, the technology at the heart of the CCGT, signals a paradigm shift for electric power generation technology. In doing so, he takes his lead from the evolutionary economics literature (for example, Nelson and Winter, 1977; Dosi, 1982). For Giovanni Dosi, a prevailing technological paradigm 'embodies strong prescriptions on the *directions* of technical change to pursue and those to neglect' (Dosi, 1982: 152). The selection of this paradigm and the development of a technology within it are influenced by many economic, institutional and social factors.

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[4] A good illustration is the Didcot power plant near Oxford, UK. A new 1500MW CCGT is dwarfed by an older fossil fuel plant which generates a similar amount of electricity.

Jorge Islas asserts that the end of the old steam turbine paradigm is associated with a number of economic, political, environmental and technological forces that have become apparent since the first oil shock in 1973. These include the fact that ‘conventional large power stations entered a phase of saturation (slowing of technical progress, exhaustion of scale economies, diseconomies connected with growing complexity of systems of generation ...) [and] the appearance of environmental constraints and nuclear security [concerns]’ (my translation from Islas, 1995: 378). The formation of a new gas turbine paradigm has been encouraged by ‘changes in the organisation of the electricity industry inspired by economic “neo-liberalism”, seen as a remedy to the crisis in the electricity industry, [which] permitted the entry of new electricity producers’ (my translation from Islas, 1995: 379).

Jorge Islas’ approach leads us to conclude that an old paradigm has been abandoned in favour of a new one. It appears to offer a convincing explanation for the success of the CCGT, a technology at the forefront of the gas turbine paradigm, and the failure of the fluidised bed which may be associated with the old steam turbine paradigm. Although it is certainly the case that fundamental shifts have taken place, it is questionable whether the paradigm shift has been so universal. Sales of traditional steam turbine power plants are still buoyant, particularly in countries such as India and China which have access to large coal reserves (Financial Times, 2000). The gas turbine paradigm has not yet had any impact on new coal-fired power plants in these countries since the technologies that enable gas turbines to burn gasified coal are still under development (Watson, 1998).

Such caveats highlight two major drawbacks of the paradigm concept. Firstly, the time at which an old paradigm ends and a new one begins is not always easy to define. Although the oil shock of 1973 marked a period in which many of the technological and institutional traditions of the electricity industry were shown to have fundamental flaws, there many other points in history which could be the start of the gas turbine paradigm. These include the start of the ‘gas turbine age’ (Scalzo et al, 1994: 6) in the late-1960s, the transition of the gas turbine to mass production as the jet engine after World War II, or the period in which electricity privatisation and liberalisation were implemented in practice during the 1980s (Watson, 1997).

The second problem that arises with the application of paradigms relates to their scope. It is not clear whether we should be thinking in terms of a gas turbine paradigm (to succeed a steam turbine paradigm), a small power station paradigm (to succeed a large power station paradigm), or a cleaner technology paradigm (to succeed a ‘dirty’ technology paradigm). Each of these cases partly characterise shifts which have already happened or those which may take place in the future. However, the CCGT and the fluidised bed do not fit precisely into the new and the old paradigms respectively. Therefore, as a tool to explain success and failure for this particular case, paradigms are of limited use. Of more relevance is Jorge Samperio’s subsequent view that the gas turbine has reversed the lock-in (Arthur, 1989) of the steam turbine. This analysis allows for the fact that steam turbine technology is still being used in a large number of new power plants, including CCGTs (Islas, 1997).

The Interpretative Flexibility of the Gas Turbine

Apart from the ambiguous nature of the paradigm, the main limitation of evolutionary economics is its narrow focus. Whilst there is some consideration of ‘the role often played in the establishment of a particular technological trajectory by public (“political”) forces’ (Dosi, 1982: 155), the primary concern is still economics. Political forces are essentially seen as an adjunct to the theory which are not explored in great depth, except with reference to military and space projects. As a result, evolutionary economics does not explicitly provide a framework which allows the influence of many different actors (primarily governments, but also consultants, utilities, financiers, manufacturers etc.) on success and failure to be clearly analysed.

