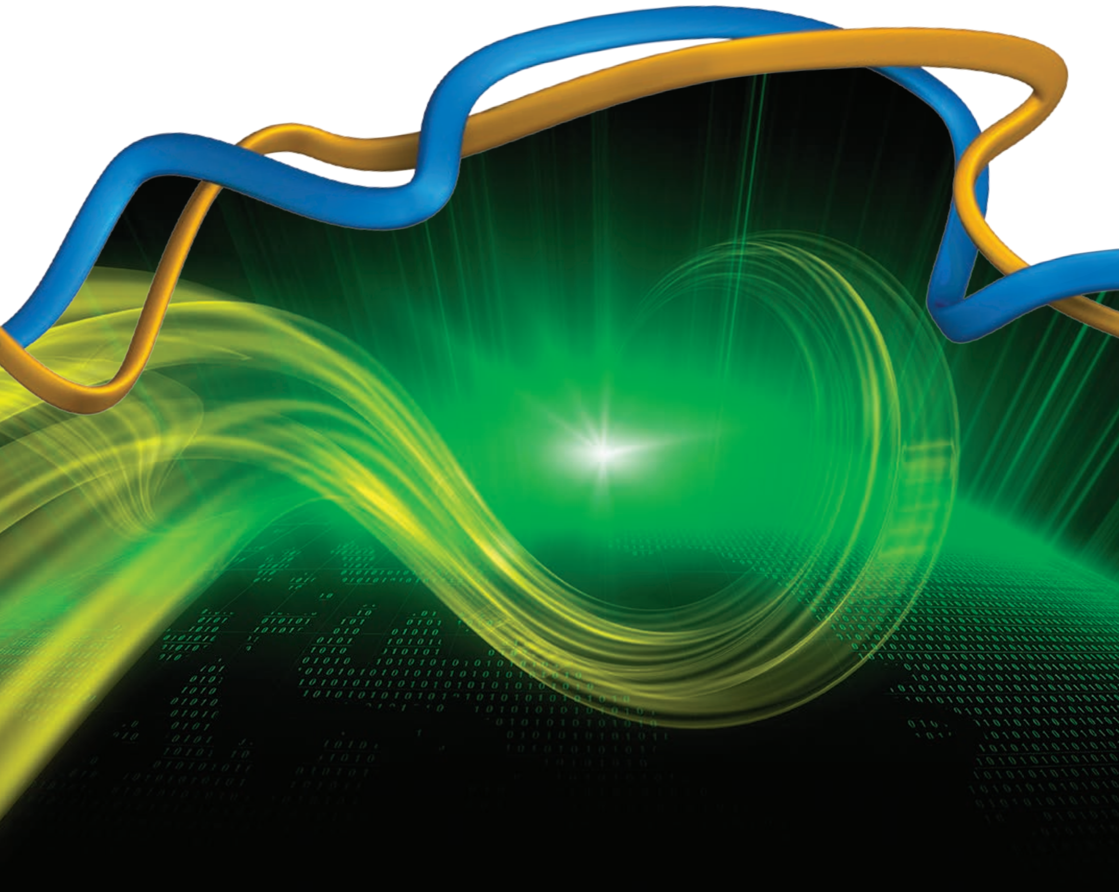
Innovation in energy

Summary of a meeting held on Monday 31 March 2014
at the Royal Academy of Engineering



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1. Introduction

The Royal Academy of Engineering has run a series of meetings under the chairmanship of the Academy's President, Sir John Parker GBE FREng, to highlight the opportunities and challenges in innovation in engineering sectors that have potential for growth and for global reach. On 31 March 2014, a half-day meeting on *Innovation in energy* brought together leading engineers, academics and business people from many branches of engineering – and beyond – to discuss issues and trends in the provision of energy and power.

The conference heard presentations and contributions from academics, industrialists, innovators, energy suppliers and users with a deliberate emphasis on the less familiar technologies that nevertheless have promise to be significant contributors to the UK's future energy mix. This report is not a verbatim record of the conference; rather, it seeks to highlight some of the issues raised and to contribute to further discussion.

Environmental and sustainability considerations have given rise to a new set of imperatives that are driving innovation in energy generation and distribution

2. The background

Energy supplies have been a subject of global concern and of political and economic tension for half a century and more. But the nature of that concern and tension has changed, with new factors making this one of the key global issues of the 21st century.

