Coal R&D Successes in the UK

The Coal Research Forum

June 1996

This report on 'Coal R&D Successes in the UK' was commissioned by The Executive Committee of the Coal Research Forum who recognised the need for an ongoing National Policy for coal research in the UK. It complements the 'Coal Research Needs in the UK' document which identifies, for government and other funding organisations, future coal research needs as perceived by Members of the Coal Research Forum.

The purpose of this report is to demonstrate that the coal R&D undertaken in the UK over the past decade or so has resulted in many successes and provided substantial benefits. Examples of coal preparation and utilisation R&D projects are given in terms of resulting technical, commercial and environmental benefits. Members of the Coal Research Forum consider that coal R&D in the UK must be sustained in order to continue to provide technical and environmental improvements, and thus help to keep coal competitive and help provide export opportunities for British industry.

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1. EXECUTIVE SUMMARY

Sustained Coal R&D activity has been crucial to the many successful clean coal technology developments that have been achieved in the UK. The aim has been to enhance the competitiveness of coal by providing technical and environmental improvements whilst at the same time reducing capital and operating costs. With coal facing severe competition from oil, natural gas and nuclear energy, these R&D initiatives have been essential.

Low cost, clean coal technologies are needed in the UK, Europe and throughout the world. For example in Europe, coal provides 20% of its primary energy and almost 40% of electricity generation. The Organisation for Economic Co-operation and Development (OECD) has forecasted that up to the year 2010 coal use in OECD Europe and world-wide will grow by some 1% and 2% per year, respectively.

The world market for clean coal technologies is enormous. It could amount to at least £500 billion over the next 15 years or so. Power Generation is the principal sector with substantial growth forecast in Asia, the Pacific Rim and elsewhere. Much of this new market will be close to the UK in Eastern Europe and the Newly Independent States. Thus, there is every incentive for maintaining a strong coal R&D base in the UK because successful outcomes will help to contribute to developing considerable export opportunities for UK companies to sell equipment and services overseas.

Recent estimates suggest that past R&D in clean coal technologies has already contributed to over £1 billion of benefits for UK Industry. The opportunities within the UK are substantial. For example, the potential market for retrofit technologies, such as low NO_x burners and flue gas desulphurisation equipment to allow existing plant to comply with current environmental legislation, has been estimated to be some £600 million up to the year 2000.

But the competition is fierce. A number of other countries have much to offer in clean coal technologies. Their industries are often supported by large research and development, and demonstration programmes, notably in the USA, Japan and several European countries. It is essential for the competitiveness of UK industry that the UK also has vibrant, well focused R&D programmes.

Government has recognised the importance of these arguments. In 1993, it increased its support for coal R&D from some £3 million to £7 million per year for 3 years, at a time when the UK energy industries were being privatised and were severely curtailing their R&D activities. In the White Paper ‘The Prospects of Coal - Conclusions of the Government’s Coal Review’, the importance was emphasised of ensuring ‘that coal is used as cleanly and efficiently as possible in existing plant and that full advantage is taken of advances in coal science or combustion engineering’.

The many successes, which have resulted from coal R&D in this country, have helped to give confidence that future activities will also provide substantial benefits. Past successes have been in all areas of coal use, including coal preparation, transportation and handling, metallurgical uses of coal, coal combustion, conversion and advanced power generation. Almost all of these successes may be regarded as providing technical and environmental benefits. Many developments have been commercially exploited and have demonstrated that coal can provide increasingly low cost, reliable, efficient energy in an environmentally acceptable manner.

In coal preparation, the Large Coal Dense Medium Separator (LARCODEMS) provides much better performance and control than is possible with jigs and barrel washers. For example, the yield of saleable coal is increased by at least 1%. Also, simpler lower cost alternatives to froth flotation, such as the hydrosizer and spiral separators, have been adapted for cleaning of fine coal. Coke and steel making have benefited substantially from R&D initiatives. Low cost filler coals have been incorporated to reduce coke costs, giving potential savings to British Steel of some $5m/yr.

Significant reductions in coke rates have been achieved which have led to savings in the region of \$1.5m/yr. With direct injection of coal, British Steel can replace some 25% of the coke combusted at the tuyere, enabling cost savings of about \$50m/yr to be made.

In recent years, many advances have been made in addressing the environmental issues associated with coal combustion. The UK has been particularly active in low NO_x burner development. Mitsui Babcock Energy and International Combustion have developed low NO_x burners for achieving up to 70% reductions in wall - and tangentially - fired power station boilers. Also low cost, dry sorbent techniques for SO_2 control have been developed for a wide range of industrial coal-fired plant.

