

“Energy at the Crossroads”

**The Chemical Engineering Contribution
to the UK Energy Debate**

A response to the PIU *Energy Review* and the joint departmental energy policy consultation
published in May 2002

**Briefing prepared by
The Institution of Chemical Engineers**

for

Mr. Brian Wilson MP, Minister of State for Energy & Industry



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Energy at the Crossroads -The UK Energy Review

Introduction

The UK Government is seeking comments on the joint departmental consultation paper *Energy Policy – Key Issues for Consultation* published in May 2002. The purpose of this exercise is to receive feedback on the earlier *Energy Review* published by the Performance and Innovation Unit (PIU) in February 2002 and to provide observations that will inform the drafting of an Energy White Paper due later this year. The Institution of Chemical Engineers (IChemE) wishes to submit comments on the content of the two documents. In particular, we draw attention to some of the fundamental scientific and engineering issues that need to be considered when constructing the UK's long-term energy policy. Several of the issues raised in this report were touched on in general terms by contributors to the Adjournment Debate in the House of Commons on 20 June 2002.

Energy at the Crossroads is the first in a new series of short briefing papers published by IChemE addressing key areas of environmental, economic and scientific policy. Chemical engineers do not claim to provide all the answers. IChemE briefing papers will focus on the challenges facing government and policy makers offering constructive advice and recommendations as appropriate, whilst at the same time highlighting perceived engineering and scientific weaknesses in other contributions to the public debate.

Chemical engineers believe that UK policymaking has suffered from a lack of coherent engineering and scientific input in the past. IChemE Briefings form part of our strategy to redress the balance.

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He retired in 1987 and formed an energy consultancy practice. His work has focused on technologies that offer solutions to emission problems from a range of fossil fuels especially related to the oil and power industries.

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Executive Summary and Recommendations

Fossil fuels are likely to remain the primary source of energy in the UK for many years. Oil is essential in the transport sector while natural gas will become a more dominant fuel in power generation. The weaknesses in the *Energy Review* centre on doubtful predictions for long-term energy prices and an overriding faith in the liberalised market to hold prices down. This seems unlikely when demand for one commodity, natural gas, is growing rapidly throughout the world and major infrastructure investment is essential to satisfy that growth in demand. IChemE concludes that the price of energy must rise in real terms in order to secure a sustainable future.

IChemE believes that UK energy policy should be both balanced and secure. The core objective for the power generation sector must be to secure stable, high quality electric power at competitive prices. Policy outcomes must reflect the following key issues:

- A strategy based on a balanced portfolio of fuels with no heavy dependency on any single primary energy source is both logical, desirable and makes political and economic sense in the uncertain world in which we live.
- The current benefits of CO₂ free nuclear capacity need to be retained if the government's ambitious CO₂ targets are to be achieved. A replacement programme for nuclear power that maintains generating capacity at present levels is essential. IChemE fully endorses the recent call by the government's Chief Scientific Adviser for the replacement of the UK's existing nuclear capacity with new nuclear capacity.
- Clean coal technology coupled with CO₂ sequestration should also be developed for a significant share of the power generated. The anticipated rises in gas prices will render investment in these technologies more attractive to potential investors.
- The government's environmental targets for 2010 and 2020 are unlikely to be met in a liberalised market. In the power sector government intervention is necessary if investment in new, clean and efficient capacity is to be progressed and built to a schedule determined by those targets. Furthermore, measures aimed at the constraint of natural gas should be considered in order to avoid over-dependence on piped imports and vulnerability to price fluctuations
- The hydrogen economy offers considerable opportunities. Nonetheless, it should be borne in mind that hydrogen is not a fuel but an energy carrier. Fuel cell development is an important step to the efficient use of hydrogen and the UK must avoid being left behind in this key area. Substantial investment in research and development will be required.
- Renewable energy is an important consideration and it has a clear place in any future UK energy mix. However, a greater degree of realism is required with regard to what is practical and achievable in the medium term. A target of 10% is both more realistic and manageable into a modified grid system

There is no panacea and as such technical capability should be retained for all potential solutions. Professional engineers must be given more opportunities to assist politicians with the development of policy solutions to complex and inter-related energy issues.

Framework and Context

The PIU *Energy Review* was drafted with considerable skill. The text and conclusions create an impression that the UK can manage its energy needs over the next 50 years without any major difficulty. The mix of primary energy sources being suggested has been set in the context of the increasingly stringent environmental constraints while providing assurances on the long-term security of energy supplies, particularly natural gas. *The Energy Review* reflects the UK's commitments to both the EU emissions legislation and to CO₂ reduction in line with the Kyoto Protocol. It also sets the longer-term goal for CO₂ reduction targets by 2050 at the level proposed by the Royal Commission for Environmental Pollution and supported by the IPCC.

At first glance, the Review appears thorough and comprehensive. However, there is little evidence of any rigorous engineering input and this has given rise to several areas of weakness:

- **The cost projections for the additional infrastructure required for both power and gas transmission and distribution are flawed**
- **The report's conclusions are predicated on a low gas price assumption that relates closely to low electricity prices and with CHP penetration but do not reflect EU cost projections for Europe's total supplies**
- **The investment needed to support energy efficiency improvements and to develop pathways towards future high efficiency may have been underestimated**
- **The projection for reduced costs of energy generated from renewables is insufficiently robust to underpin such an important government decision on the country's energy strategy**
- **Development of low carbon technology has not been covered in the logical stepwise manner that will be required to achieve the UK's emissions targets**

IChemE believes that the UK's 2050 targets for CO₂ cannot be met without a radical improvement in energy conversion efficiency. The efficiency gains required can only be achieved by investment in higher efficiency plant especially in the power sector.

The *Energy Review* is complacent about future gas supplies. It "ring-fences" the UK and appears to have overlooked the impact that Europe's parallel growth in gas demand will have on prices. There is also an environmental impact in Russia resulting from the transporting of increasing quantities of gas from reserves in the eastern states that is not adequately addressed.