An underlying and continuing source of tension is the geographical inequality of energy distribution across the world. Traditionally, it has been the unequal distribution of fossil fuel reserves that has caused tension, and that remains the case with, for example, the current reliance in Western Europe on gas supplies that originate from or pass through Russia. But newer energy sources such as solar power and wind are also not distributed equally across the globe and alternatives such as nuclear rely on technologies that may not be universally applicable.

Environmental and sustainability considerations have, however, given rise to a new set of imperatives that are driving innovation in energy generation and distribution. The identification of fossil fuel use with pollution of many kinds and, more recently and more controversially, with climate change has led to worldwide programmes to substitute traditional energy sources with alternatives. There is also concern about resource depletion that has put an emphasis on the development of energy sources that are sustainable or renewable. Worldwide agreement on specific targets has not been easy and remains the subject of ongoing negotiations, but within individual nations and in broader political groupings such as the European Union there are challenging programmes for reducing carbon emissions and increasing renewable sources of energy. These will require significant investment to drive innovation across the whole energy system.

The innovation challenges for engineers in the energy sector include the reduction of traditional fossil fuel energy sources, diversity of supply, improving the efficiency of alternatives and decarbonising current processes. There are emerging issues for the UK energy infrastructure in terms of ageing and systems capable of working with new energy storage technologies and intermittent energy sources. There are an increasing number of technological options to be considered in the future energy generation mix, and also some urgency if targets are to be reached.

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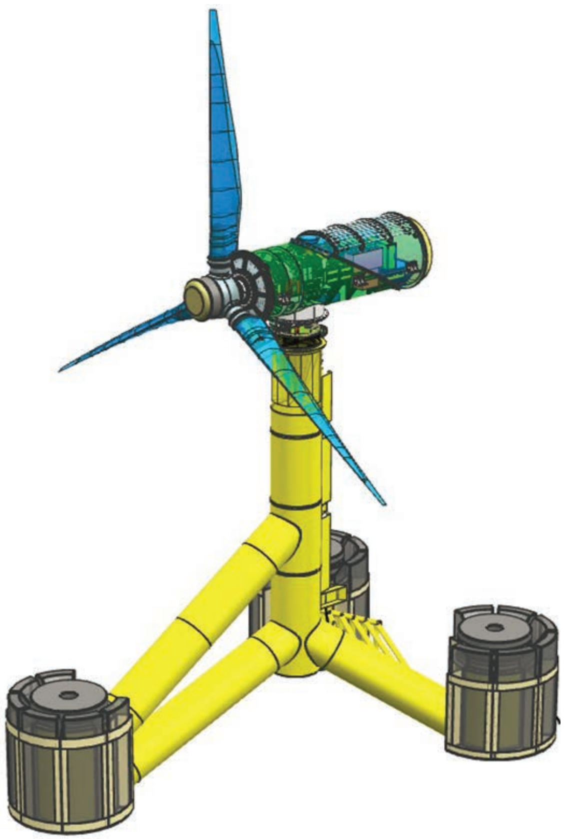

Next generation turbines © ScottishPower Renewables

The Energy Technologies Institute has developed models of the UK energy system to determine which options offer the lowest cost pathways for reaching the mid-century targets of a reduction in carbon emissions of 80%

3. The innovation options

The complexity of issues relating to the whole energy system and the large number of possible solutions mean that, at some point, choices have to be made; otherwise there is a risk of developing a sub-optimal system. The Energy Technologies Institute (ETI), an independent research organisation whose members include major energy suppliers and large-scale users as well as the government, has developed models of the UK energy system to determine which options offer the lowest cost pathways for reaching the mid-century targets of a reduction in carbon emissions of 80%.

The models developed by ETI, said Jo Coleman, Director of Strategy, are complex and sophisticated and they cover energy in its many forms: electricity, heat, vehicles, industry and the infrastructure that binds them. In the future, she said, the interdependencies of currently separate forms of energy were likely to become more evident much more than they do today: for example, waste heat recovery would be more prevalent, and decisions on future vehicles and home heating would have an impact on electricity supply.

