March 2010 Energy Research Partnership report

Energy innovation milestones to 2050
Executive Summary

Energy Research Partnership

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Foreword

Managing the transition to a low carbon economy while continuing to ensure energy security and affordability is one of the greatest challenges of our age.

Moving to a secure, sustainable energy system will require the deployment of new technologies, many of which are still at the development stage.

We are faced with critical technological questions. There is uncertainty about both the future cost and effectiveness of some technologies. Resolving these uncertainties requires years or even decades of work. Moving a technology from the demonstration stage to deployment at material scale can also take decades. Since our target date of 2050 is just four of these decades away, we must take action even though we are uncertain about the technologies that will ultimately prove to be the most effective.

The aim of this report is to shed light both on the current consensus regarding the broad direction of travel of the energy system and on the areas of uncertainty about technology choices. By so doing, it will highlight the timescales at which the key pieces of technological learning may be expected to bear fruit.

One of the themes of this work is the pressing need for investment in well-chosen, innovative demonstration experiments to help this learning process.

This is vital work which will help to safeguard our environment for future generations. We believe that industry, government and communities will find this analysis helpful.

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Executive Summary

This study of innovation milestones to 2050 sets out how and when selected new energy technologies are expected to develop and what the implications of their deployment could be on the UK energy system. Our objective has been to provide a high-level view to help ensure that policy and investment decisions are taken with a better understanding of the risks and opportunities involved in the transition to a low carbon energy system. We have drawn on scenarios and analyses from across the energy community, and our conclusions represent views that are broadly shared across the public and private sectors. The Energy Research Partnership is in a unique position to offer authoritative and strategic advice to inform decision makers on these matters.

Key messages

Achieving the goal for 2050 of a secure, affordable and low carbon energy system, means deploying technologies that are currently, or soon to be, available, as well as developing new technologies which may have an impact in the future. To chart the progress that is required by 2020, we have adapted ERP's 'innovation funnel' diagram in Figure 1. This 'pipeline' of technologies balances our analyses of what is needed to meet emission reduction targets and deliver a secure energy supply against that which can be achieved with technology developments. Progress towards these milestones should be monitored and used to guide policy or further investments.