Coal liquefaction moved away from the laboratory when the large pilot plant-scale facility at Point of Ayr in North Wales was built. Its operations have shown that the British Coal Liquid Solvent Extraction process is technically ready to be taken forward to the demonstration stage.

The British Gas/Lurgi slagging gasifier has been demonstrated and is now commercially available for the manufacture of substitute natural gas. It is also suitable for use in Integrated Gasification Combined Cycle plant for power generation. Successful trials have been undertaken on their 500 tonnes/day demonstration plant at Westfield in Scotland.

The Air Blown Gasification Cycle development, which is being managed by the industrially led consortium known as the Clean Coal Power Generation Group, has now reached the stage where plans for a Prototype Integrated Plant are being developed. The process offers potentially superior performance compared to other advanced coal-fired power generation technologies in terms of lower generating costs coupled with higher efficiency and low environmental impact.

Whilst major advances have been made in developing competitive clean coal technologies, there is still much scope for further significant improvements to conventional power generation plant and the opportunity of even better performance with the new generations of clean coal technology. Similarly, there are many opportunities for further improvements in the use of coal in steel making and other markets. Maintaining a strong coal R&D base will help industry and thus the country to benefit from the opportunities within the UK and from the vast markets overseas for clean coal technologies.

2. INTRODUCTION

For some 200 years coal was the major source of energy in the industrial development of the UK. Most of this coal was home-produced. In recent years, increasing competition from oil, natural gas and nuclear energy as well as overseas coal has resulted in a marked decline in UK coal production and consumption. Increased attention to environmental concerns has also been an important contributing factor. Thus, UK coal production and use were 48 and 82 m/tonnes respectively in 1994 compared with 194 m/tonnes for both in 1964.

There is no doubt that the decline in coal production and use would have been even greater had it not been for the many remarkable technical advances which have resulted from sustained R&D effort over the decades. For example, enormous improvements in productivity have been achieved by the introduction of modern mining techniques. The development of large scale, clean and efficient coal-fired power plant has meant that some 80% of coal production in recent years has been used for electricity generation.

For coal to continue to contribute to its full potential towards meeting UK energy requirements into the next century, it is essential that coal R&D activity is sustained. This has become increasingly critical following the privatisation of the coal, gas and electricity industries. Historically much coal R&D was carried out within the public sector but now commercial imperatives have meant a substantial decrease in R&D funding by these three privatised industries. In March 1993, the Government confirmed the importance of maintaining a strong coal R&D capability within the UK when the President of the Board of Trade presented to Parliament the White Paper, ‘The Prospects for Coal - Conclusions of the Government's Coal Review' (Cm2235, HMSO). As part of its remit, the paper looked at 'Clean Coal Technologies' and the impact these could have on the future of the UK coal industry. It concluded that it is important to ensure 'that coal is used as cleanly and efficiently as possible in existing plant and that full advantage is taken of advances in coal science or combustion engineering'.

To demonstrate its commitment, the Government increased its support for coal R&D from £3m/yr to around £7m/yr for 3 years to help research in academe and industry be maintained, and to help ensure that full advantage could be taken of international collaboration as well as securing substantial levels of funding provided by the European Coal and Steel Community (ECSC) and other Programmes of the European Commission (EC). Many opportunities for international collaboration are provided by these EC Programmes and those of the International Energy Agency. A major incentive for this increase in Government support for coal R&D is the recognition that there are substantial opportunities for UK companies to have a share in the enormous world market for clean coal technology.

For some time previously, the coal research community in the UK had been concerned at the increasing vulnerability of funding coal R&D as well as being aware of the benefits of greater contacts within the community. As a result, the Coal Research Forum was formed in 1989 to bring together interested scientists and engineers employed in industry and academic institutions. Its aims are to encourage, promote and co-ordinate pre-competitive research in coal, coal products and coal utilisation in the UK. With inputs from its Research Divisions, a 'Coal Research Needs in the UK' document was produced and distributed widely within the coal community in 1990. A second revised Edition was issued in 1993.

Undoubtedly, this document has made a useful contribution to the debate regarding the direction that current and future coal utilisation R&D should take. But the concern remains, 'Will funding for coal research be sustained?' Members of the Coal Research Forum are conscious that part of the case for maintaining research must be that worthwhile benefits have resulted, and will continue to do, from funding such research. This report addresses this question by demonstrating that there have been many successes and substantial benefits arising from coal R&D in the UK over the past decade or so.