The models are used both to determine the economic cost of alternative system designs and to investigate the effect of individual technology choices. This analysis is used to inform ETI investment strategy as well as to provide advice to policymakers. There are uncertainties built into the models on the availability of resources and their costs, as well as on the rate of technology change. There are other considerations too: the geographical spread of final energy demand and the availability of energy resources; the seasonal and daily fluctuations in demand; and the variability and flexibility of different energy sources. "We need to look for solutions that are robust against a range of future scenarios," Coleman said.

"But the good news is that we can afford to decarbonise our energy system: it will cost us maybe about 1% of our GDP in the UK." However, she added, there are provisos. To achieve this cost model, it would be necessary to design an optimal energy system, and it would also need significant investment funding in the near future in research and development of the technologies most likely to be serious contenders in our energy system beyond the mid-2020s.

The timing is important, Coleman said. The target of 2050 for carbon-based emission reductions might seem distant, "but we need to be starting to deploy the new infrastructures at scale by the mid-2020s if we are to meet the climate change challenge". And with a plethora of options, choices would have to be made: "We simply can't develop infrastructure for every alternative; we need to make choices to avoid underutilisation, or worse, stranding of expensive infrastructure assets," she said. "We have about 10 years in which we have to develop our options."

Out of this range of energy options, the ETI sees most value in two interlinked technologies that appear to offer the most promising combination of potential energy contribution and meeting environmental goals. "We see carbon capture and storage and biomass as the most valuable technologies that we can deploy," she said. Other elements that could also form important parts of a future energy strategy included measures to improve the energy efficiency of buildings, vehicles and industry and an increase in nuclear power generation.

The combination of carbon capture and storage (CCS) and biomass is particularly attractive, Coleman said, because of the possibility of using the technologies in tandem. This could help to prolong the use of carbon-based fuels in domestic fuels (such as hard to retrofit homes and heavy goods vehicles) where substitution was difficult. In addition, there was potential to develop a synthetic gas industry through CCS that could be used as a low carbon fuel in large-scale industrial applications. "The benefit from this combination is largely going to be outside the conventional 'power' sector".

But to achieve the targets requires decisions: "We haven't yet demonstrated full-chain CCS," she said. "We need to make decisions about it in order to know what kinds of infrastructure we should be investing in. But we do see CCS and bioenergy as key enablers, with decisions needed on them by the mid-2020s."

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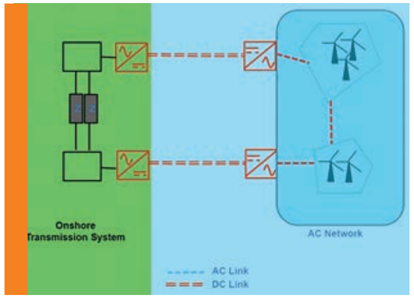


Integrating offshore windfarms © National Grid

4. Innovation in the energy infrastructure

The UK's power generation and transmission infrastructure was developed in first part of the twentieth century and essentially reflected the population and industrial concentrations of that time and the dependence of the entire system on a limited range of fuels: first coal on its own, then coal with oil and gas. Changes since then, with the bringing on line of gas from the North Sea and then from further afield, have altered the system, but the fundamental structure remains. This presents difficult challenges for the likely future shape of power generation.

The UK's current energy infrastructure is centred on large-scale generating units and needs to be adapted to also handle smaller-scale and more varied types of input which will be likely in the future, some of which will be intermittent, such as wind and wave. There are geographical challenges as well; with future energy sources more distant from the centres of demand. In remote areas, there appears to be scope for wave and tidal energy as well as hydro, and through offshore wind development.

There is a need for innovation in the transmission and distribution networks to handle the new variabilities of energy generation and to improve the efficiencies of a system that was set up for different priorities. The meeting heard of two particular developments.

4.1. High voltage direct current transmission

As the UK's national electricity transmission system operator, part of National Grid's role is to integrate the existing infrastructure and technology with newer developments which are, in some cases, less certain. Phil Sheppard, Head of National

© National Grid

Strategy for National Grid, told the conference that high voltage direct current (HVDC) transmission is an important part of this transition because it enables greater control, with flexibility and efficiency that are not available by other means.