Another area of concern to chemical engineers is the omission of a table that sets out the energy input to the power sector required to meet the nations' total annual demand including winter peak and the emissions from that capacity. Without a summary of the equipment needed to meet requirements, it is impossible to cost the system in order to gauge whether it is competitive or affordable.

Energy Policy - Key Issues for Consultation raises many questions. This is unsurprising given the complexity of the issue. However, the questions are too numerous to answer individually and as such IChemE believes that it is more productive to address some of the major challenges raised by these questions along with possible ways in which those issues might be resolved.

The following points have been developed in discussion with chemical engineers working across the energy sector and in conjunction with other experts with many years experience in matters of energy security and energy supply:

- **Energy use, emissions and conversion efficiency**
- **Regulation versus the incentive for new investment**
- **Security of electrical power supplies - the benefits and risks of renewable energy**
- **Security of primary energy supplies**
- **Why set target for renewables - fossil fuel conservation or CO₂ reduction?**
- **CO₂ avoidance, control, capture and sequestration**
- **Renewables in the UK power system – instability and flawed economics**
- **Sustainability and energy recovery from wastes as a renewable resource**
- **Nuclear replacement**
- **Pathways to a hydrogen economy and fuel cell development**

These points are reviewed in the context of *Energy Policy - Key Issues for Consultation* with specific consideration to the background points set out in paragraph 1.8, in particular, the stated objectives of competitiveness and affordability.

1. Energy use, emissions and conversion efficiency

The two critical factors that link energy use to pollution levels are the efficiency of use and the energy source. Each of the fossil fuels has a different hydrogen/carbon ratio and thus a range of CO₂ emissions result from their direct combustion. They also contain varying levels of sulphur and other substances that cause pollution. The combustion process itself produces the oxides of nitrogen and releases any nitrogen in the fuel. Natural gas - methane - is unique in having the highest hydrogen to carbon ratio of all fossil fuels. This characteristic, and the fact that it is virtually free of sulphur, makes it the most desirable fossil fuel for reducing CO₂ and other emissions. Coal is at the other end of the scale but that need not preclude its use when appropriate technologies are harnessed.

The last decade has seen a major tightening of emissions standards in the developed world. This has resulted in a widespread shift away from coal and heavy oils to natural gas. In parallel with this switch in fuel, technology has advanced especially in the field of power generation. Combined cycle gas turbine systems have taken over from the conventional steam based boiler systems for new plant with substantially improved efficiency. They offer the lowest cost, fastest build and smallest footprint of all major power generation technologies. In broad terms, the benefits are a near doubling in the efficiency of primary energy conversion into electricity, substantial reductions of all pollutants and at least 50% reduction in CO₂ per unit of electricity produced compared with typical coal-fired boilers. That trend is likely to continue around the world.

In assessing the options available to achieve the environmental targets, it is essential to evaluate the thermodynamics of energy conversion systems. The efficiency limits of the steam cycle have been known for 150 years while the efficiency of all other heat engines is constrained *by the Carnot Cycle*. The only way to get round these constraints lies in the application of electro-chemistry with the application fuel cell technologies. Fuel cells development and commercialisation presents significant opportunities for improving energy efficiency still further via the use of hydrogen and are important for any move towards a low carbon economy.

A measure of the current inefficiency of energy use in the power sector is best illustrated with data from an analysis both by Siemens and by the IEA. The efficiency of existing European generating capacity averages 35%. If this is extended to the global average, it has just reached 30%. That means between 65-70% of the heat in virtually all fossil fuel being used in this sector is being wasted. The efficiency of the current generation of combined cycle gas turbines is just under 60% and advanced machines that exceed 60% are currently undergoing trials. Hence, there is huge scope for energy efficiency improvement to achieve environmental goals. In the transport sector, the efficiency of typical current generation petrol engines is around 28% and diesels around 44%. Some improvement is possible on both types of engine but an important aspect of energy for transport is that the energy content per unit volume of fuel is high. On that scale diesel is best with petrol a close second. All other fuels lag well behind on that criterion. Similar efficiency improvements should be possible in the domestic and commercial sectors.

The UK's prime source of CO₂-free electricity is nuclear power. Nuclear has been contributing up to 30% of the UK's electricity demand. Most of the existing capacity will reach the end of its operational life over the next 20 years and as such is scheduled for decommissioning. Unless this capacity is replaced by another readily available CO₂-free source, the UK target of a 20% emissions reduction by 2020 will not be met. The use of any fossil fuel as a replacement for nuclear capacity would increase CO₂ emissions. The only way to approach the target would be to replace all existing coal, oil and gas capacity with the very latest CCGT technology making the entire power generation system totally dependent on natural gas.

The key to securing our environmental goals lies in investment in appropriate technologies. Ageing nuclear capacity must be replaced with new nuclear capacity: coal with clean coal technology and natural gas using with the latest plant designs. The UK's 'flag-ship' coal-fired station at Drax in

Yorkshire, is now approaching 20 years old and since the mid-1980's, neither UK nor Europe has build any significant number of boilers. Many of the famous names in boiler-making no longer exist and one of the few remaining power plant contractors, ABB, has reported financial difficulties due to sparse order books¹. There is a real risk that by the time new plant is ordered, there will be few companies who can supply it.