3. BENEFITS OF COAL R&D

The purpose of undertaking coal R&D is primarily to help improve the economics of coal use and environmental protection. Thus, R&D is needed to help coal to compete with alternative energy sources, such as natural gas, in its various markets viz. utility, industrial, commercial and domestic sectors. Although historically the markets were mainly UK-based, an increasing emphasis is being placed now on the development and exploitation of UK know-how world-wide by British companies, and the resulting benefits to the UK economy. The overseas opportunities are vast: the potential worldwide market for Clean Coal Technology is at least £500 billion over the next 15 years or so. Power Generation is the principal sector with substantial growth forecast in Asia, the Pacific Rim Countries and elsewhere. Much of this new market will be close to the UK in Eastern Europe and the Newly Independent States. Thus, there is every incentive for maintaining a strong coal R&D base in the UK because successful outcomes should contribute to developing considerable export opportunities for UK companies to sell equipment and services overseas.

The immediate aim of coal R&D is to provide technical benefits, either through direct industrial application or as the basis for further development and demonstration of technologies. Technology transfer is a key element in order to help ensure that project results are taken up by industry, so that commercial benefits can be realised. In addition, most areas of coal use need R&D to provide environmental benefits because of the ever-increasing pressures to reduce their environmental impact. Clearly, these benefits contribute to the general public good and the UK as a whole as progress is made towards cleaner, more competitive energy from coal. Nor should the benefits be ignored which arise from the development of skilled scientists and engineers in the energy and environmental fields, and the opportunities for technology transfer to other industries, e.g. the process industries which have benefited from work done on solids handling/transport and solids separation.

Since its formation, the Coal Research Forum has been an important focus for the coal community in the UK for promoting coal research by providing opportunities for dissemination of information on Coal R&D progress and achievements. It has seven Research Divisions; viz. Coal Preparation, Coal Characterisation, Combustion, Advanced Power Generation, Liquefaction, Carbonisation and other Metallurgical Uses, and Environment. They hold regular meetings and symposia to discuss the R&D being undertaken in the various areas and to identify future R&D needs. These meetings provide valuable opportunities for industrial and university groups to consider how best to co-ordinate their various activities. As a result, the coal R&D undertaken by non-industrial organisations has been targeted better for addressing the needs of industry, thus greatly increasing the relevance and resulting benefits of such research.

ETSU is another organisation committed to promoting, co-ordinating and maximising the successes and benefits of coal R&D in the UK. Its Coal Team manages the Coal R&D Programme for the Government's Department of Trade and Industry. A key milestone for the programme was the publication of Energy Paper 63, 'Clean Coal Technologies - A Strategy for the Coal R&D Programme' (HMSO). It presents Government's policy towards clean coal technology research, development and demonstration, and summarises the strategy for implementing the policy. The document describes the rationale for the DTI's Programme, the current and planned collaborative work as well as the main targets and management structure to ensure value for money.

In implementing the strategy, the ETSU Coal Team works closely with industry and academic institutions. Its staff provide key inputs in the management of the many projects, most of which involve a high degree of collaboration between organisations. Overall direction and guidance is provided by the Advisory Committee on Coal Research and the Industry-led Clean Coal Power Generation Group. These committees help to ensure that the research is industrially relevant and potentially of benefit.

Technology transfer is key to the Coal R&D Programme because of the importance of industry taking up the results of the research as soon as possible. To help in the dissemination of information, ETSU produces and publishes comprehensive series of Project Profiles, Project Summaries and Project Reports. It also contributes to relevant national and international conferences as well as organising a variety of meetings to encourage and promote technology transfer.

As a result of the activities of ETSU and the Coal Research Forum, the profile of coal R&D in the UK has been greatly enhanced. This has led to a much better awareness of the successes and benefits, which have resulted from coal research in this country.

The various bodies (e.g. Government, European Commission, Industry) from time to time analyse to varying degrees the cost/benefits of funding research. One such analysis was undertaken for the Commission of European Communities, entitled 'Evaluation of the ECSC Technical Coal Research Programme' and published in January 1995. It includes a detailed evaluation of coal technology and utilisation research in terms of realised technological, commercial, environmental and regional benefits. The success of each research project was assessed under these categories in terms of some thirty potential objectives and achievements. The ECSC report was consulted when preparing this report as many of the projects analysed were undertaken in the UK.