In the UK, there is currently 4GW of transmission capacity between Scotland and England. National Grid and Scottish Power have joined forces on a new 2.2GW subsea HVDC line that will be commissioned in 2016. This, said Sheppard, was very much the shape of things to come, as undersea links were cheaper than traditional overhead power lines, raised fewer objections and were also faster to build.

But HVDC has additional potential for the UK's electricity infrastructure. Current offshore wind farm developments are concentrating on areas at some distance from the shoreline, "beyond the practical range of alternating current connections". Direct current (DC) interconnection lines are needed to harvest this new energy source and connect it to the UK grid, but Sheppard said the project also required "a lot of onshore reinforcement of the grid as well". In addition, there are increasing links between the UK's grid and those of other western European nations.

To this end, National Grid has a large programme of direct and sponsored research and development, looking

at innovation in crucial areas such as power electronics and DC circuit breakers. It has a network of UK universities that it works with on modelling high voltage transmission systems and the implications for power electronics, and is actively pursuing innovations that will make such systems more efficient in terms of power losses and more responsive to meet the new and more fragmented generation and distribution realities.

4.2. Energy storage in the gas grid

Variability is a feature of many renewable energy sources that are being increasingly exploited as part of the drive towards reducing carbon emissions. Technologies such as solar, wind and wave power are unavoidably intermittent and have seasonal and daily variations as well: at times, too much energy is generated, and at other times, too little.

Across the whole of the electricity system, both supply and demand, there are wide variations on seasonal and daily bases, and these fluctuations are forecast to grow with the greater use of technologies such as electric vehicles or heat pumps.

Together, these factors mean that there is an increasing challenge within the electricity system to be able to balance supply and demand. This has been achieved in the past through a policy of having excess capacity available when required, but that approach is now becoming inefficient. There is a worldwide demand for an alternative strategy that will enable energy to be stored within the system for release at times when it is needed.

Dr Graham Cooley, Chief Executive Officer of ITM Power, said that, for renewable energy systems, storage "is the killer app". While there is much global research into batteries and other devices such as flywheels, ITM Power has been working on an alternative that would make use of the huge storage capacity that there is on the gas grid.

The UK gas grid, Cooley said, delivers around three times as much energy annually as the electricity grid and has inherent storage capability. ITM Power's innovative proposal is to use excess energy from renewables to produce hydrogen that can be stored within the gas grid. This would avoid wasting any potential excess electricity production and help decarbonise the existing gas system. The hydrogen production process has potential byproducts in terms of heat recovery, and the hydrogen can be used both as a fuel for vehicles in its own right or, mixed with the existing hydrocarbon gas supply, as a synthetic gas for conventional uses.

> The UK gas grid, Cooley said, delivers around three times as much energy annually as the electricity grid and has inherent storage capability

Completed Thuga energy storage project with visitor centre © ITM Power

> Small modular reactors (SMRs) are smaller units that could be bundled together to create a large power station with greater flexibility or used individually as local energy sources.

5. Innovation in generating technology

The need to move away from fossil-fuel technologies to meet carbon reduction targets has already led to the adoption of renewable energy sources such as wind power and a revival in large-scale nuclear power generation. The meeting heard about three lesser-known candidates for future power generation that could contribute to both climate change targets and energy diversity aims.

5.1. Small-scale nuclear

The nuclear power stations that are foreseen as part of the current investment programme in the UK are large-scale installations. Like the current nuclear fleet that is mostly nearing the end of its working life, they are likely to be used for baseload generation. This is because nuclear power stations cannot be powered up and powered down as quickly as some other technology options.

Dr Fiona Rayment from the National Nuclear Laboratory outlined the concept of a different type of nuclear power plant called small modular reactors (SMRs). These are smaller units that could be bundled together to create a large power station with greater flexibility or used individually as local energy sources.

SMRs can generate up to 300MWe and the concept of smaller-scale nuclear

NUSCALE SMR powering 45MWe and reactor vessel submerged in a water pool © NNL power is not new. It has been used in defence and marine applications – such as nuclear submarines – for many years, and has been worked on intermittently by many companies, including some of the world's largest suppliers of the larger power stations.