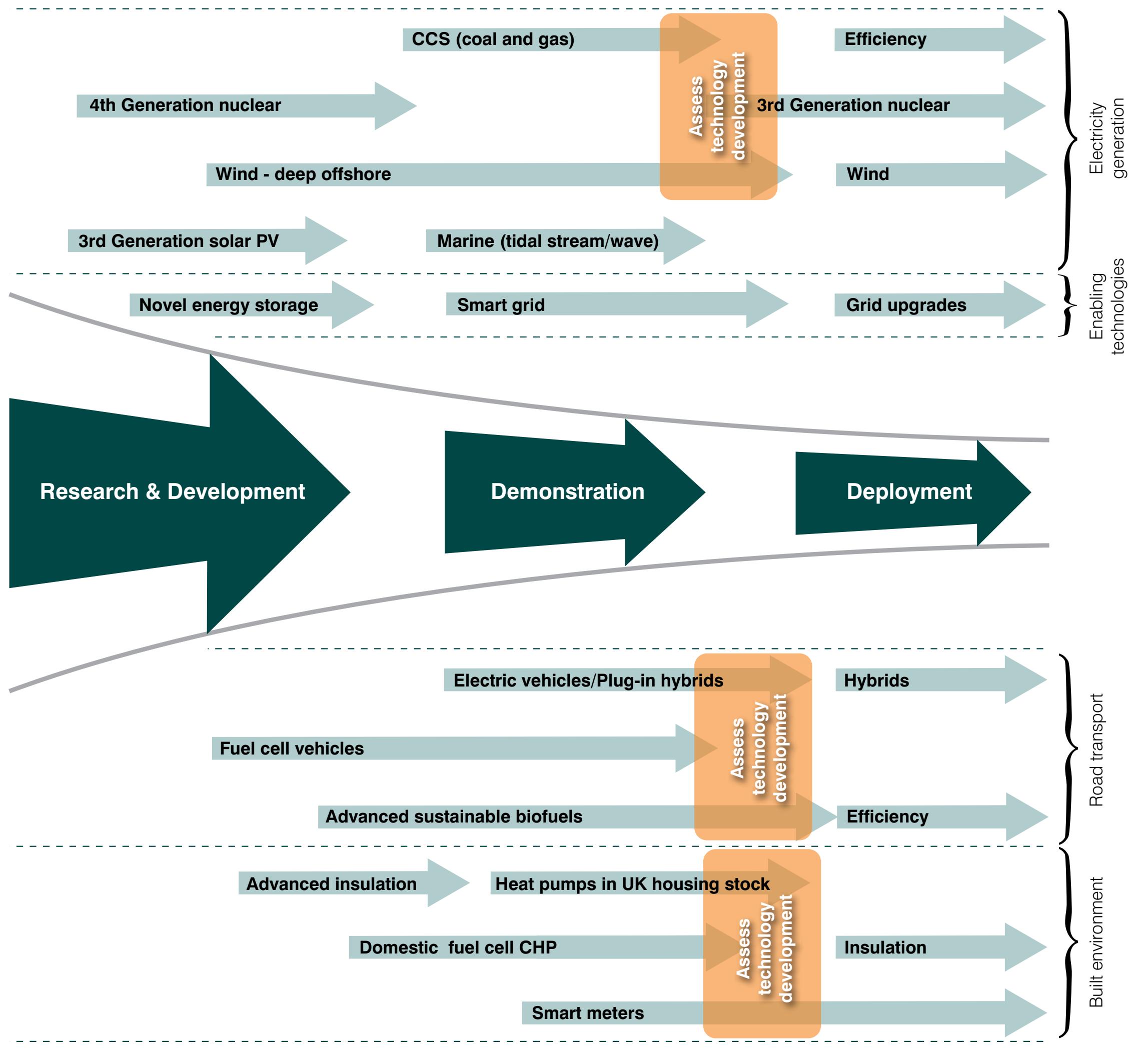


Figure 1. Pipeline of selected energy technologies showing progress required by 2020

Some potentially competing technologies (indicated by orange boxes on the chart) will have very different impacts on the energy system. Given the implications for building expensive new infrastructure and on power generation and management, assessments across these areas (particularly for electricity generation, domestic heating and road transport) will need to consider whether there is a case for more specific policy intervention. Although a simplification of the process, this 'pipeline' can offer an overview of some fundamental issues that may arise. When making choices in the next decade, considering the longer term is essential otherwise we risk locking both the energy system and society in an undesirable future.

Technologies will require either funding or policy interventions according to their current status:

Deploy
Most of the technologies that will form part of the energy system in 2020 are either available now or at the later stages of the innovation chain. ERP's remit does not extend to advising on mechanisms to ensure technologies are deployed. However, it is clear that their rapid deployment will be essential to meet emission reduction targets and allow new technologies to make a further impact.

Demonstrate
Our most important conclusion is that large scale, strategic, demonstration activities are needed over the next decade, which need to be commissioned now. This applies across the energy spectrum and includes electricity generation, transport and the built environment. In some cases, such programmes are already underway. However, the scale needs to be increased over the coming years so that decisions which may affect the long term future of the energy system can be taken with the best available information.

Research and develop
More basic research and development (R&D) is needed to develop technologies that will maintain the trajectory of decarbonisation beyond 2030 as well as R&D to support improvements in deployed technologies. A wide range of physical and biological sciences underpin applied energy technology and engineering disciplines and need to be maintained.

The focus of this work is on providing a deeper understanding of a set of new technologies which has the potential to deliver significant carbon reductions in the UK. We have not sought to cover all areas in which innovation will play a part in putting the UK on a low carbon pathway to 2050, nor provide the ideal mix of technologies for the future energy system. Clearly, improvements in efficiency of industrial processes and currently deployed technologies will have a beneficial impact and are vital components of a low carbon energy system. Such improvements are often taken into account by scenarios through 'learning curves' and are implicit in our analysis of an evolving sector. Other technologies exist which have already been deployed commercially in the UK, such as heat networks. They may have a role to play, but their further uptake will be subject to policies outside of ERP's remit.