A similar approach, albeit in less depth, has been taken here in considering coal preparation and utilisation R&D, that has been undertaken in this country, in terms of the resulting technological, commercial and environmental benefits. The R&D has been sub-divided into the following four areas :-

- coal preparation, transportation and handling
- metallurgical uses of coal
- coal combustion

- coal conversion
- advanced power generation

In each section, a brief review is given of relevant R&D successes. Although not exhaustive, many examples are given of equipment and expertise that have been developed and are now being exploited commercially by Industry. Historically, successful R&D made a major contribution in helping to defend the market for coal in the UK. Now the successes are helping the UK economy by enabling British companies to develop and sell clean coal technology equipment, services and expertise overseas.

3.1 Coal Preparation, Transportation and Handling

With competition from imported coal, it has become increasingly important for the UK coal industry to produce coal of high grade and consistent quality. The basic processes involved in coal preparation are well established although there have been significant new British advances that have been deployed in recent years. An example is the Large Coal Dense Medium Separator (LARCODEMS) developed by British Coal. This is capable of treating a wide size range of raw coal (0.5-100mm) with much better performance and control than is possible with jigs and barrel washers.

For example, a conservative assessment indicates a minimum of 1% increase in yield from a Larcodems separator compared with a Baum jig. To put this in perspective, an increase in the yield of 1% from a plant treating 500 tonnes/hr of raw coal with, say, 50% reject would provide an annual gain of 10,000 tonnes of saleable coal, thus providing a significant contribution to reducing costs. The differences in favour of the Larcodems against barrel washers are even more marked.

Whilst there may be limited scope for technological breakthroughs, there has been a steady and continuous refinement of conventional techniques helped by better process monitoring and control. Improving coal quality and maintaining consistency to meet customers' requirements have been the main thrust with particular emphasis on quality monitoring together with the cleaning, dewatering and handling of fine coal (<0.5mm) which can be a significant proportion (up to 15%) of run of mine coal. The latter is much better understood now and a number of improvements have been implemented following successful R&D initiatives. For example, simpler lower cost alternatives to froth flotation, such as the hydrosizer and spiral separators, have been adapted for the cleaning of fine coal, (<1mm). Other successful research initiatives have included the disposal and utilisation of colliery discard and flotation tailings.

Perhaps one of the most significant advances has been the impact of computers. They have been used extensively in many coal preparation research projects and increasingly to support operations at collieries. Similarly, on-line measurement techniques are being applied to ensure product quality is maintained particularly where blending or other processing is required to keep it within specification. An on-line ash monitor based on the natural gamma emissions from coal has been developed by British Coal and is now deployed. Shortly, an equivalent on-line moisture monitor should be available.

In recent years, environmental pressures have meant that more attention has needed to be given to reducing sulphur and chlorine in coal because of their comparatively high occurrence in UK coals compared with internationally traded coals. Laboratory studies in conjunction with pilot-scale tests and the development of mathematical models to predict commercial plant performance have resulted in a much better understanding of the occurrence and release of pyrite and chlorine in coal. For example, the fine grinding of coal liberates appreciable amounts of pyrite but the application of process models to the treatment of the crushed coal has highlighted the need for improved fine coal cleaning methods to be developed in order to reduce calorific value losses. In summary, most coal preparation R&D projects have been targeted towards addressing and solving specific problems. Frequently, these have resulted in technical improvements albeit not all may have been implemented on economic grounds. But significant commercial and environmental benefits have been gained from better and more consistent coal quality through improved coal washing, including introduction of computers, on-line measurement techniques, and better dewatering of fine coal.

Other important contributions to enable coal to compete more effectively with other fuels have been the many developments in coal delivery and handling as well as ash removal equipment. As a result, there is a wide range of equipment available commercially, particularly for the industrial users of coal, which has helped to improve considerably the general amenity of using coal by providing for cleaner operations, better availability and greater reliability with coal-fired plant. These highly successful developments include improved bunker, silo and hopper designs, dense and lean phase pneumatic handling systems, and a wide range of mechanical handling and conveying equipment, some of which are finding application in other process industries.

3.2 Metallurgical Uses of Coal

Coke making is a mature technology, which has been the subject of much research in all the major coal producing countries of Europe, as well as in the USA and Japan. Therefore further major developments are unlikely. Rather, R&D has been concentrated on achieving continued improvements in product quality and process economics, as well as widening the scope of coals that can be used and reducing air and water pollution associated with coking plant. Increasing coke oven productivity and availability, automating operation and extending coke oven life are also areas where R&D is being undertaken to reduce costs.