"There are lots of small modular designs," Rayment said. "The sector is dominated by light water reactors which are based on existing large-scale designs, though they are probably still 10 years from being ready to deploy. There are also some non-pressurised water reactor designs led mainly by non-industrial organisations: it's often difficult to compare the pros and cons of these without all of the baseline information and only a few will ever stand a chance of making it through into a competitive market".

In terms of economics and the technology, there are claimed advantages for SMRs, Rayment said, but also fundamental challenges that require further innovation. Economic benefits might include simplified design and manufacturing that could lead to mass production and a vibrant supply chain; there were also claims that these units would be quicker to start up than larger nuclear power stations and would therefore be more flexible in use, and that they would need less maintenance. "All of these economic benefits are theoretical and need to be demonstrated," she said. "None of the concepts has yet been validated."

There is a similar need for practical innovation in the technology. Claims are made of simplified safety systems, with integral layouts, large coolant masses and natural circulation, and there is potential for underground sites; refuelling cycles might be longer. "The challenge is that all the features need validation at component level as well as within the whole system," Rayment said. She said that safety is not dependent on size: "These systems still need a rigorous safety case," she said.

5.2. Fuel cells

The motivation for innovation in fuel cells is not just about the contribution to sustainability but also about increasing their already impressive efficiency, emphasised Professor Nigel Brandon FREng from Imperial College London.

The UK has a strong track record in fuel cell innovation, he said, and there was already a strong industry in North America and Asia. But the huge range of types of fuel cell meant that there were still significant opportunities for innovation and new applications in areas such as micro combined heat and power (CHP) to explore.

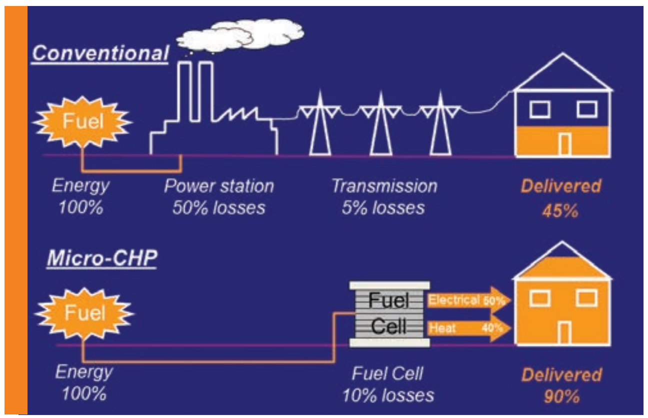
Professor Brandon said that there was a natural synergy between the carbon reduction agenda and fuel cell development, but there were other environmental benefits as well, including lower levels of pollution and quiet operation.

5.3. In-shore tidal power

Renewable energy technologies are often categorised as intermittent and unreliable, but to categorise tidal power alongside wind and wave energy is unfair, said Barry Carruthers, Senior Marine Engineer at ScottishPower Renewables and a leading engineer on a demonstration tidal power array in the Sound of Islay. "Tidal power essentially cycles in line with the phases of the moon and subsequently over a period of 18.6 years," he said. "That's the only long-term variation. It's actually very predictable and known."

The technology is challenging and the Islay project is a world leader intended as the first pre-commercial development using an array of multiple subsea turbines to generate power for local communities. Up to 10 tidal power devices are to be installed in the narrow sea channel between the Inner Hebrides islands of Islay and Jura.

Unlike other tidal power demonstrator sites, in the Islay project, the wind and wave exposure is low and the channel approximately a kilometre wide and 60m deep. Carruthers said, "it is more like a bi-directional river". The megawatt-scale devices are fixed on the seabed and operate in the same manner as a wind turbine.