It is therefore necessary to draw on some concepts which stem from sociological theories of technology development, particularly the Social Construction of Technology (SCOT) approach (e.g. Bijker et al, 1987; Bijker, 1995; Rosen, 1995). The most important characteristic of this approach is the lack of rigid boundaries between the economic, the social, the political and the technological. It emphasises the need for a stable socio-technical network of interrelated actors around a new technology in order for it to succeed. As Thomas Hughes has argued, there is a strong rationale for a network-based analysis of the electricity industry that takes into account economic, social and political factors:

> Technological systems contain messy, complex, problem-solving components. They are both socially constructed and society shaping. Among the components in technological systems are physical artefacts, such as the turbogenerators, transformers, and transmission lines in electric light and power systems. Technological systems also include organizations, such as manufacturing firms, utility companies, investment banks, and they incorporate components usually labelled scientific, such as books, articles, and university teaching and research programmes. Legislative artefacts, such as regulatory laws, can also be part of technological systems. Because they are socially constructed and adapted in order to function in systems, natural resources, such as coal mines, also qualify as system artefacts (Hughes, 1987: 51).

For this paper, the most important SCOT concept is interpretative flexibility (Pinch and Bijker, 1987:40), a term which explains how different groups of actors or relevant social groups (Bijker, 1995) attach different meanings and problems to the same technology. For example, Wiebe Bijker has observed that during the development of the bicycle, ‘the high-wheeled Ordinary [which became the Penny-farthing] was at once a dangerous machine, prone to failure in the marketplace, *and* a well-working machine that allowed highly skilled physical exercise, resulting in a commercial success’ (Bijker, 1995: 270). The implication is that if a technology is particularly flexible, it could support these different meanings *simultaneously.* As this paper will show, key relevant social groups for the CCGT include the power plant equipment industry, the aircraft engine manufacturers and electric utilities.

To illustrate this point, Table 2 lists the most common applications for a number of power generation technologies, including the fluidised bed boiler and the gas turbine. The four generic technologies shown in Table 2 have at least one application outside the power generation industry. However, generic gas turbine technology stands out with its particularly high degree of interpretative flexibility. To the relevant social group of the armed forces, the gas turbine is the most efficient propulsion unit for fighter aircraft as well as Naval frigates. The relevant social group of electric utilities sees the gas turbine as the most important component of their current technology of choice, the CCGT. Elsewhere, the relevant social group of oil and gas companies uses this technology for pumping gas through long pipelines and to provide power for offshore installations. In addition, the gas turbine is also a large source of revenue and a strategic core technology for the relevant social groups of power plant equipment manufacturers and aircraft engine producers.

Table 2: The Interpretative Flexibility of some Power Generation Technologies

Application	Conventional Fossil-Steam	Nuclear Technology	Gas Turbine	Fluidised Bed Boiler
Chemical processing	No	No	No	Yes
Oil and Gas Industry	No	No	Yes	Yes
Utility	Yes	Yes	Yes	Yes
Independent Power Producer	Yes	No	Yes	Yes
Weapons	No	Yes	No	No
Aircraft Propulsion	No	No	Yes	No
Ship Propulsion	No	Yes	Yes	No
Combined Heat and Power	Yes	No	Yes	Yes

Note: Two experimental nuclear aircraft engines were built in the USA during the 1960s, but perhaps thankfully, they were never used (Sellix, 1995).

Source: Author's elaboration.

The Struggle for Acceptance

During the past 50 years, the interpretative flexibility of the gas turbine has allowed the steady and successful enlistment of the electric utilities as a relevant social group.

The first attempt to sell the industrial gas turbine to the electric utilities began as early as the late 1940s. However, this attempt failed because this new technology was outperformed by steam turbine power plants which were going through a phase of rapid technical change. As a result, the gas turbine was too small and inefficient for most electric utilities. A typical industrial gas turbine, with an output of 5MW and a thermal efficiency of up to 20% (Schneitter, 1953), was unable to match fossil-fuel steam plant sizes of up to 100MW and thermal efficiencies of at least 25% (Sherry,1984).

The gas turbine equipment manufacturers responded by developing complex variants of their designs, with theoretical efficiencies of up to 34% (Schneitter, 1953: 206). However, the few machines that were built suffered from acute reliability problems. For the fluidised bed boiler, the prospects of utility interest were even more remote at this stage since the idea of using this technology for steam generation had not yet emerged (Patterson, 1978). As a result, the links between both technologies and the relevant social group of electric utilities remained slight at best.