During the past 20 years, major R&D effort has been aimed at defining the coke quality requirements for optimum furnace operation. This has been achieved by extensive blast furnace sampling and pilot scale testing of coke under blast furnace conditions. As a result, significant reductions in coke/fuel rate have been achieved which have led to considerable savings. For example, assuming a conservative coke rate of 500kg/tonne hot metal (tHM) and a purchase coke price of $120/tonne, a reduction in coke rate of lkg/tHM for British Steel results in savings in the region of $1.5m/yr.

Well recognised are the technical successes with resulting commercial benefits that have followed from an increased understanding of how to make good quality metallurgical coke more economically from a variety of coals and coal blends. This research has contributed to enabling metallurgical coke to be made considerably stronger now than that produced 10 years ago. In this instance, basic research has played a vital role in examining coke reactivity, coke strength and breakage as well as the influence of coke structure. With conventional wet charging systems, low fluidity coal blends can now be used, which fall within close limits defined by petrographical/rheological blending principles. More recently, low cost filler coals have also been incorporated to reduce coke costs still further, giving potential savings of some $5m/yr.

Excessive coking pressure in coke ovens can result in damage to oven walls. But basic research into the mechanics of coking pressure generation and the development of laboratory-scale test procedures have yielded sufficient information to minimise the risk of damage to oven walls and so prolong oven life. The development of ceramic welding for the repair of coke oven refractory is another technological success of direct practical benefit, which has been successfully and widely applied. Indeed, these advances together with other measures such as improved refractories have enabled coke oven life to be greatly extended in recent years. Typically, the lifetime of coke oven batteries is now of the order of 40 years compared with just 20-25 years some 30 years ago.

Other projects have addressed the need to achieve greater energy efficiency by reducing the energy demands of coke manufacture and to reduce air and water pollution. As a result energy losses have been significantly reduced and coke ovens are much cleaner now than 10-20 years ago. A major contribution has resulted from the substantial increase in direct injection of coal into blast furnaces.

The UK has been in the forefront of these advances. British Steel can now replace some 25% of the coke combusted at the tuyere as the result of extensive laboratory research, together with pilot plant and full scale trials. This R&D has been essential to ensure satisfactory combustion of the granular coal, maintenance of furnace stability and permeability, and acceptable carbon carry over. As a result, British Steel is able to make cost savings of about $50m/yr with direct injection of coal.

3.3 Coal Combustion

Combustion is the main process by which coal is utilised whether it be for the utility, industrial, commercial or domestic sectors. It is achieved using pulverised-fuel burners in power generation and by stoker firing at the industrial and commercial scale with static grate combustion used in household appliances. All these combustion systems are mature technologies albeit with significant potential for improvement. In more recent years, much R&D has been directed towards developing fluidised bed technologies for application in the utility and industrial sectors.

Competition is fierce from the alternative fuels, particularly natural gas. Thus there is the need to strive towards reducing capital and operating costs, improving the efficiency and reliability of coal-fired plant and reducing their emissions of pollutants. Improved amenity is particularly important for small and medium sized appliances where there has been much scope for improved coal handling, storage and operation of equipment. The development of advanced, clean coal power generation technologies through the use of combined cycles is another major area of development as it offers the prospects for low cost electricity with improved efficiencies and lower emissions of pollutants.

The great driver over the last decade has been the environmental concerns associated with coal use, in particular the need to control SO_2, NO_x and particulate emissions to meet emission standards. Clearly, unless technology and strategies for measuring and controlling emissions are available to enable coal-fired equipment to meet current and future emissions requirements, coal use will cease. This area of coal combustion R&D is the one which has been most successful in terms of producing technology, commercial and environmental benefits with a variety of emissions control technologies being developed and deployed. Within the UK, the potential market for retrofit technologies, such as low NO_x burners and flue gas desulphurisation (FGD) equipment, to allow existing plant to comply with current environmental legislation has been estimated at some £600 million up to the year 2000.

The UK has been particularly active in low NO_x burner development. Collaborative research involving British Industry (including CEGB, PowerGen, National Power, Mitsui Babcock Energy, International Combustion) with DTI and European financial support has featured prominently. Mitsui Babcock Energy and International Combustion have developed low NO_x burners for achieving up to 70% reductions in wall - and tangentially - fired power station boilers. These low NO_x burners have been fitted widely to plant in the UK and overseas. Crucial to these successful developments has been the research aimed at improving the understanding of NO_x formation and reduction, and the effects of coal type on NO_x and burnout. Much of this R&D has been undertaken by the companies in collaboration with academe and research institutions.