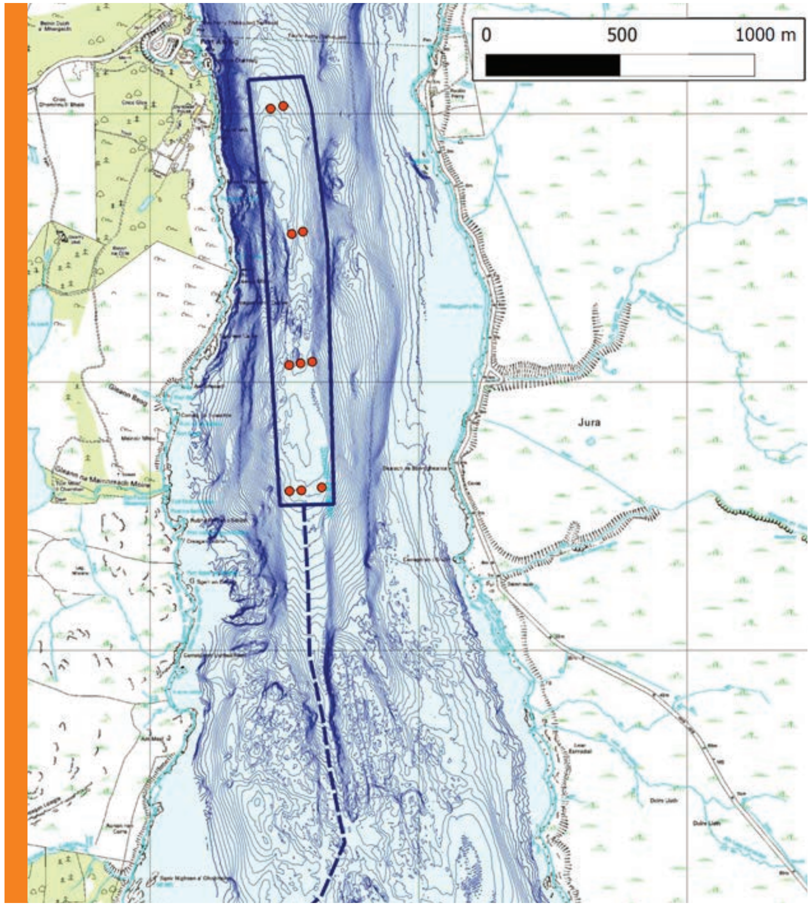


Fuel cell boilers for the home (micro-CHP) could reduce energy loss through transmission © Professor Nigel Brandon

The Islay project is a world leader intended as the first pre-commercial development using an array of multiple subsea turbines to generate power for local communities

© Scottish Power Renewables

Carruthers revealed that next generation devices would be bigger, with rotors up to 26m long and weighing in excess of 200 tonnes. The current installation is intended to answer general questions about the deployment of multiple devices and different methods of taking power to shore. There is also a lot that can be learned about tidal flows and site surveys from experiencing the relatively controlled and benign conditions at Islay. The risks of tidal power are very great and the forces that are being tapped into are extreme, he said; but to balance this, there is also huge potential worldwide for tidal power systems and the promise of energy security.



Sound of Islay
© ScottishPower Renewables

> Greenhouse gas emission reduction is forecast to be achieved through the development of non-fossil fuel alternatives

6. Innovation in fossil fuels

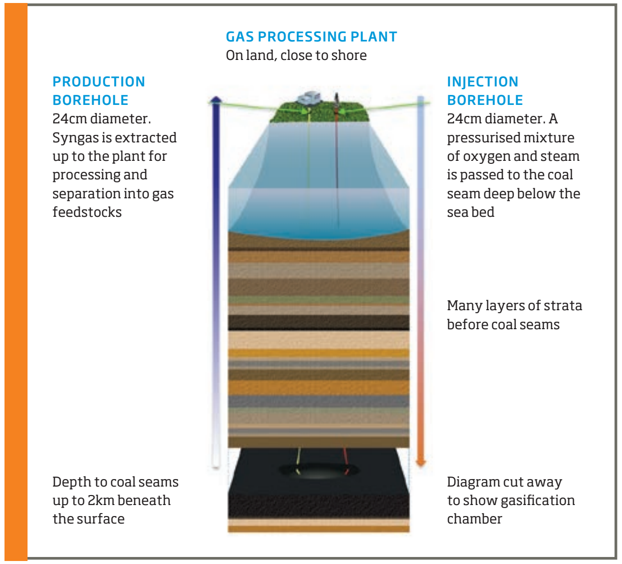
Future energy strategies are driven in part by commitments to reduce greenhouse gas emissions. Much reduction is forecast to be achieved through the development of non-fossil fuel alternatives and cutting the use of the carbon-based fuels that have been the main energy sources of the industrial age.