2. Regulation versus the incentive for new investment

Deregulation and privatisation in the power sector has led to a substantial reduction in wholesale power prices throughout Europe and especially in the UK. While these lower prices have been widely welcomed as a visible benefit of the privatisation process, the invisible penalties are:

There is no incentive whatsoever for investment in newer cleaner power generation capacity at current prices

Some generators such as British Energy are losing money because the wholesale prices are lower than generating costs

The market therefore offers no incentive to improve efficiency

New, cleaner and more efficient capacity is required to meet the UK's environmental objectives and some external intervention will be required to initiate such a move. Under current market conditions, the reverse is true. Across the UK we find that the oldest, fully depreciated, most inefficient and dirty coal fired stations are amongst the prime generators, because these are the only units that can be operated with any margin of profit. As a result, CO₂ missions have increased over the past 2 years. If the government's longer-term goals on CO₂ emissions are to be met, then the CO₂-free benefits of the UK's existing nuclear capacity need to be recognised. The nuclear industry requires support for the development of a commercially viable replacement programme with correspondingly robust wholesale electricity prices. British Energy suggest that this should be around 2.7p/kWh – a level that would support new investment in other clean technologies as well.

To make matters worse, electricity trading has become an established business activity. Electricity traders have agreed contracts with generators to purchase power and then sell to the distributors at a price that yields a profit margin to the trader. One of the most prominent of the energy traders was Enron. Visitors to any major European power industry exhibition will find that such events are dominated by the promotion of energy trading with exhibitors, including major consultancy companies, offering all types of software packages to guide traders to greater profit. Power generators and equipment suppliers are rarely seen. The existence of traders makes the task of attaining emissions targets more difficult because the commercial drivers run counter to the new investment that is required.

In the UK and Europe, there is a surplus of generating capacity at present. Until that surplus is reduced, contracts for power at low prices appear likely to continue. Some UK contracts are said to have been signed out to 2004 at these prices. However, the financial difficulties facing British Energy and others could result in the rapid closure of some of this capacity. Low prices will deter investors and their financiers so any progress towards cleaner technologies will probably remain in abeyance unless the UK government initiates some new incentive. The low electricity prices currently being experienced throughout Europe are stifling investment. A recent study by the University of Vienna summarised in the UK Utilities Journal (OXERA)² indicates the days of low electricity prices are now numbered. New investment will soon become essential and prices will have to rise to attract investors. IChemE assesses that the paper was well researched and the conclusions are valid.

3. Security of electrical power supplies - the benefits and risks of renewable energy

Electricity cannot yet be stored in any quantity so power has to be consumed the moment it is generated, a phenomenon that separates it from all other forms of primary energy. A major weakness in the *Energy Review* is the lack of distinction between the security of electrical power supplies and that of primary energy sources. The developed world is heavily dependent on a totally reliable supply of high quality electricity at competitive prices. In creating a framework for the power sector, it is imperative to examine the nature and reliability/availability of all sources and the choices open to power generators. It is also important to assess the true reduction in emissions from the alternative low/zero carbon technologies because the notional environmental benefits resulting from the use of renewables overstate the real savings attainable technically.

Modern society relies on supplies of power at a constant voltage and frequency. It must be readily available on demand. Short-term, or even momentary, power failure can bring chaos and in certain cases endanger life in a world where many vital functions, including hospitals, traffic management and key industrial and commercial operations are computer controlled. The UK's national grid system was designed to transfer power from a limited number of large power stations to markets throughout the country. The introduction of embedded and renewable sources brings new challenges to the task of power transmission. Substantial amounts of generated power will shift away from large plants to a much larger number of small units. Such changes will dictate additions to the transmission system and to the existing power management infrastructure. The full expenditure on that infrastructure has been overlooked in the *Energy Review*.

The high capital investment required cannot be financed on the narrow margins upon which National Grid currently operates. Power generation from wind power provides a good illustration. The best wind conditions are to be found in areas remote from centres of demand. Thus it is clear that extensive new transmission cables would be needed to deliver power from say West Wales or Scotland to the areas of England where demand is highest.

Experience gained over the past decade in Denmark³ suggests that it is very difficult to control the supply system with more than about 10% wind power connected. These findings support the view of the Institution of Electrical Engineers (IEE), which reports that grid stability can only be guaranteed if wind power is limited at a relatively low level. National Grid has made similar comments and has highlighted the need for further major investment if renewables and CHP grow much beyond today's levels.

The *Energy Review* advocates 20% of power generation from renewable sources by 2020 but it does so without tackling the perilous issue of grid stability and the maintenance of a totally reliable supply system once such a significant increase in the percentage of renewables connected has been achieved. The review also makes no mention of the need to support the electrical supply system continuously with reliable stand-by capacity while accommodating wind power. In simple terms, how do we cope on a frosty winter day when the air is still and there isn't much wind around?

The *Energy Review* also anticipates Combined Heat and Power (CHP) rising to 20% of the total UK electricity supply. The apparent high thermal efficiency of CHP relies on the concomitant use of heat. The review suggests its expansion will be driven by future gas price predictions below today's level. In the absence of a sustained fall in gas prices the economics of CHP comes into question and yet gas prices are projected to double in the medium term according to EU forecasts⁴ outlined by the Director for Energy and Transport Affairs, Dominique Ristori. More significantly, CHP extended to the domestic sector presents technical challenges because of difficulties encountered in balancing electricity production with heat output because of daily and seasonal fluctuations in demand. CHP schemes may be commercially viable in new housing developments, the cost and disruption of pipe laying is likely to preclude its wide application for existing housing stock. Micro-CHP using fuel cells however would appear to have much potential.

4. Security of primary energy supplies

While global fossil fuel reserves are undoubtedly finite, very substantial quantities remain accessible. Beyond coal, crude oil and natural gas, there are also extensive deposits of tar sands, shale oils and natural bitumen that could serve as potential sources of primary energy, albeit at higher cost than current carbon fuels. The technology to find and exploit resources continues to improve - oil and gas is now being extracted from offshore reserves in progressively deep water. For several decades, the reserves/production (r/p) ratio of oil has remained at about 40 years and there is little justification to alter that type of ratio. Gas reserves have been increasing in spite of growth in demand. While the use of r/p ratios has been challenged as an overstatement by suppliers, it remains a widely accepted measure in the energy industry.