Further NO_x reductions can be achieved by Selective Catalytic Reduction but this is a relatively high cost approach. Mitsui Babcock Energy are developing low cost, NO_x - reduction techniques based on furnace air and fuel staging aimed at reductions of 70% on top of that achieved by low NO_x burners. A major demonstration of gas reburning technology will be commissioned on one of the 600 MWe units at Scottish Power's Longannet power station in the autumn of 1996. The project involves a consortium of UK and European electricity utilities and boiler manufacturers, including Scottish Power, Mitsui Babcock and British Gas. Results from both Mitsui Babcock's and British Gas' R&D have been used in the process design of the boiler reburn modifications. In complementary research, British Gas and AEA Technology have developed and deployed sophisticated measuring devices, based on lasers, to aid understanding of the combustion and pollution control processes involved in low-NO_x technologies.

Successful implementation of gas reburn technology at Longannet will allow Scottish Power to increase the load factor at the station whilst maintaining their overall emissions of NO_x within prescribed levels. For British industry, the prospects for commercial exploitation of this technology overseas is good.

Whilst relatively little R&D was necessary to support the 2 major FGD installations at power stations in the UK, more effort has been diverted towards developing low cost SO_2 control systems for industrial coal-fired plant. As a result, dry sorbing techniques are available for stoker-fired boilers, which can be retrofitted or installed on new plant. Similar techniques have also been developed for fluidised bed combustion (FBC) boilers. Development and demonstration was undertaken by British Coal in collaboration with a number of industrial boiler manufacturers and users some 10 years ago.

The list of successful projects is extensive and varied; a few more achievements are summarised below to serve as further illustrations of the benefits resulting from coal research undertaken in the UK.

- Greater understanding of the role of coal mineral matter in the fouling, corrosion and erosion problems of combustion systems, and identification and application of steps to alleviate the problems. For example, through a major collaborative DTI - funded programme involving equipment manufacturers, power generators and academe, much progress has been made in understanding the complex mechanisms of ash deposition during coal combustion. This has led to more reliable methods, based on computer modelling, for the prediction of slagging in pf-fired boilers with guidelines for more efficient operation and improved boiler design.

- Major advances in the development and application of mathematical modelling of large coal-fired power station boilers. In one major collaborative programme, undertaken by industry and academe, mathematical models have been shown to be a useful tool for achieving improved efficiency and environmental performance. In this project data from full-scale plant and pilot test rigs have been used to validate multi-burner computations with full coal combustion.

- Coal characterisation for combustion providing greatly improved understanding of the chemical processes involved in conventional coal-fired power generation. With recent major advances in sophisticated analytical and modelling techniques, considerable progress has been made by academe and research institutes in establishing and modelling the mechanisms involved. These studies, which involve also pilot scale test facilities, have provided essential underpinning to industrial developments and demonstrations of new and improved combustion technologies. They also provide valuable insights into how indigenous and overseas coals will perform in conventional plant and the new, more advanced clean coal technologies.

- The development and application of blending strategies for producing suitable coals for specific coal-fired equipment in order to help satisfy market requirements and maintain markets for coal. Blending enables consistent quality, competitively priced fuels to be supplied to commercial and industrial customers to suit their combustion systems, and so help to reduce maintenance and operating costs.

- Many improvements in systems for dust removal in industrial boilers have been developed and deployed, including improvements to filtration and cyclone systems. These developments have been essential to ensure that new emission standards can be met in as cost effective a manner as possible.

3.4 Coal Conversion

The trigger for substantial R&D into coal conversion were the major oil price increases of the 1970s. In particular, it was considered important for strategic reasons to develop technology to enable coal to be converted into liquid fuels, substitute natural gas (SNG) and chemical feedstocks. As a result, major research programmes were undertaken by British Coal on coal liquefaction and British Gas for the manufacture of SNG.

The early R&D on coal liquefaction was carried out in the laboratory and on small pilot plant at CRE. In 1991, direct coal liquefaction moved away from the laboratory when a large pilot plant-scale facility started operations at Point of Ayr in North Wales. This pilot plant programme, recently concluded, showed that the British Coal Liquid Solvent Extraction (LSE) process is technically ready to be taken forward to the demonstration stage. The process can convert almost any coal into low boiling liquids, which, after a simple upgrading step, yield petrol, and diesel fuel that can be substituted directly for their conventional counterparts. This ability to produce directly substitutable transport fuels will allow coal liquefaction to be phased in gradually at the appropriate time, without the need for infrastructural changes.