Despite the lack of utility interest in the industrial gas turbine of the 1950s, generic gas turbine technology was not short of supporters. Following the reliability problems of complex gas turbines, the return to simple designs by the equipment manufacturers led to the enlistment of the oil and gas industry[5]. For this relevant social group, the gas turbine was not primarily a device to generate electricity. Instead, its interpretative flexibility meant that it was an economical means of pumping natural gas and oil through long distance pipelines.

By the end of the 1950s, the limited success enjoyed by the industrial gas turbine had encouraged the equipment manufacturing companies to experiment with their first CCGTs. However, the CCGT remained peripheral to their power generation business for another thirty years. By contrast, the airborne counterpart of the industrial gas turbine, the jet engine, had already emerged as the dominant technology for aircraft propulsion. The Korean War had provided the incentive for the expansion of military R&D spending to levels which would be sustained for the next forty years (Mowery and Rosenberg, 1982; Williams and Larson, 1988). In addition, the first jet powered civilian airliners had begun to enter service in Europe and North America. The support of this network of relevant social groups allowed generic gas turbine technology to flourish in a way that would eventually aid the enlistment of the electric utilities by the CCGT.

Enlisting the Electric Utilities

The chain of events that eventually led to the first substantial link between the electric utilities and the industrial gas turbine may be traced to the power blackouts in the UK and North America during the early and mid-1960s (North American Electric Reliability Council, 1994). These blackouts exposed the lack of provisions to cope with such emergencies within the electricity supply grids of most industrialised countries. In the years that followed, the utilities in these countries installed a large number of emergency gas turbines to restore electricity supplies. The fast start-up capability of both the industrial and aircraft engine-derived variants of gas turbine meant that they were ideal for this type of application.

Although hindsight provides evidence that the 1960s blackouts could have been predicted and avoided, they can be viewed as a classic unpredictable historical event (Arthur, 1989). The subsequent increase in demand for industrial gas turbines allowed the equipment manufacturers to re-invest their revenues and improve their designs. These improvements, which yielded increases in unit size and efficiency, provided the utilities with increasing returns from their adoption of the gas turbine. It is this process which eventually led to the emergence of the CCGT.

The most important consequence of the 1960s power blackouts is the establishment of a vital lead for gas turbine technology over the fluidised bed for power generation applications. Although the idea of using fluidised bed boilers for steam generation (and, by implication, power generation) emerged during this decade, the amount of practical development work remained small until the mid-1970s (Patterson, 1978). By this time, the first CCGTs had been constructed in the USA.

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[5] From interviews with employees of equipment manufacturers and evidence from manufacturer reference lists of historical gas turbine sales.

Once the electric utilities had become more familiar with their new gas turbines, it was much easier for the equipment manufacturers to incorporate larger versions of these machines into CCGT plants. Indeed, some of the American equipment manufacturers reported that the electric utilities began to enquire about gas turbines for continuous rather than emergency service[6]. At this point, the interpretative flexibility of this technology was vital since it allowed the manufacturers to import advanced materials and cooling techniques from the jet engine in order to scale-up their designs to a useful size. The advent of gas turbines with capacities of over 50MW allowed the construction of 100MW CCGT blocks which operated with a thermal efficiency of around 40% (for example, Maslak and Thomson, 1994). Several of these blocks could be constructed side by side in order to form a medium-sized power station that matched the efficiency of contemporary steam turbine power plants.

This combination of factors led to the enlistment of the first batch of electric utilities by the supporters of the CCGT. Many of the first orders were placed in the USA, where a bubble of cheap natural gas had improved the economics of gas-fired power.[7] In addition, General Electric (GE) and Westinghouse were technologically better placed than the European manufacturers as a result of their current and previous aircraft engine connections. At the same time, the fluidised bed boiler finally became attached to the same socio-technical network with the construction of the first demonstration plants for electricity generation in the UK and the USA (Patterson, 1978).