World energy resources are set out in the annual *BP Amoco Statistical Review of World Energy*. The review states that the estimates of recoverable reserves are based on current technology, not on major advances or different techniques. As an example, it is assumed that coal can be won by conventional mining methods and over 200 years of reserves exist on that basis of extraction alone. However, Russia and Australia have already demonstrated underground gasification of coal – a topic also under study by the UK's own Coal Authority. This technology offers some potential to open up substantial reserves of coal that have been identified in many parts of the world while drilling for oil and gas but have hitherto been excluded from the statistics as non-accessible. The technique is made even more feasible by advances that have been made in drilling technology and computer enhanced geological scanning. This allows penetration of underground resources with pinpoint accuracy. In-situ conversion of coal into gas therefore offers substantial quantities of additional clean fuel gas in the future.

The physical supply of fossil fuels is a long-term problem – there is an ample supply at a market-driven price for the foreseeable future. The use of fossil fuels is more likely to be constrained by environmental considerations.

Natural Gas

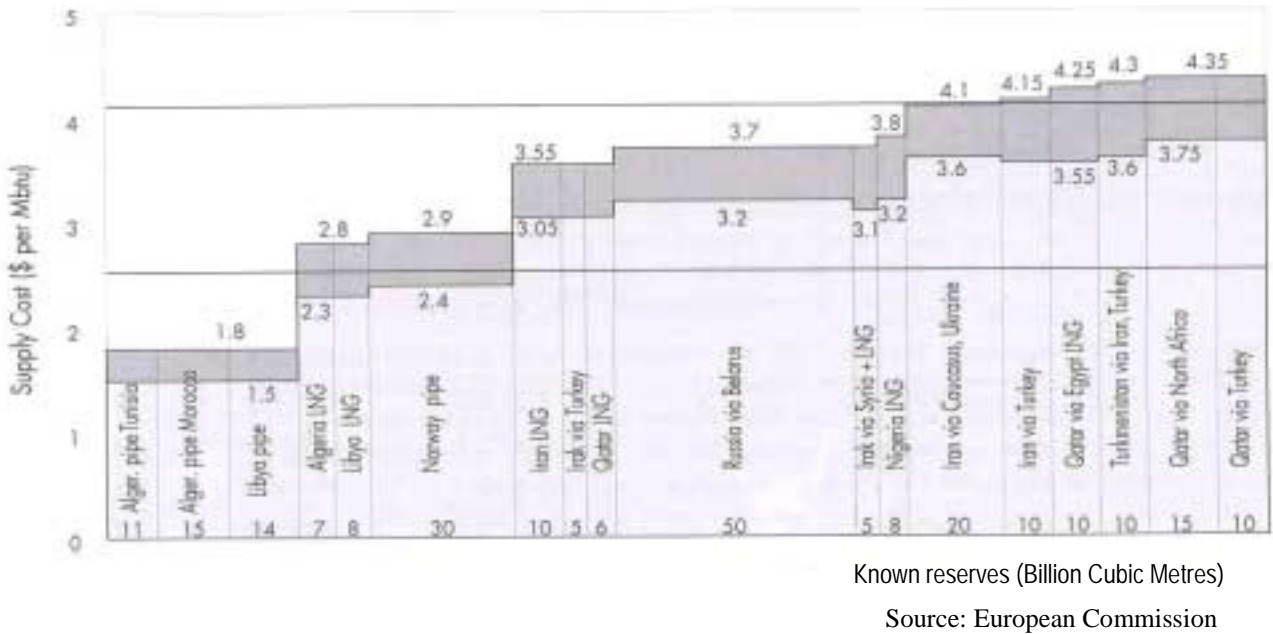
The *Energy Review* focused on the use of gas and correctly identified the availability of substantial resources. The review suggests that the UK power sector will become over 80% dependent on gas by 2020/25 (confirmed in Energy Paper 68). A key issue overlooked by the review is the critical issue of gas pricing. Few would disagree that the reserves physically exist and could be transported to the markets at a cost. However, there are two fundamental issues that can be expected to drive prices up.

First, all EU member states are attempting to meet the same environmental legislation in reducing pollutants, particularly SO_x, NO_x and particulates. Commitment has also been given to meeting the Kyoto CO₂ targets. Most EU member states are experiencing the same drivers and have similar incentives to switch to natural gas, thus the forecast growth in demand is substantial over the next 20 years. A further 10 countries have also applied for accession to the EU and, if these applications are successful, will become subject to compliance with the emissions standards. Within an enlarged EU the number of potential buyers of gas will increase further, driving up demand and, almost certainly prices.

Second, Western Europe will become increasingly dependent on imports of gas from the former Soviet states, the Middle East and the African continent. The distances from reserves to market are great so the cost of new pipelines, Liquefied Natural Gas (LNG) facilities, storage and other infrastructure is very substantial. New pipelines under the North Sea would also be required to supplement UK supplies. The EU Energy Directorate set out its views on the future energy outlook at the European Energy Millennium Forum in June 2000⁵. While 70% of the world's gas reserves lie within 'economically deliverable' distance of Europe, their studies showed that a \$2.00/mmBtu addition to the gas price would be needed to deliver gas to Europe as LNG. The corresponding pipeline cost was

between \$1.75-3.00/mmBtu for the range of pipelines would be required. Furthermore, at least 15% of the 2020 supplies were described as being of ‘uncertain origin’ and in view of this, the costs of final tranche were estimated to be in excess of \$4.00/mmBtu.