Coal liquefaction is not economically viable at current oil prices. However, economic modelling studies indicate that the LSE process is a lower cost route than competing technologies. Although a wide range of assumptions is necessary, it has the potential to be commercially viable at a crude oil price as low as $25/barrel in favourable circumstances. The abilities to process low-grade coals and to integrate with existing oil refinery operations give it a very large potential market, both in Europe and worldwide. By way of indication, a commercial scale plant processing 5 million tonnes/year of coal would meet only about 0.5% of current European transport fuel demand.

Similarly, substantial effort has been deployed in the research, development and demonstration of the British Gas/Lurgi slagging gasifier. The technology, which is based on the development of the conventional fixed-bed gasifier so that the coal ash is rejected as molten slag, is now commercially available. Whilst initially developed for the manufacture of SNG, it is considered particularly suitable also for use in Integrated Gasification Combined Cycle (IGCC) plant for power generation.

Underpinning these coal conversion developments and other processes for producing energy from coal, are the many projects carried out in Universities and industrial laboratories, aimed at adding to our basic knowledge of the fundamental processes involved. For example, major advances have been made in the area of coal characterisation and analysis using modern analytical techniques, including nuclear magnetic resonance (NMR) and proton magnetic resonance - thermal analysis (PMRTA). This fundamental research has yielded invaluable basic knowledge, which can be applied in many areas. It contributes to the better selection of coals and the ability to predict with greater confidence the performance of coals in all utilisation processes.

3.5 Advanced Power Generation

Power generation is the main market sector for coal use in the UK and in many other countries. There is considerable emphasis throughout the world on improving the efficiency and reducing the environmental impact of coal-fired power generation. The importance of clean coal power generation as a key opportunity area has been highlighted by the Energy Panel of the Government’s Technology Foresight Initiative.

British Coal pioneered the early development of pressurised FBC for use in combined cycle power plant as a means to increase efficiency and reduce emissions. This led to the construction and commissioning in 1980 of the 80MWt Grimethorpe PFBC facility. It then operated for many thousands of hours over some 12 years, during which several major national and international collaborative programmes were undertaken. Important technical developments included designs for the combustor, hot gas clean up and solids handling equipment together with successful operation with a gas turbine. The technology has now been commercially demonstrated in Sweden with other plants in Spain, the USA and Japan. Plans for further large-scale exploitation of this technology are well advanced in Japan.

For sometime it has been recognised that the use of gas derived from coal in combined cycles offers the promise of even higher efficiency, lower cost and more environmentally acceptable electricity production. In recent years, the importance of developing advanced power generation systems has grown considerably. They are seen by the power industry, producers and equipment manufacturers alike, as offering considerable export potential in the future.

Although British Gas initially developed the slagging gasifier for the manufacture of SNG, it is particularly suitable for use in Integrated Gasification Combined Cycle (IGCC) plant for power generation. In order to demonstrate this concept, British Gas undertook trials sponsored by the DTI, National Power and PowerGen on its 500 tonnes/day demonstration plant (25 MWe) at Westfield in Scotland. Many thousands of hours of successful operation were carried out on a wide variety of UK and US coals of varying ash content and rank. Very high gas conversion efficiencies (cold gas efficiencies of over 92%) were achieved. The process was shown to be capable of meeting operating requirements, including full and part load operation as well as rapid load changing. As a result, the technology is now commercially available for use in IGCC power plant.

Over recent years, much R&D effort in the UK has been directed by British Coal and its collaborators into developing the Air Blown Gasification Cycle (ABGC), earlier known as The British Coal Topping Cycle process. It offers potentially superior performance compared to other advanced coal-fired power generation technologies in terms of lower generating costs coupled with higher efficiency and low environmental impact. The main features of the process are the use of an air-blown pressurised, fluidised-bed gasifier with hot gas clean up and an atmospheric pressure, circulating fluidised-bed combustor (CFBC) to provide, respectively, a clean fuel for the gas turbine and high temperature steam for the steam turbine.

The development is managed by the industrially led consortium known as the Clean Coal Power Generation Group. The R&D programme has been designed to address the development of the major components of the ABGC process. The stage has now been reached when plans for a Prototype Integrated Plant (PIP) are being developed. Such a plant would bring together all the various elements of the process in order to prove the process concept and obtain design information for larger scale plant. An essential feature of this major programme is its collaborative nature centred on industrial participation, DTI and European Commission funding whilst also involving research institutes and academe.