Temporary Interest in the Fluidised Bed Boiler

The new wave of interest in the CCGT as a power generation option did not last for long. Its end, like its beginning, was precipitated by an unpredictable historical event. This time, it was the decision of the Middle-Eastern OPEC nations to quadruple their oil prices which had a large impact on the CCGT since it was accompanied by a sudden increase in natural gas prices (Flavin and Lenssen, 1995). The problems of the CCGT were subsequently compounded by a number of serious reliability problems which affected the newly scaled-up industrial gas turbines (Bechtel, 1980).

For the fluidised bed boiler, the 1973 oil shock represented a much needed boost to its prospects. An attitude of indifference amongst relevant social groups such as governments, utilities and large boiler makers was replaced by a growing interest. Faced with the twin problems of high oil prices and localised environmental pollution, governments and equipment manufacturers in North America, Europe and Japan began to look at ways of burning coal more cleanly and efficiently. Since fluidised bed technology offered the prospect of fulfilling the first (and perhaps the second) of these criteria, a number of demonstration projects were initiated (Patterson, 1978).

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[6] Comments by Malcolm Jarvis, Applications Engineer, GE Power Systems, Egham, UK during an interview with the author in March 1995.

[7] Comments by Douglas Todd, Manager, Combined Cycle Programmes Marketing, GE Power Systems, Schenectady, NY, USA during an interview with the author in November 1995.

The fluidised bed was not the only beneficiary of the new public R&D programmes. These programmes also included ambitious plans to develop high efficiency industrial gas turbines and jet engines, some of which eventually yielded CCGT improvements.[8]

By the late-1970s, utilities had formed an attachment to both of our two technologies, though the extent of this attachment was still weak. Although the demand for gas-fired power had almost disappeared outside the Middle East, the CCGT's position remained much stronger than that of the fluidised bed. The existence of a significant number of plants in commercial service in the USA and Europe, together with the strong network of relevant social groups that were continuing to support the jet engine, placed this technology in a strong position for the future. By contrast, the fluidised bed boiler was set to remain a demonstration technology for several more years despite the support of some governments, large boiler makers and utilities.

Success is Confirmed

Although the first oil shock appeared to signal an abrupt end to the new gas turbine age, the development of the CCGT continued throughout the 1970s and 1980s. Trends in capital costs, environmental performance and reliability combined to increase the advantages of the CCGT over the alternatives. Whilst the performance of traditional technologies did not improve substantially, the CCGT of the late 1980s was substantially more attractive than its predecessor of the early 1970s. Even though orders for gas turbines and CCGTs remained scarce until the end of this period, the CCGT was well placed by the time that oil prices fell in 1986. Faced with such rapid improvements the fluidised bed boiler was left behind, even though its supporters made considerable progress in terms of unit size and reliability.

Figure 3 shows a comparison of typical fossil-fired steam plant capital costs with those of a CCGT between 1970 and 1995. The figures, which are all taken from estimates under conditions in the USA, have been adjusted to year 2000 prices.

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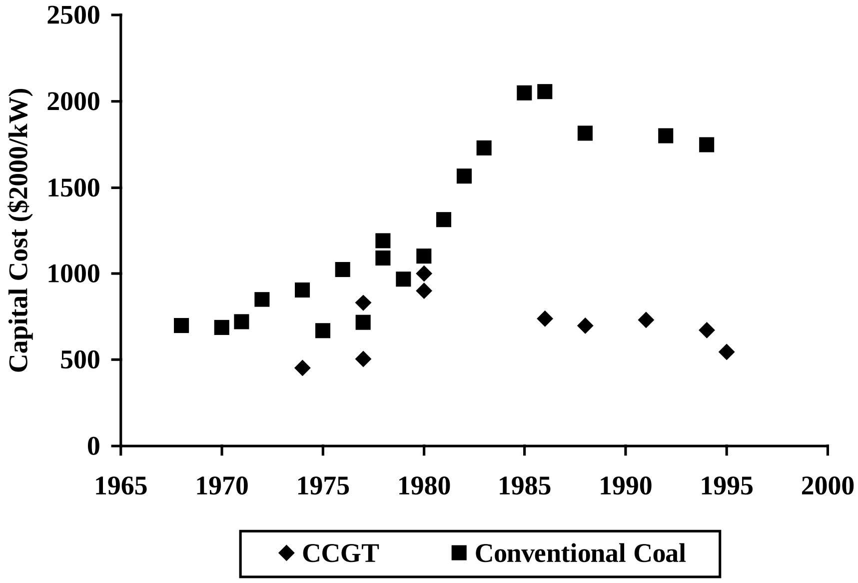
[8] Comments by Harold Miller, Manager – Technology Programmes, Advanced Technologies, GE Power Systems, Schenectady, NY, USA during an interview with the author in November 1995.