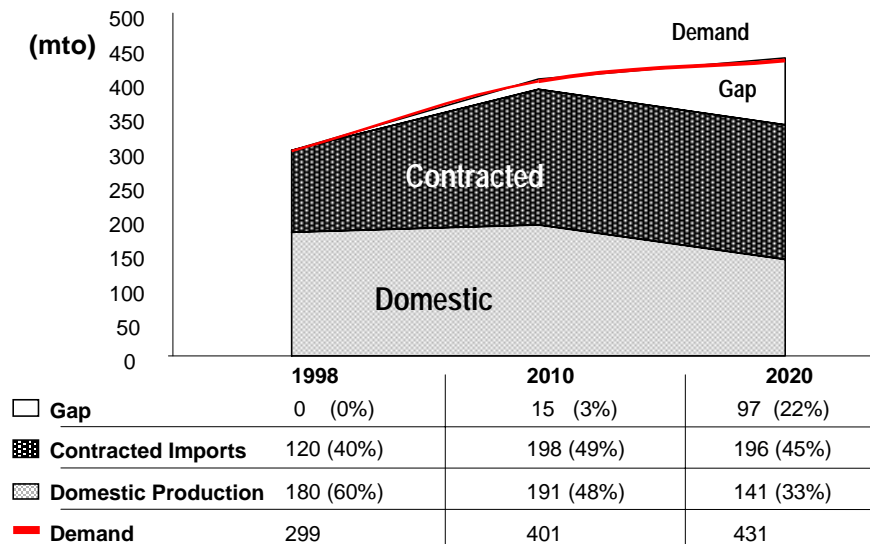
Figure 1: Supply costs for potential exporters of natural gas to Europe



Note. The current UK gas price is about \$2.0/mmBtu from existing wells so the price has to more than double to recover investment costs. While gas may be a necessary transitional fuel, other technologies will to be considered since they would become economically attractive at higher gas prices.

The EU Energy Directorate has predicted that European gas demand will outstrip local supplies by 2008. Forecasts indicate that Europe will have to draw on external sources to an increasing extent from that date⁴ (Reference). In March 2002, the German Economics Minister stated at a conference in Amsterdam that the date of growing dependence on imports had advanced to 2005. He reported that the Russian gas company, Gazprom, had increased forecasts for local demand to a level that would require 25% of natural gas output to be consumed internally, reducing export availability as a result.

Figure 2: Long term EU15 gas supply outlook



Source: European Commission

In April 2002, the CEO of Eni in Italy, Vittorio Mincato, announced that Gazprom had just notified them that there would be an 80% price increase on the contracted quantities over the next 5 years.

The findings of the EU study do not appear to have been taken into account by the PIU energy team. Instead, the PIU seems to have placed more faith in the political ambition of liberalising the European gas market as the mechanism to keep prices stable and low through competition. Whether liberalisation will have such a result is highly questionable when rapid growth in demand is forecast coupled with high infrastructure expenditure. The political desire to achieve liberalisation also has to be set against the commercial reality of the structure of the gas supply industry. A few companies have been positioning themselves to gain market share and influence. For example, Ruhrgas already has a 25% share in Gazprom, the Russian gas company while Eon has just taken control of Ruhrgas. Eon also purchased PowerGen and other power companies in Europe. RWE is one of the largest German producers and now owns Innogy while Électricité de France (EDF) has a stake in UK power distribution including London Electricity. Neither EDF nor ENEL, the Italian generator appears to be considering 'privatisation'. Hence, in spite of the wish to see an open European market in gas and electricity, a handful of very powerful companies are becoming dominant. These companies have clearly identified the commercial opportunities that will develop from Europe's growing dependence on gas for electrical power generation.

Some observers and parliamentarians have mentioned security of supply issues related to the long distance pipeline exposure ranging from natural causes such as earthquakes to sabotage. This is not a technical issue on which the IChemE has firm views. However, new long distance pipelines to Europe are being considered from Russia via Belarus, Iran via Turkey, the Ukraine and Syria, Qatar via Egypt, Turkmenistan via Iran and Turkey and Nigeria via the Sahara. From the UK point of view, the country would be on the end of these long supply chains and as such buffer storage/LNG may need to be considered to ensure continuity of supply, assuming that security experts were satisfied with the pipeline systems. The one technical issue relates to whether the lines are sufficiently robust to survive the geological faults and earth movement that are likely exist over such great distances. This is an area that requires careful assessment but it is not one in which IChemE has sufficient expertise to comment.

The *Energy Review* promotes the case for natural gas for the environmental advantages it would bring to the UK alone. It does not mention that in the process of transporting gas over vast distances, approximately 25% of the gas leaving the well may be consumed in the recompression stations needed to move it to Europe. IChemE does not have access to the design specifications for new pipelines, however, the number of re-compression stations that will be required to traverse such long distances suggests a substantial use of gas as 'transmission fuel' in gas turbine compressors and CO₂ from its combustion would be emitted into the atmosphere. Furthermore, assessment of methane leakage on the lines has been estimated at as much as 4% depending on design. Methane is 20 times more potent than CO₂ as a greenhouse gas and thus a leakage of this magnitude represents a significant increase in greenhouse gas emissions, albeit not in Europe.

The UK's energy policy should be set on a holistic analysis of system effects and not solely on the UK emissions. On a global emissions basis it would be more environmentally acceptable to make synthesis gas in the UK from coal and capture CO₂ than to use Russian gas. At the EU forecast of natural gas prices, it would be more economical as well.

The *Energy Review* also overlooked the fact that the pattern of fossil fuel usage may well change if price differentials between primary fuels alter. The global demand for electricity is growing faster than the demand for total energy. Hence, the fuels chosen for power generation will influence the market price of that fuel. Technology, efficiency, cost and emissions constraints are progressively driving the power industry to gas. It enables generators to take advantage of the advances in combined cycle gas turbine systems but if gas prices rise above about \$3.50/mmBtu, gasification becomes a realistic option and the USA is already evaluating several projects.

Oil

The *Energy Review* acknowledges that oil will remain the dominant fuel for the transport sector. Certainly for the next decade or more, gasoline and diesel will be the dominant vehicle fuel worldwide. It also recognises the major improvements that have been taking place in engine technology, fuel efficiency and in reducing exhaust emissions. However, the tightening of regulations on emissions from the transport sector dictates parallel improvements in fuels quality with reductions in sulphur and aromatics in both the main transport fuels. Diesel containing no more than 10 ppm sulphur will be mandatory in the USA by 2010 and the EU is likely to follow suit when agreement has been reached. The European oil industry acknowledges the possibility that the 2010 levels may be advanced in the same way as the 2005 specifications. The UK government conceded a price reduction on ultra-low sulphur transport fuel in the 2001 budget after public protests about fuel prices. The budget move forced the early introduction of fuels that were not required by law before the 2005 to comply with the EU specification.