The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment (RDD&D) in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed RDD&D investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other key stakeholders and decision makers as appropriate.

ERP is co-chaired by Professor David MacKay (Chief Scientific Advisor at the Department of Energy and Climate Change) and Nick Winser (Executive Director at National Grid). Members come from Government departments, funders of energy RD&D and the private sector. ERP is supported through members' contributions.

This report has been prepared and written by the ERP Analysis Team: Richard Heap, Jonathan Radcliffe and Charlotte Ramsay. More information on the work and role of ERP is available at **www.energyresearchpartnership.org.uk.**

Box 1: Review of scenarios

We undertook a review of over 20 scenarios from government, academia, industry and NGOs which described the UK's energy system. Our primary aim was to identify some of the main areas of commonality and of divergence in their outputs and to focus our work on the innovation requirements of technologies expected to have significant impact on the transition to a low carbon energy system. The main findings were:

Electricity generation mix

- There was consensus on the need for rapid decarbonisation of power generation. Subsequently, heat and transport were potentially decarbonised through electrification thus leading to an increase in demand for electricity. There was less agreement on the increase in the scale of demand which ranged from 50% to more than 100%.
- The main components of the mix came from centralised power generation using nuclear, wind and fossil fuel (mostly coal) with CCS but with variations in the proportions. The degree of dependence on other technologies (such as tidal, wave, waste, bioenergy, solar) was also varied.
- It was not clear how intermittency and load balancing was tackled; some scenarios using unabated fossil fuels with less emphasis on storage and active management of demand and the grid.
- There was consensus that intelligent system operation would be required but divergence on functionality of smart grid operation and how system flexibility and control would be achieved. Some cited a role for energy storage in provision of flexibility but were divergent on whether this would come from distributed (e.g. demand response, low grade heat storage etc.) or centralised (e.g. pumped hydro, compressed air storage etc.) resources.

Transport

- The scenarios agreed that efficiency gains in conventional and hybrid vehicles, with greater use of biofuels, would drive the bulk of emissions reductions in road transport up to 2020 / 2025.
- There was a diversity of fuels in scenarios post 2020 according to vehicle type but with a growing role for electric drive-train light duty vehicles between 2020 and 2050. Biofuels, fuel cell vehicles and battery powered vehicles could all have niches if not more widespread application.
- There was uncertainty in technology limitations (between batteries, fuel cells and producing sustainable biofuels); the role of bioenergy (including its availability and conflicting demands between modes of transport, other energy services and non-energy sectors); and delivery of infrastructure change.

Demand reduction, energy efficiency and heat

- With energy savings and improved efficiency crucial, there was consensus that final energy demand from end users must stabilise and, preferably, reduce.
- The provision of decarbonised heat is generally met through a shift to electrification between 2020 and 2050.
- However, there were some concerns about the responsiveness of technologies and the capacity of the power system to accommodate additional electricity demand (from heat and also from transport).

A workshop was held in September 2009 to validate this analysis and to bring together those involved in energy scenarios to discuss our preliminary findings. It also allowed us to identify a set of technologies which would require more detailed study; to understand their impact on the wider energy system and to present the options where there was uncertainty.

Technology innovation timelines

Further study was focused on technologies that are expected to deliver significant carbon emission reductions, and whose development would have wider implications for the energy system. We were guided by the conclusions of the scenarios meta-analysis and an appreciation of current thinking which emerged at the workshop. Areas where 'competing' technologies could have profoundly different impacts and where there may be a case for favouring one or another technology at some time in the future were of particular interest.

This analysis took into account output from the scenarios (see Box 1) as well as other technology-specific roadmaps and analyses. The main findings are presented in the figures below which illustrate the innovation timelines for selected energy technologies by sector. The orange boxes indicate where there are potentially competing technologies which, if developed further, could have differing impacts on the energy system. Given the implications for building new infrastructure and on power generation and management, assessments across these areas will need to consider whether there is a case for more specific policy intervention.