Figure 3: Capital Costs of the CCGT and Conventional Coal-fired Power Plants in the USA (1970-1995)



Note: All figures are approximate, for plants 300-500MW, and are adjusted to year 2000 prices
Source: Authors elaboration from journal articles and interviews with equipment supply companies.

Since 1980, there has been a substantial increase in the capital costs of conventional fossil-fired steam plants whilst the cost of a typical CCGT has actually fallen slightly. According to some estimates, the cost of a typical large coal-fired station has escalated by 20% as a result of the need for flue gas scrubbers and cooling towers (Joskow and Rose). Although they appear to be large, these cost escalations are not as substantial as those for nuclear power stations (e.g. MacKerron, 1992). The reasons for the downward trend in CCGT costs may be traced to the intense competition for orders within the heavy electrical industry as well as rapid advances in thermal efficiency.[9]

During the period of time covered by Figure 3, the maximum size of fluidised bed power plants was increased from less than 10MW to 250MW (European Commission, 1996). Although historical capital cost data is difficult to locate, it is possible to conclude that the fluidised bed failed to outperform traditional fossil-fired steam plants in economic terms. The early fluidised beds that were constructed in the USA following the introduction of the Public Utility Regulatory Policy Act of 1978 featured an economic advantage over a traditional coal-fired plant with flue gas desulphurisation to reduce sulphur dioxide emissions. It was at this time that interest rose in this technology as a way of burning coal and other polluting fuels

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[9] From authors interviews with various manufacturers including Alstom and Westinghouse.

whilst minimising emissions. However, this advantage was soon lost as the proponents of traditional boiler technology fought back.[10]

As well as increasing the comparative economic advantage of the gas turbine and CCGT, the equipment manufacturers also had to restore utility confidence in the reliability of their designs. Attitudes during the mid-1970s were typified by one utility executive who is reported to have said that ‘the only good gas turbine is one that doesn’t have to run’ (Moore, 1988). If the relevant social group of electric utilities were going to be encouraged to renew and strengthen their attachment to the CCGT once the fuel price situation changed, the image of this new technology would have to be improved.

Despite this dismissive attitude from some quarters, the utilities played a crucial role in the improvement of reliability, particularly through the efforts of the Electric Power Research Institute in the United States (Della Villa et al, 1989). When oil and gas prices fell in 1986, their reluctance to embrace CCGT technology did not last long because the steady efficiency improvements implemented by manufacturers began to yield substantial economic benefits. These benefits have outweighed concerns about reliability even though some newer CCGT designs have suffered from significant technical problems (Watson, 1998). Asian utilities such as the Tokyo Electric Power Company and the Electricity Generating Authority of Thailand were the first to recognise the CCGT’s potential. They were accompanied by the new breed of independent power companies in the UK and the USA, who were keen to use the CCGT as a way of entering newly liberalised electricity markets.

Powerful Relevant Social Groups

Whilst the evidence presented so far shows how the CCGT eventually enlisted electric utilities and independent power companies through its interpretative flexibility, an exclusive focus on these relevant social groups misses out some important ingredients of success. This paper has already alluded to the influence of other relevant social groups on success and failure, namely the power plant equipment manufacturers and various government agencies.

Before bringing the analysis to its conclusion, it is important to acknowledge the power of these relevant social groups to shape success and failure. SCOT approaches to technical change have already addressed the issue of power in previous empirical case studies. In his social construction of the fluorescent light bulb, Wiebe Bijker introduced power ‘to account for the obvious differences in economic power between some of the relevant social groups ... [including] Mazda companies [a lighting cartel], utilities, independents, consumers, fixture manufacturers, and the government’ (Bijker, 1995: 267).