These quality improvements are leading the oil companies into major investment programmes for the production of hydrogen to process more high quality diesel and are also beginning to invest heavily in the synthesis of sulphur-free high quality diesel from natural gas. Most major oil companies and Sasol, the South African energy company, are promoting this technology – a step that has the potential to raise the demand for natural gas still further. Projects are progressing in Nigeria, Qatar and Indonesia using Sasol, Shell and Exxon technology.

Coal

The *Energy Review* says little about the future use of coal. It is surprising that the closure of nuclear capacity is addressed in some detail yet there is no comment about the age of the coal and oil fired capacity. Between 1950 and its eventual privatisation in 1990 the CEGB built about 38.5 GW of coal-fired capacity. Of that total build, only 7 GW is now less than 30 years old today and by 2008 only 2 GW will remain. Similarly, oil-fired capacity in excess of 8 GW was built in the 1960s and while much has already closed, some capacity is still utilised. The review makes no reference to closure of the remaining coal and oil capacity other than by suggesting it is all replaced by gas by 2020.

Coal is by far the world's most abundant fossil fuel resource and its distribution is more geographically diverse than any other sources of primary energy. Chemical engineers recognise that global warming issues are of paramount importance, nonetheless technologies for the clean use of coal do exist and their potential should be examined in more detail. Since the 1970s, the international market has been very competitive especially against other fuels. South African and Australian supplies dominate the market but the USA, Colombia, Venezuela and Indonesia are also significant exporters. The technology exists to use coal cleanly and efficiently, a conclusion reached by the DTI in its *Review of the Case for Government Support for Cleaner Coal Technology Demonstration Plant* published in December 2001. Despite the positive conclusion, no demonstration of advanced technology was perceived as necessary on the grounds that it has been fully tested to commercially acceptable standards in other countries. This would appear to have been a missed opportunity to demonstrate the potential for UK coal to be used cleanly and efficiently. The conversion of coal to clean gas becomes commercially attractive with relatively modest increases in the natural gas price. The USA is beginning to adopt clean coal technology to take advantage of resources and the development of the combined cycle gas turbines.

While the power industry views coal gasification to be a new technology, coal was the sole source of town gas from 1812 to the mid-1960s. Modern technology converts the entire hydrocarbon feedstock to gas and does not leave coke as a by-product. Furthermore, the CO produced can be converted to more hydrogen and CO₂ that can be captured under near ideal conditions for sequestration.

5. Why set target for renewables - fossil fuel conservation or CO₂ reduction?

The key question that stands unanswered in both the *Energy Review* and the *EU Green Paper on Security of Energy Supplies* can be summed up as follows – What is the objective behind the setting of targets for usage of renewable energy?

If the answer is fossil fuel conservation, then from the technical and economic standpoints energy efficiency gains are likely to conserve more fuel and cut CO₂ emissions than might be achieved through a switch from fossil fuel to renewables. However, if the real target is to reduce CO₂ then notwithstanding the fact that any contribution from renewables is both valuable and greatly welcomed, it may prove more cost-effective to tackle CO₂ reduction in a direct manner through CO₂ capture rather than by notional avoidance.

6. CO₂ avoidance, control, capture and sequestration

Studies published by Chevron-Texaco, the Jacobs Consultancy and others^{7,8} at IChemE's biennial gasification conference in 2002 suggest that the incremental cost of CO₂ capture as an addendum to the gasification process offers a very cost effective way to recover CO₂. Furthermore, an EU report funded under the Joule 2 Programme CT92-0031 on the underground disposal of CO₂ concluded that there is around 500 years of storage capacity for Europe's anticipated production of CO₂ in abandoned oil/gas wells and saline aquifers. The report states that the UK is among the countries that have ample storage available. Commercial scale storage has already been demonstrated 800m below North Sea with the EU funded Sleipner Project. Since 1996 nearly 1m tonnes of CO₂ per annum have been injected into saline aquifers and positive results have been reported⁹.

Chemical engineers are fundamentally concerned with the challenge of identifying process problems and developing of sustainable, cost-effective solutions. IChemE fully supports the development of renewables technologies, however, it is important that politicians, engineers and environmentalist alike recognize the shortcomings posed by over dependence on renewables. Their application needs to be clearly understood both in economic terms and environmental impact. Wind power is seen as "CO₂ free". However, the Danes have discovered that the flow of electricity from wind farms is not sufficiently reliable or predictable to match demand and that 'spinning reserve' of fossil fuelled capacity is essential to stabilize the power system. This means that fossil fuel has to be wasted and CO₂ discharged to atmosphere in order to accommodate wind generation into the system. Thus, the notional CO₂ reduction benefit of wind is dissipated to around 50% of the theoretical saving according to a review of the Danish experience.

7. Renewables in the UK power system – instability and flawed economics

The *Energy Review* aspires to a target of 20% renewables in the power sector by 2020. It has now become clear that the figure of 20% refers to the proportion of the total terawatt hours generated within the UK, not 20% of the installed generation capacity. This distinction is an important one and it poses a further question - how much capacity would need to be installed to achieve that generated output? Given that wind suitable for the generation of electrical power is only available 30-35% of the time, the *Energy Review* target can only be met by overbuilding windmills to about 3.5 times their nominal capacity in the hope that the annual target can be met.