The orange arrows at the top and bottom highlight how the four energy technology areas interact. Feedback from one set of technologies may require interventions to promote one technology over another or to accelerate development of a group of technologies. For example, advances in electric vehicles could lead to greater uptake which could require grid enhancements and an increased demand for decarbonised electricity.

The main conclusions from the timelines were:

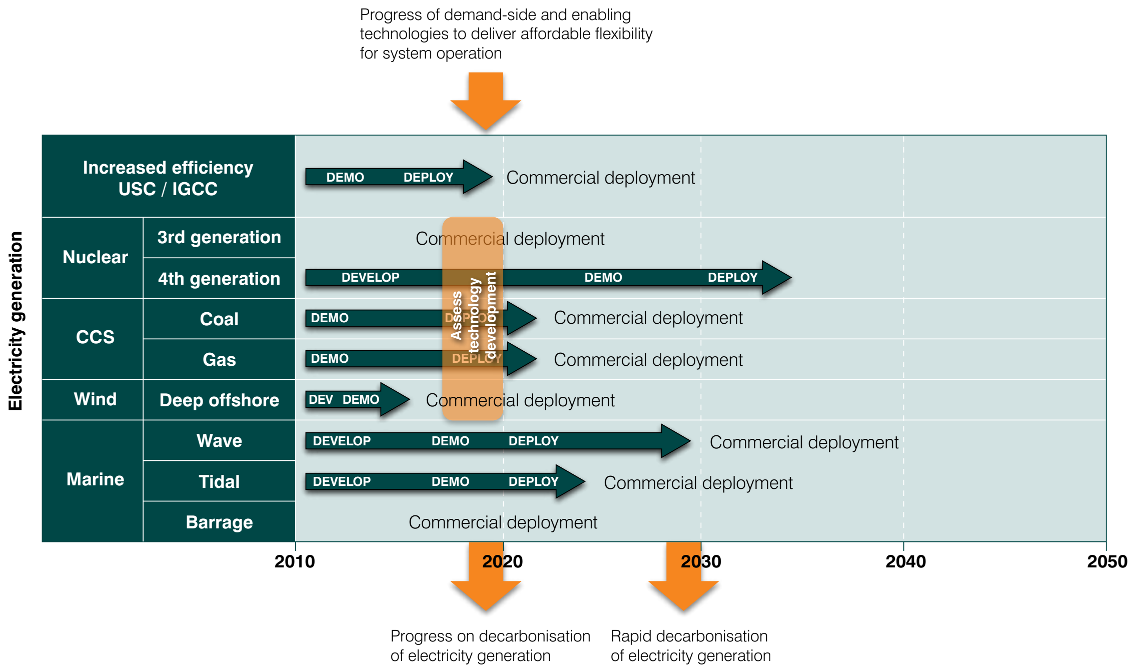
Electricity generation

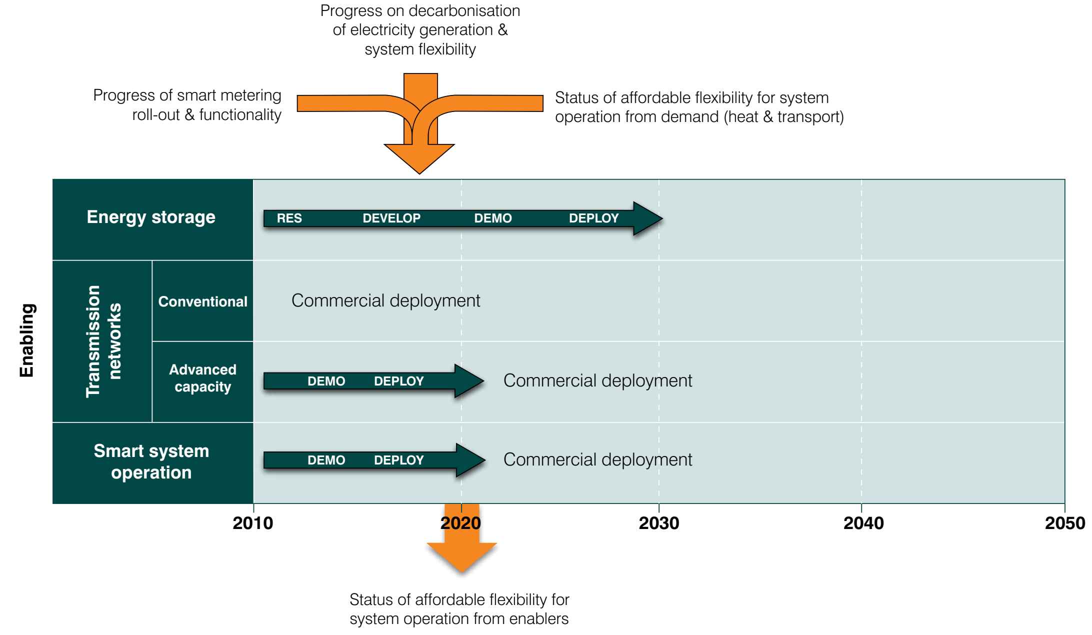
The early demonstration of carbon capture and storage technologies (CCS) on coal and gas fired power stations is critical in determining what generation technologies will be deployed for electricity generation out to 2050. Should CCS prove too expensive or unable to deliver on the scale required, both wind and nuclear power will have