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[10] This pattern of behaviour fits the observation by previous authors that the supporters of the normal technology will innovate in order to stave off the challenge of a new competitor (Constant, 1980; Von Tunzelmann, 1986a and 1986b).

The International Equipment Companies

The world's dominant manufacturers of equipment for electric power plants have been in existence for over 100 years. Companies such as Siemens of Germany and GE of the USA were founded by electricity industry pioneers during the late 19th century. For at least the first sixty years of its existence, the heavy electrical industry operated through a series of cartels. These included the famous Phoebus electric lamp cartel of the 1920s and the International Electrical Association which acted as a cartel for at least 40 years from the mid-1930s (US Congress Committee on Interstate and Foreign Commerce, 1980). Illegal activities such as price fixing and market allocation were common within these cartels, as were more legitimate associations through product licensing agreements. As a result, the heavy electrical industry has always been a financially strong and powerful relevant social group for the technologies it championed.

One of the defining features of the dominant companies within heavy electrical industry is their strong technical competencies in the area of turbine design (Constant, 1980). Companies such as GE, Westinghouse and Siemens were the first to take up the steam turbine following its invention by Charles Parsons in 1884. They were also heavily involved in the jet engine development programmes during and after World War II, and were the first companies to develop the land based gas turbine as a new electricity generation technology. The turbine-based competence of these companies meant that they were able to subsequently develop and sustain an interest in CCGT design and manufacture.

The success of the dominant heavy electrical industry firms in commercialising turbine-based technologies such as the CCGT contrasts sharply with their general lack of interest or skills in boiler equipment manufacture. As one manager from GE explained, his company felt that there 'was very little unique contributed value in putting together a bunch of tubes and putting a shell around it'.[11] In fact, the first efforts of gas turbine manufacturers such as GE and Westinghouse to build heat recovery boilers for their CCGTs were a disaster, and they soon contracted out this activity (Bechtel, 1980). Similarly, their performance in the construction of nuclear steam generators was much weaker than rival boiler makers like Babcock and Wilcox and Combustion Engineering (Thomas, 1988).

The upshot of this technical specialisation is that the largest power plant equipment manufacturers only showed limited interest in new boiler-based technologies such as the fluidised bed. Instead, this technology was developed on the sidelines by a number of small and medium-sized boiler makers, and was only picked up by larger equipment companies as a by-product of industry take-overs during the 1980s and 1990s. Whilst the CCGT emerged as the fastest developing power plant technology with a global market share approaching 50% (Financial Times, 2000), the boiler makers became less and less technologically important. Although orders for power station boilers have continued, the CCGT boom has strengthened the position of the big four heavy electrical industry companies (GE, Siemens-Westinghouse, Alstom and Mitsubishi) at the expense of the boiler makers.

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[11] Comments by Jim Corman, General Manager, Power Generation Systems, GE Power Systems, Schenectady, NY, USA during an interview with the author in November 1995

A Political Economy of Technology Choice

Governments and their agencies influence the success and failure of energy technologies in many different ways, some direct and some indirect. In doing so, governments can comprise several relevant social groups which become linked to a particular technology for a variety of different reasons. The UK dash for gas provides a good illustration of some of these links. As stated earlier, the dash for gas led to the rapid diffusion of CCGT technology within the UK electricity industry starting in the early 1990s. This phenomenon is particularly relevant here since it confirms Wiebe Bijker's observation that the 'stabilisation of artefacts is a social process and hence subject to choices, interests, and value judgements - in short, to politics' (Bijker, 1995: 281).

In the early 1990s, parts of the UK government acted as particularly powerful relevant social groups for the CCGT. Their clearest influence can be traced to the privatisation and liberalisation of the electricity supply industry which began in 1989 (Surrey, 1996). Strong government support for privatisation and the development of competition led to the encouragement of independent power producers to challenge privatised generating companies. As this paper has already illustrated, the post-privatisation financial climate gave strong incentives for power companies to choose CCGT technology for new power plants. However, obstacles remained to new entry based on CCGTs due to legislative restrictions on the use of natural gas as a power station fuel. The government Minister responsible, Cecil Parkinson, chose to overrule both UK and European laws to allow the first batch of CCGT stations to be built (e.g. Young, 1988). As a fortuitous by-product of the CCGT's popularity, the government was subsequently able to meet its international commitments to curb emissions of carbon dioxide and sulphur dioxide without the need for further intervention (Department of Trade and Industry, 2000).