The UK's population is heavily focussed in the major conurbations leading to high concentrations of demand for electrical power. Weather can patterns affect the whole country, so a stationary anticyclone may result in wind speeds insufficient to turn windmills for several days. Such weather conditions give rise to the coldest days in winter – unsurprisingly the period when power demand is very high. Consequently, continuity of power supply can only be guaranteed through the provision of back up fossil fuelled plus nuclear capacity capable of meeting the peak winter load with a safety margin for maintenance and other eventualities. Such a scenario gives rise to a further challenge albeit one of a different nature. New payment mechanisms will be necessary for the operators of that fossil fuelled and nuclear capacity who are required to provide stand-by and support capacity for the renewables sector. This becomes a critical issue when the full 20% of total terawatt hours sold has to be covered in that way. Similar scenarios can be developed for other renewable power sources. Tidal barrage is non-continuous albeit predictable but moving daily as is tidal flow. Wave power is again dependent on weather conditions.

In this area, the *Energy Review* contains a significant calculation error. Para 6.36 Page 100 cites the system costs of using renewables to be 0.1 p/kWh for a 10% renewables scenario and 0.2 p/kWh for a 20% scenario. The total infrastructure cost was assessed and the divisor used was the total annual market figure in tWh for electricity generated in the UK from all sources not the proportion of power that was to be generated from renewable sources. As a result the figures quoted are out by an order of magnitude and as such the system costs are far from negligible.

Another contentious calculation relates to the means used to calculate the 2025 price of wind energy by extrapolation based on the learning curve for wind power. IChemE strongly suggests that these forward price projections should carry a major 'health warning' and it is foolhardy to base a major plank of the nation's energy policy on such a tenuous extrapolation.

8. Sustainability and energy recovery from wastes as a renewable resource

The *Energy Review* contains many references to sustainability and one area mentioned is energy from waste. Sections 6.43, 6.44 and 6.45 appear to miss the main issue for the future efficient recovery of energy. Landfill, landfill gas and incineration are all mentioned. However, energy recovery has almost become synonymous with recovery as electricity. Incineration is a very inefficient way to generate electricity but pyrolysis, pyrolysis/gasification and anaerobic digestion offer ways to recover energy efficiently as gas.

IChemE believes that the recovery of energy from waste streams should be considered as a renewable source and that energy recovery should be more actively encouraged. There are many potential applications, including municipal wastes, agricultural residues, sewage sludge, spent organic chemicals, solvents, lubricants and plastics. The development of modular systems for the smaller communities may offer a means of reducing the transportation of low energy material to large centrally located incinerators, thus overcoming some of the so-called 'NIMBY' issues. The *Energy Review* identified landfill as producing gas as a useful by-product but government statistics show a substantial portion of the UK's methane emissions coming from landfill, i.e. equivalent to about 30 million tonnes of CO₂.

9. Nuclear replacement

One of the most critical issues addressed in the *Energy Review* is the future role of nuclear power. Nuclear is currently producing nearly 30% of the UK's electricity without CO₂ emissions. The progressive closure of the UK's ageing nuclear capacity over the next decade presents a significant challenge. If the government's 20% CO₂ reduction target by 2020 is to be achieved, replacement of this nuclear capacity with CO₂-free sources is imperative. As discussed in previous sections, wind and wave power suffer from considerable stability and reliability problems. IChemE has also highlighted the need for a spinning reserve to support these renewable sources and CO₂ emissions associated with maintaining back-up capacity means that wind and wave power cannot be viewed as entirely CO₂ free. This leaves us with only two proven, cost-effective and reliable options: a nuclear replacement programme and fossil fuel gasification with CO₂ capture/sequestration.

British Energy and the Chief Scientific Adviser have presented technically and commercially sound cases for replacing nuclear with nuclear. Without such a replacement programme, the CO₂ target will simply not be met. Given that the renewables target has to be in doubt, IChemE believes that the government has no option other than to support the advice coming from the Chief Scientific Adviser.

Public concerns over the safe handling and disposal of nuclear waste are clearly recognised. Nonetheless, it should be borne in mind that the incremental increase waste generated by the new generation of nuclear power plant is small in comparison with the existing quantities of waste that are already being managed safely. Further research and development will lead to improved handling and disposal techniques and it is important that the UK's skill base is maintained and refreshed in this field. It should also be emphasised that the Chief Scientific Adviser views the risks associated with greenhouse gas build-up as being far greater than those associated with nuclear waste.

IChemE supports the Chief Scientific Adviser's views on the need for a replacement nuclear programme building new capacity on existing sites. The extent to which the capacity is fully replaced is dependent on the parallel development of a hydrogen economy and acceptance of CO₂ sequestration. The use of gasification plus carbon capture creates an opportunity to produce high quality gas that can be used for low carbon power generation via combined cycle gas turbines or fuel cells. A major gas turbine manufacturer, GE, has already tested their equipment on hydrogen rich fuels and significant progress has been reported¹⁰. Gasification technology has been proven outside the power industry and used for over 30 years. CO₂ capture systems have been known and used by the oil industry for about 50 years. The need to demonstrate the scaled up technique described in section 6.56 of the *Energy Review* is very much a non-issue. The government drive for CO₂ reduction is only just starting to draw out the solutions.

Nuclear power does not generate CO₂ and so to progress to the 2020 or 2050 targets without replacing nuclear capacity assumes about 30% of the UK's power can be produced economically in some other CO₂-free way. IChemE cannot see how this can be achieved without replacing existing capacity.

The *Energy Review* identifies that natural gas fired combined cycle gas turbines offer a readily available source of power with a relatively low carbon emission profile compared with coal and oil-fired stations. Efficiency gains in gas fired stations have reduced the CO₂ generated by over 60%. Further advances can be made through the deployment of CO₂ capture techniques and the technology exists to reduce CO₂ while producing power from coal or other low quality hydrocarbon feed stocks. This route offers several advantages. Indigenous coal could be used extending the lifetime of the UK's remaining coal production units. The CO₂ removed and could be utilised for enhanced oil and gas recovery extending the life of UK oil and gas reserves that have gone beyond peak production. Such an approach offers a classic win-win scenario in any energy strategy. Around 35 million tonnes per year of CO₂ is already being used for this purpose in the USA and Canada – much of it derived from coal.