to be deployed on a much larger scale. However, both wind and nuclear face challenges that are not all technical and which might restrict the scale and rate of their deployment. This could lead to an increase in gas-fired power stations being built in the short term to meet the electricity demand, emphasising how gas CCS could be an important technology.

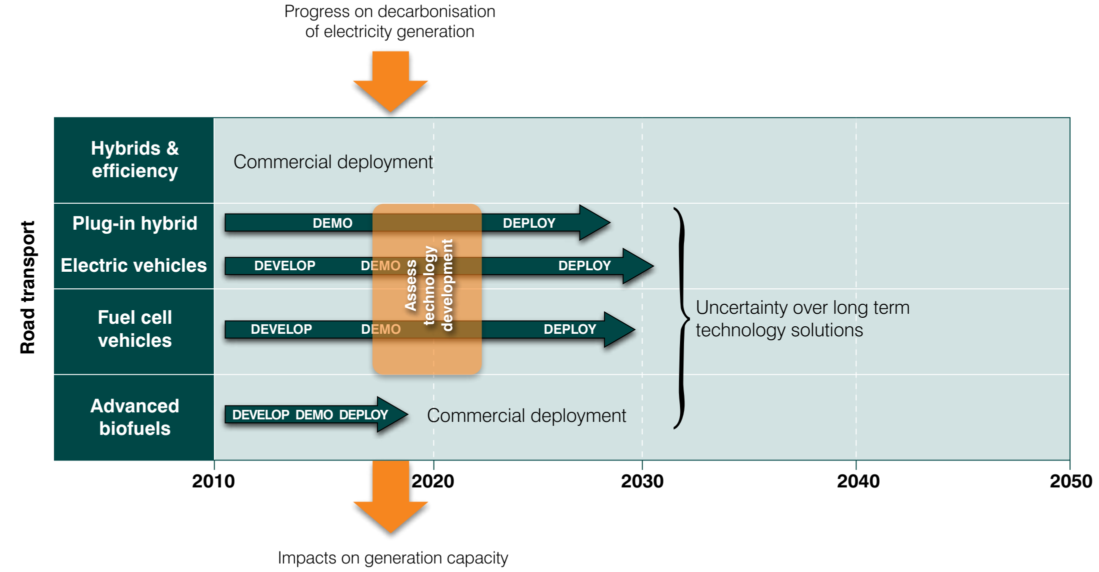
Once the real capability of CCS to reduce emissions is established, an assessment can be made about progress towards decarbonisation of electricity generation on which other parts of the energy system are dependent – in particular, heat and transport. By 2020, a clearer picture will be available of the scale of deployment of other technologies and what impact they will have on the development of the generation system, including grid reinforcement, demand reduction and decentralised generating technologies.