Alongside the government's economic and environmental reasons for encouraging the dash for gas, there was a deeper political motivation for its actions. Following their return to power in 1979, a key part of the Conservative Party's agenda was the desire to curb trade union power in the aftermath of the 1978-79 'winter of discontent' (Milne, 1995: 8). Since the UK's coal mining union (the National Union of Mineworkers or NUM) represented the more militant strand of trade unionism, it became the primary target of government efforts. Even though the power of the NUM was severely diminished following the strike of 1984-85, the dash for gas may be seen as a convenient way to weaken its influence in the UK energy system.

This additional ideological driver helps to explain why the shift in favour of the CCGT in the UK has been much more pronounced in the UK than in other countries. It also partly accounts for the continued absence of the fluidised bed and other cleaner coal technologies from the UK power generation scene. In other industrialised coal producing countries such as Germany and the USA, the switch to gas has not been so rapid and the fluidised bed boiler has made a limited impact.[12] Whilst the UK government relevant social groups were not dominated by people who were positive advocates of the CCGT, they became firmly linked to this

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[12] Data from SPRU CCGT database and from fluidised bed manufacturer reference lists.

technology by default. To use the terminology of Bruno Latour (1991: 104), the UK government was *translated* to support the CCGT due to the combined effect of the Conservative Party's agenda of economic liberalisation and its crusade against trade union power. In the light of these considerations, it is not surprising that the introduction of competition into the electricity was carried out in a way that was extremely detrimental to the coal industry. In addition, it is now clear why the UK dash for gas was allowed to continue unabated until the Conservatives left office in 1997.[13]

Conclusions: Government, Technology and Sustainability

This paper has shown why one power generation technology has become a world-wide success, whilst another equally promising technology has failed to make an impact. Although the reasons for the CCGT's popularity are clear under current economic conditions, it is less apparent how this technology came to be in such a position of strength. The explanation for its ascendancy involves a complex array of factors. It has been shown that the economic dimension of the CCGT's development provides insufficient evidence for its success. Substantial weight must also be given to the structure of the electricity and power plant equipment industries, the role of unpredictable events and political motivations particularly within the UK government.

At the heart of the explanation of success and failure lies the interpretative flexibility of the gas turbine, the most important CCGT component. This flexibility has allowed the gas turbine to develop rapidly, first as the aircraft jet engine and subsequently as a power source for the oil, gas and electricity industries. Through the application of jet engine technology to land-based gas turbines and improvements in reliability, the relevant social group of electric utilities was enlisted as a strong supporter of the CCGT in the late 1980s and early 1990s. Whilst some fluidised bed boilers have been built as a result of stringent environmental regulations in a few countries, its position has been undermined by the arrival of cheap natural gas.

In conclusion, it is important to examine the implications of success and failure for future government policies, particularly those for the encouragement of more sustainable energy technologies. The experience of government support for new energy technologies suggests that the most direct policy options - particularly R&D funding – do not necessarily lead to commercial success. In face, much of the evidence points to the opposite conclusion - that the success or failure of a given technology has little to do with government R&D funding of it. Examples of failed State-funded technologies include the fast breeder nuclear reactor (Keck, 1988) and the supersonic passenger aircraft (Nelson and Eads, 1972).

The axiom that government funding and success have little in common would appear to be supported by the cases of the CCGT and fluidised bed. Whilst the fluidised bed boiler has benefited from considerable public financial support, most notably from the US government

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[13] Following its election in 1997, the Labour government introduced a partial moratorium on consents for new CCGT power plants (Department of Trade and Industry, 1998). This moratorium is expected to be lifted in early 2001.