The development activities have been aimed at assuring the availability of the technology for component parts of the ABGC. Some components (e.g. gas and steam turbines, and CFBC) are well established although they require modification for the specific application. Other components, which carry the higher technical risk, are the gasifier, pressurised solids handling and hot gas clean up systems. Much of this component development is of generic value and will provide valuable technical contributions to other advanced power generation developments involving IGCC technologies.

4. CONCLUSIONS

There is no doubt that much of the coal R&D carried out over the years in the UK has resulted in many successes in the areas of coal preparation, transportation and handling, metallurgical uses of coal, coal combustion, conversion and advanced power generation. Almost all of these successes may be regarded as providing technical and environmental benefits and many have been commercially exploited. Undoubtedly our understanding of coal and how to effectively utilise it have been enhanced greatly over the decades. Coal can provide increasingly low cost, reliable, efficient energy in an environmentally acceptable manner. Even though production and use of indigenous coal in the UK has declined markedly over recent years in the face of severe competition from other fuels (including natural gas and imported coal), the need for sustained coal R&D is compelling. There are important strategic arguments for ensuring that coal remains an important energy source in the UK. Natural gas is plentiful and cheap. But for how long will this abundance last? Imported coal is currently also very competitive. Generally, it is cleaner with lower ash, sulphur and chlorine contents. But how will these coals perform in coal-fired plant designed for British coals and what are the financial implications in terms of overall operating costs? And, inevitably, the UK's increasing reliance on natural gas and imported coal has its political and strategic implications.

There is no doubt that there are strong incentives for maintaining and developing further our coal expertise in the UK. The prospects for improving further the competitiveness of coal are excellent.

Furthermore, there is and will continue to be a vast world-wide market for Clean Coal Technology during the coming decade or so, particularly in Asia and the Pacific Rim Countries. Recent estimates suggest that past R&D in clean coal technologies has already contributed to over £1 billion of benefits for UK industry. The future will provide many more export opportunities for UK companies, but the competition is fierce. A number of other countries have much to offer in clean coal technologies: their industries are often supported by large research and development, and demonstration programmes, notably in the USA, Japan and several European countries. It is essential for the competitiveness of UK industry that the UK also has vibrant, well focused coal R&D programmes.

In recent years, profound structural changes in the UK energy industries have had serious repercussions for coal R&D in this country. There are no longer the substantial research laboratories of the CEGB and British Coal. The privatised industries are not funding coal R&D on the same scale, although there is still a strong coal research base in Academe. The Universities are skilful in generating new ideas and providing the underpinning support to developments. But, generally, they are not able to take the research into the market place. Therefore, the role of industry is still crucial in providing the direction for the research as the result of greater commercial awareness through their business activities, and then being ready to take the developments to demonstration and commercialisation.

Unfortunately, commercial imperatives currently dictate against heavy investment by industry into coal R&D, but unless the UK maintains a strong base in coal know-how and continues to develop clean coal technologies, its industry will become increasingly less able to compete internationally. Continued financial support by Government and the European Commission is thus essential. Without it the technical advances will not be made, decline in coal use in the UK will continue and its industry will lose out on the opportunities to capitalise on the vast markets overseas for clean coal technologies, with the consequent strategic and economic implications for this country.

Inevitably with the passage of time, the priorities for coal R&D have changed markedly. At one time, the domestic sector was a considerably more important market. Now power generation is the major market for coal in the UK and many other countries. Social, economic and environmental pressures have resulted in demands for more competitive, cleaner and more efficient coal technologies. There is still much scope for further significant improvements to conventional power generation plant and the opportunity of even better performance with the new generations of clean coal technology. Similarly, there are many opportunities for further improvements in the use of coal in steel making and the other markets.

Identification of the current coal R&D needs in the different market areas is addressed in the complementary document, entitled ‘Coal Research Needs in the UK’, also produced by the Coal Research Forum. It provides comprehensive coverage. Understandably, different perspectives and priorities will be advocated by different groups; for example, by the industrialists, academics, regulators, environmentalists. But common themes emerge - these include:

- Continued development and demonstration of advanced power generation systems based on coal gasification in combined cycles.

- Further efficiency and environmental improvements in conventional coal-fired plant for power generation and other markets.

- Co-firing of coal with waste/biomass in coal combustion and gasification plant.

- Advanced optimisation and control techniques, such as neural networks.

- Development of advanced low cost, on-line measurement and analysis techniques.

- Further targeted coal preparation R&D in support of coal utilisation technologies to provide holistic solutions to ever strengthening environmental regulations.