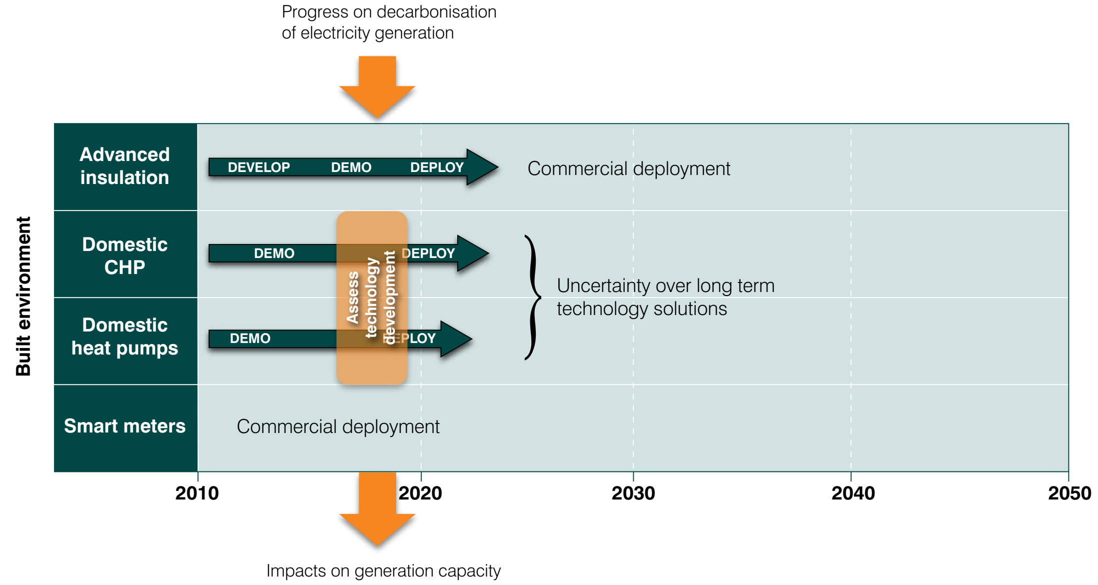
Enabling technologies

Enabling technologies have an important role in facilitating efficient integration of decarbonised power generation and various demand side resources. Development and









demonstration of the smart grid, in parallel with novel network technologies to increase network capacity, are essential foundations for the future system. Ongoing development of large scale energy storage technologies could also assist in provision of flexibility for power system operation.

Consumer behaviour and full participation in the smart grid operation is essential for success of this concept. Therefore, large scale demonstrations are needed in the short term to demonstrate not only technologies at scale but the way in which end-user behaviour will modify technology performance and smart grid functionality. Open architecture for all smart grid technology developments is important to avoid lock-in to a particular energy future and to provide flexibility in the face of uncertainty. Furthermore, developments in this area will be heavily influenced by the functionality of smart meters and the rate of nationwide roll-out of this technology together with an associated IT infrastructure.

Road transport

A range of technologies is likely to be used in the transition to 2050, but vehicles with electric drive trains appear to offer the most promising technology option providing electricity generation is decarbonised. An evolution from the current range of hybrids to full hybrids reaching the mass market, transition to plug-in hybrids and eventually electric vehicles can be expected during the 2020s. However, a failure to improve battery technology, offset by breakthroughs in low-carbon hydrogen production and storage, may make fuel-cells a viable low-carbon option. The role of biomass and biofuels in the energy system is very sensitive to competing demands from energy and other sectors and sustainable alternatives to current biofuels have yet to be fully demonstrated.

Given the uncertainties, a period over the first half of this decade should be used to assess technology development of electric (including plug-in) and fuel-cell vehicles. These pilot studies need to be of sufficient scale to demonstrate what outcomes could be achieved with wider uptake. With some projects already underway, there should be strategic coordination both nationally and internationally. This will also give time to further our understanding of the issues around the sustainability of biofuels.