(US Department of Energy, 2000), it has not become a mainstream technological option. By contrast, the conventional wisdom with regard to the CCGT is that it was developed by private companies in response to demand for a cheap, environmentally friendly and trouble free source of electrical power.[14]

Although this particular contrast between the CCGT and the fluidised bed boiler reflects some of the truth, this paper has revealed a more complex picture. The close link between the gas turbine and the aircraft jet engine means that the current generation of CCGTs have benefited from billions of dollars of public R&D support (e.g. Mowery and Rosenberg, 1982). As a result of the military jet engine connection, the armed forces and defence agencies of many countries comprise a particularly powerful relevant social group for the gas turbine and, by implication, for the CCGT. Similarly, some observers are of the opinion that the most successful designs of fluidised bed were developed by private companies with a minor role played by government programmes.[15] However, the fluidised bed has not benefited from obvious State-sponsored spin-offs due to its lower degree of interpretative flexibility.

The implications for governments wishing to support the development and use of more sustainable energy technologies are complex. The cases of the CCGT and fluidised bed do not give any encouragement to those who advocate ‘do nothing’ governments - governments which provide minimal direct support for the development of new technologies and those which prefer to leave such matters entirely to the market. It has been shown that it is highly unlikely that the CCGT would have been a success if it had not been helped by billions of dollars of government money through military budgets. It has also been established that the fluidised bed boiler has failed despite considerable public financial commitments, particularly from the US government.

Such unpredictable effects reinforce the conclusions drawn by previous studies (e.g. Kemp et al, 1997; Stirling, 1994) that a government strategy that supports a diverse range of technologies is likely to be the most effective. Along with other evidence presented in this paper, these effects also add weight to the view that technologies are not developed from concepts to commercial successes in a linear or path dependent way. Rather, they are the result of complex interactions between various relevant social groups which have to be enlisted as part of a new, stable socio-technical network.

Even though new technologies may seem to be practically feasible as well as more sustainable, there are often large barriers to their adoption. For example, the relevant social group of electric utilities may not be interested in solar cells because they are too small, too expensive or too novel. Alternatively, the power plant equipment industry - a relevant social group that dominates the power generation equipment market - may be impossible to enlist because they do not have the competencies or the inclination to adopt a given technology. The fluidised bed boiler is a case in point. In view of these potential barriers, it is not enough to provide lists of technological possibilities with an exhortation to use them simply because

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[14] This perception is particularly widespread amongst electric utilities, financiers and regulators (Watson, 1998).

[15] Personal communication from Jason Makansi, Editor in Chief, Power, New York, USA, 11th April 1995.

they are more sustainable as von Wiezsacker et al (1997) have done. Instead, mechanisms have to be devised which allow confidence to be built amongst the various parties and the establishment of new socio-technical networks, whilst allowing for the fact that some technologies will not be taken up and others will be the subject of unexpected interest. A partly successful example of such a mechanism is the UK's Non Fossil Fuel Obligation subsidy for renewable energy technologies (Mitchell, 1994).

Finally, from the perspective of the UK, it is easy to hold the view that revolutionary structural change is always necessary to alter established technological habits. Since the abandonment of traditional coal-fired power plants in favour of the CCGT has also led to dramatic reductions in the UK electricity industry's environmental impact, it is equally easy to conclude that such an upheaval is a pre-requisite for a shift towards a more sustainable energy system. However, the evidence from outside the UK contradicts this view. For example, the large Japanese utilities have adopted the CCGT even though they are private monopolies. They have also reduced the environmental impact of their existing fossil-fuel power plants through an extensive programme of flue gas desulphurisation and denitrification. Elsewhere, the State-owned monopoly utilities of South Korea, Indonesia and Thailand have also built large numbers of CCGTs. Therefore a radical change in the structure of the electricity industry is not a necessary condition for the success of the CCGT. If this conclusion were generalised to other technologies, it would mean that more sustainable options can thrive within existing institutional structures.

Whilst it is may not be necessary to privatise (or even liberalise) the energy industries to encourage sustainability, some of the technologies to help combat global climate change could ultimately originate outside the established socio-technical network. Unless all of the power equipment companies follow the example of the Swiss Swedish company, ABB, and jettison their interests in traditional energy options, the progress of many new technologies may be very slow. It would appear that there is still a lot to be learned from the actions of the US government 55 years ago. Instead of giving their newly acquired jet engine to the existing piston aircraft engine suppliers, the US Airforce decided to involve the steam turbine manufacturers - manufacturers which did not have a vested interest in blocking the progress of this revolutionary new technology.

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