There is a parallel strand of energy strategy that seeks to decarbonise current carbon fuels by mitigating the emissions associated with conventional extraction processes from fossil fuel sources. The meeting heard from two areas of investigation where innovation is occurring not only in the technology but also in the economic infrastructure needed for successful implementation.

6.1. Unconventional gas from coal

Coal gas was one of the principal fuels of the Victorian industrial revolution and remained a prime source of UK domestic energy until the advent of natural gas supplies in the second half of the 20th century. Dr Dermot Roddy, Chief Technology Officer of Five-Quarter Energy, outlined different ways in which the UK's huge reserves of coal, much of them under the North Sea, could be exploited to produce new kinds of gas supply.

Roddy said that most of the estimated three trillion tonnes of coal resource was considered unmineable, but that underground coal gasification technology could be used to produce a synthetic gas that could be brought to the surface. The technique involves injection of oxygen and steam into coal seams to react with the coal and produce a gas; the voids created by this method could then be used to store carbon dioxide in a self-contained process.



The Five-Quarter deep gas winning process © Five-Quarter Ltd

Bloodwood Creek trial of underground coal gasification in Australia

Bloodwood Creek trial of underground coal gasification in Australia

A second gas-from-coal technology is the potential exploitation of the native gas found within coal seams and in the strata that overlay them. There have been successful projects to exploit this resource in coalfields around the world. Roddy described a "Deep Gas Winning" process which combines all of the above to maximise total economic gas recovery from a lithology at a large scale and purifies the gases for use as chemical feedstocks or in fuels.

For such unconventional gas developments to play a role in future generation mixes required further technology development and innovation in terms of downstream processes to render them economic, Roddy said. The gas produced by conventional underground coal gasification has a calorific value of only a third of natural gas. A key application for gas derived from coal, he said, was likely to be its use in petrochemicals. The need for innovation is not just in the extraction or synthesis processes, but also in developing the markets.

6.2. Carbon capture and storage

The UK has stated its intention to be a world leader in carbon capture and storage (CCS), said Dr Angela Whelan, Chief Executive of the Ecofin Research Foundation. Successfully deploying CCS would be a huge economic prize for the UK in its transition to a low carbon economy, cutting the annual cost of meeting its carbon targets by up to 1% of GDP by 2050. The UK has committed significant public funding to develop CCS and is at the forefront of CCS development in the European Union. Although there are two potential demonstration projects in the UK CCS commercialisation programme, Whelan cautioned there was a need for quicker action: "We can't wait for the commercialisation programme to provide all the answers before developing a CCS industry in the UK."

In 2013, the UK CCS Cost Reduction Task Force recommended that three national leadership groups be set up to develop CCS in the UK - the Commercial Development Group, the Transport and Storage Development Group and the Knowledge Transfer Group. The Commercial Development Group is led by the Ecofin Foundation with the support of the Energy Technologies Institute. The CCS Commercial Development Group aims to secure ways, together with the UK Government, of making UK CCS projects bankable, and reducing the cost of capital for CCS projects. The three groups work together to achieve the aim of commercialising CCS in the UK, and provide input into the UK CCS Development Forum. The Forum is co-chaired by Michael Fallon , Minister of State for Energy and Michael Gibbons, chair of the Carbon Capture and Storage Association (CCSA).

CCS projects, she said, had particular challenges that made potential investors wary. Although not a new technology, CCS has not been proven at a large scale for the full chain. There are many barriers to developing CCS, including counterparty risks resulting from different organisations running different parts of the value chain, risks related to CO_2 storage liabilities, and risks arising from changes in energy markets and regulation at both national government and international levels. A key issue raised by project developers and financiers is also the lack of confidence in long-term commitment of the government towards CCS. Investors require greater certainty before they commit financing: "We can't have absolute certainty, but we need more than we currently have," she said.

To mobilise private sector finance for CCS, the Commercial Development Group is working with financiers, project developers and policymakers. The team is working on identifying ways of tackling some of the barriers that discourage investment in CCS in the UK.

7. Acknowledgements

The Academy would like to thank the following for their contribution to *Innovation in energy*:

Chair

Sir John Parker GBE FREng
President, Royal Academy of Engineering

Speakers

Professor Nigel Brandon OBE FREng
Director of the Energy Futures Lab, Imperial College London

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