Built environment

For heating technologies, heat pumps are favoured by scenarios and other analysis into how to meet the heat demand of domestic buildings. However, the performance of heat pumps in the UK's climate and housing stock, and by real consumers, has not been fully tested. Similarly, the performance of domestic Combined Heat and Power (dCHP) for single households has yet to be proven on a large scale, and new dCHP models are expected to be marketed widely in coming years. An assessment of 'real world' performance is required before wide ranging intervention policies on technology choices are taken. Over this time, a better understanding of future electricity and gas carbon intensity will be formed and will provide a better indication of the relative emission reduction potentials.

There is very little available data that characterises how users interact with the new technologies or on behavioural elements of technology uptake and usage. This means that there is a high degree of uncertainty around whether the demand side will participate in the energy system to the extent required. For example, the roll out of smart metering and intelligent control systems is an enabler of a number of different aspects of the 2050 energy system future. However, a common theme that emerges from scenario analysis of the use of smart meters is a high degree of uncertainty over how end users will use and respond to smart meters and therefore what contribution this technology will make to reducing energy demand. Although the technology itself is well developed, large scale demonstration of the technology in the whole house / whole system context is needed to gather data on actual usage of smart meters and smart appliances in the home.

To understand the extent to which the demand side can become the resource that many scenarios describe, further analysis and consideration is required supported by significant demonstration of these new technologies and concepts.

Implications for the energy system

It is clear from the timelines that the next decade is crucial for technology innovation, if we are to have the technologies needed to meet the 2050 targets. As highlighted above, there is a pipeline of technologies at various stages of development that need to be deployed, demonstrated and researched by 2020. However, from our analysis of the innovation required across whole energy system, a number of issues are raised which need to be considered when making decisions based on the timelines for the technologies.

Investment in innovation

The costs of innovation (from public and private sectors) escalate as technologies move towards commercial deployment. To establish which technologies will be viable and most cost effective over the longer term, costly demonstration activities will be required. In the case of CCS, this nettle is being grasped. But for demand side technologies, such as in transport and for retrofitting buildings, the investment will equally be required for large-scale demonstration projects.

Costs

The cost of a technology is a key determinant of its deployment. Cost can be influenced by a range of factors, of which innovation has a major role. Deployment may also be accelerated by policy intervention including through target setting, fiscal incentives and carbon pricing. While not reducing costs of a technology directly, these interventions create market opportunities by reducing the risks, and therefore the cost, of investment. The effectiveness of the policy signals is dependent on them being appropriately long term so as to provide certainty of returns on investments, particularly where they are in early stage R&D.

Understanding the barriers to market and introducing the appropriate incentives could accelerate technology deployment and development. However, while stimulating the market towards particular technologies may be useful in delivering particular energy options, these interventions need to be set in the context of the wider energy system. For many options a significant cost could be the development of new infrastructure (for hydrogen fuel cell vehicles or CO_2 transportation) or strengthening of existing infrastructure (to deliver more electricity to households for heating).

The new 'decarbonised electricity' orthodoxy

Breakthroughs in particular technologies or the stimulation of a particular market can lead to the creation of orthodoxies on which the future energy system will be based. If this report had been prepared 10 years ago, the focus may have been more on the role of hydrogen as a low carbon storage vector with little on CCS as an enabler of low carbon fossil generation. Four years ago, bioenergy was seen as playing a significant role, particularly in the provision of biofuels for transport. Now, most of the scenarios studied for this analysis conclude that decarbonisation of our electricity supply is the key to providing a low-carbon energy system in 2050 with much of transport (and heating) energy demand being met by a decarbonised electricity supply.

Understanding the rise and fall of these technology trends is important in our evaluation of the current thinking around the energy system of 2050. Ultimately, analysis of any projected future system requires a planned, coordinated approach. One that understands and responds to the challenges of decarbonisation using the array of technologies already available, is flexible enough to include breakthrough technologies and maintains a whole system perspective that characterises the implications (positive and negative) of technologies in context.