The *Energy Review* and the DTI's cleaner coal review both imply that such technology is unproven and that further research and development is needed. IChemE challenges this view. Techniques for the absorption of CO₂ have been known for decades and government funded research by British Gas in the 1980s demonstrated effective extraction of CO₂ from gas streams on a commercial scale.

10. Pathways to a hydrogen economy and fuel cell development

In section 6.66, the *Energy Review* suggests that fuel cell driven cars will replace conventional internal combustion engines by 2050. No reference is made to developments currently under way in the motor industry globally or that companies such as Ballard have already made significant advances in fuel cell powered buses. Fuel cell powered cars and buses may well be in service in selected areas of the UK by 2020. It is worth noting that hydrogen is not a fuel in its own right rather it is an energy vector or carrier. Hydrogen must be manufactured either from fossil fuels, or by electrolysis where the electricity required for the process necessitates the consumption of energy.

Many sections of the public perceive hydrogen to be the 'Holy Grail' in fuel terms given that the only by-product of its combustion is water. This premise only holds true when hydrogen is used in a fuel cell. It does not hold true when hydrogen is used in an internal combustion engine because the high combustion temperature results in the formation of oxides of nitrogen – smog-forming pollutants. It should also be noted that the cheapest commercial process available for the manufacture of hydrogen is the reforming of methane, a process producing CO₂ at the point of production. This example provides a simple illustration of the need to assess the full implications of a total system when addressing the carbon load for any given power source. Hydrogen is a carbon free 'fuel' at the point of use but not at the point of production.

Some environmentalists advocate renewable hydrogen by using 'carbon free' wind generated electricity for the electrolysis of water to produce hydrogen. While this may become an attractive route at some future point in time, it is an expensive way to produce hydrogen for many technical reasons that extend beyond the scope of this document.

The development of a hydrogen economy presents a classic "chicken and egg" situation. As already stated, hydrogen is not a fuel but an energy carrier. It needs to be produced, transported and stored with major implications for investment in infrastructure. Until a demand develops, the energy industries are reluctant to make the investment in infrastructure. However, demand will not increase unless potential users have ready access to hydrogen. Opinion remains divided on the best way to manage a supply system. Motor manufacturers and the oil companies are ambivalent over whether fuel cells should be run by hydrogen stored on-vehicle or whether an on-board reformer should generate hydrogen alongside the fuel cell from petrol or perhaps methanol. Use of petrol or methanol would enable existing distribution and storage infrastructure to be used substantially reducing costs for the energy companies.

Hydrogen can be used in conventional engines. BMW recently launched a 7 Series vehicle running on compressed hydrogen. They have also developed the Mini to operate on compressed hydrogen. The larger car has a 5.5 litre engine and a range of 200 km on hydrogen. Their launch literature indicates a commitment to the internal combustion engine but they were not able to address the issue of NO_x emissions that would arise

The most important development to initiate the use of hydrogen is the full commercialisation of fuel cells. Until costs are reduced and mass production is developed, the evolution of a hydrogen economy will be slow. However, considerable progress is being made in other countries, including the USA, Canada, Germany and Japan. The UK still lags badly but opportunities for catch up exist through the development of centres of excellence as recommended by the Chief Scientific Adviser. Several cities have proposals to focus on fuel cell research and development including London, Birmingham, Warwick, Sheffield, Cambridge and Teesside.

Conclusion

IChemE believes that UK energy policy should be balanced and secure. This necessitates a mixed portfolio of sources with no heavy dependence on any single primary energy source. Policy mechanisms must take into account the need for the power generation sector to supply secure stable, high quality electric power at competitive prices.

IChemE considers that the current benefits of CO₂ free nuclear capacity need to be retained if the government's ambitious CO₂ targets are to be achieved. A replacement programme for nuclear power, which maintains generating capacity at existing levels is essential. In addition, fossil fuels still provide opportunities for low-carbon power generation. Clean coal technology coupled with CO₂ capture and sequestration should also be developed for a significant share of the power generated.

Constraint on natural gas should be considered in order to avoid over-dependence on imports and the vulnerability to price fluctuations that can reasonably be expected. Without market intervention, investment in clean technology will not take place and the UK government is unlikely to achieve its stated environmental target for 2010 and 2020.

The hydrogen economy offers considerable opportunities. Nonetheless, it should be borne in mind that hydrogen is not a fuel but an energy carrier. Fuel cell development is an important step to the efficient use of hydrogen and the UK must avoid being left behind in this key area. Substantial investment in research and development will be required.

Renewable energy is an important consideration and it has a clear place in any future UK energy mix. However, a greater degree of realism is required with regard to what is practical and achievable in the medium term. A target of 10% is both more realistic and manageable into a modified grid system. There is no panacea and, as such, technical capability should be retained for all potential solutions. Professional engineers must be given more opportunities to assist politicians with the development of policy solutions to complex and inter-related energy issues.

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Appendix A – About IChemE

IChemE (Institution of Chemical Engineers), the leading professional body for chemical engineers, aims to encourage best practice in the process industries. With an international membership approaching 25,000, the Institution has the role of learned society, publishing books, journals and training packages and organising conferences and courses.

IChemE has been a regular respondent to UK government consultations and is a participant in the DTI Foresight Programme. In 2001 IChemE secured DTI and Research Council funding totalling £2.2 million for CRYSTAL, a new Faraday Partnership aimed at securing major advances in Green Chemical Technology for the Process Industries.

In 2002, IChemE launched The Sustainability Metrics; a comprehensive toolkit designed to assist chemical and process engineers with the measurement of progress towards sustainable development in the process industries.

IChemE participates in the work of the UK parliament through its membership of two Associate Parliamentary Groups, the Parliamentary and Scientific Committee and the Parliamentary Group for Energy Studies.

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