Taking early action

Taking early action to reduce CO_2 emissions, either by 'leap-frogging' directly to zero carbon technologies or implementing shorter term stringent targets, could have implications for innovation. Some analysis argues for the immediate implementation of zero carbon technologies rather than investment of effort and resources into incremental energy efficiency changes to existing technologies. This could have the dual effect of decarbonising the system faster and ensuring that total emissions are minimised.

However, this is countered with the argument that efficiency gains are often 'low-hanging fruit' in the form of quick and cheap changes that could have immediate effect and get us on the right trajectory to 2050. The alternative of 'leap-frogging' to novel zero carbon technologies could take time to implement, ultimately be far more costly and require greater levels of investment in immature, unproven technologies.

Bioenergy

Biomass for heating, electricity generation and transport fuel has issues that are well known with global demand and supply uncertain and the true carbon costs sometimes hidden. Aside from competition between energy sectors, there may be wider environmental concerns, even from non-food crop biofuels. As yet, however, there is no consensus on the best course of action and addressing these concerns must be a priority.

Life cycle impacts of energy technologies

The choice of energy technology has wider implications than just its greenhouse gas emissions and includes availability of land and mineral resources and impact on water resources. Some of the impacts will be in the UK; others will be global. The need to understand these impacts was highlighted by the recent debate over land use and food crops for biofuels.

Next steps

Technology development
Action is needed to put in place the policies and investment to ensure that the innovation needs highlighted in the technology pipeline diagram above are delivered. An ongoing role for ERP will be to keep track of progress against the innovation milestones set out in this report.

How the UK chooses to deliver this and encourage domestic innovation is particularly salient. One country cannot expect to lead development across the board. According to our domestic strengths and requirements there must be some prioritisation of technologies. Firstly, to decide which technologies to take a lead on developing in the UK; secondly, which to collaborate in the development of (and with whom) and, thirdly, those which we should take an active interest in so that we are ready for deployment but do not necessarily have the expertise to play a role in developing.

ERP's ongoing work on International Engagement will help the UK take a more strategic approach both to prioritisation, and to taking advantage of collaborative energy innovation activities.

Supporting analysis
This study describes the innovation challenges at a high level in order to provide guidance for policy makers and funders/investors. That the analysis comes from a broad spectrum of stakeholders should give confidence that the conclusions have support from across the sector. But further analysis is required to address the issues that we have highlighted and to review our progress towards achieving the 2050 goals. We therefore propose some next steps:

- ERP's future work will look at many of these technology areas in more detail to consider whether there are any funding gaps, and the potential role for the UK in driving forward RD&D.
- Further modelling and scenario work is essential. A diversity of approaches will improve our understanding of how the energy system could develop. The Energy Technologies Institute's new Energy Systems Model will bring a fresh perspective, including the ability to balance energy security and cost considerations. Also, the development of the global TIMES model as a successor to MARKAL will study the UK's position with respect to worldwide resource flows and global technology innovation.
- Energy system modellers would benefit from continued interaction to exchange information, outputs and ideas. The academic community, with input from ERP, has been organising workshops and events to bring researchers together, and to feed messages in to policy makers.
- The development of detailed technology requirements, or specific activities to assist them, such as from the Carbon Trust's 'deep dives', should be undertaken as a matter of urgency.
- Communicating messages effectively from scenarios to those who will use the information is critical. ERP will have a role to look periodically across scenarios and new analyses to assess whether any of our conclusions need revising.

The whole energy community has a responsibility to take forward these conclusions. ERP is well placed to coordinate these activities and ensure that decisions affecting energy innovation are informed by the best available information.

This report has been prepared by the ERP Analysis Team, with the support of the ERP membership. The views are not the official point of view of any organisation or individual and do not constitute government policy.

The full report with supporting analysis is available from ERP. Details of how to obtain a copy are available on our website www.energyresearchpartnership.org.uk.

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