Accelerating low carbon energy innovation in the UK

A conceptual model of the UK low carbon energy innovation system

Contents

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Key headlines

» The UK needs innovation to meet its carbon targets and for this process to be effective and rapid – with several critical components: market confidence, finance, public policy and the capability to innovate

» Collaboration and shared understanding is required – involving interactions across science, business and government to facilitate knowledge transfer and learning – it is easier to achieve a transition with a shared understanding of the drivers of new low carbon energy technologies

» The slower the pace of energy innovation, the less time the UK will have to transition to a low carbon economy and the more expensive it will be to do so

» Successful innovation systems often involve open and iterative processes, which are complex. They depend on multiple interactions between different actors

» Policy interventions are required to drive innovation in energy and low carbon – business needs certainty so policy stability matters

» Industry and government should work together to set strategic priorities – low carbon markets are almost entirely driven by public policy but delivered by private sector firms

» Successful innovation in low carbon energy requires new technology capabilities, new markets, new business models together with appropriate changes to the regulatory framework

The low carbon innovation challenge

Meeting the challenge of delivering safe, secure and affordable energy combined with substantial reductions in emissions of greenhouse gases will require significant innovation in new, low carbon technologies over the coming decades. Innovation will be required in the way our energy is generated and delivered and the way in which it is used in our homes, transport systems, industries and places of work.

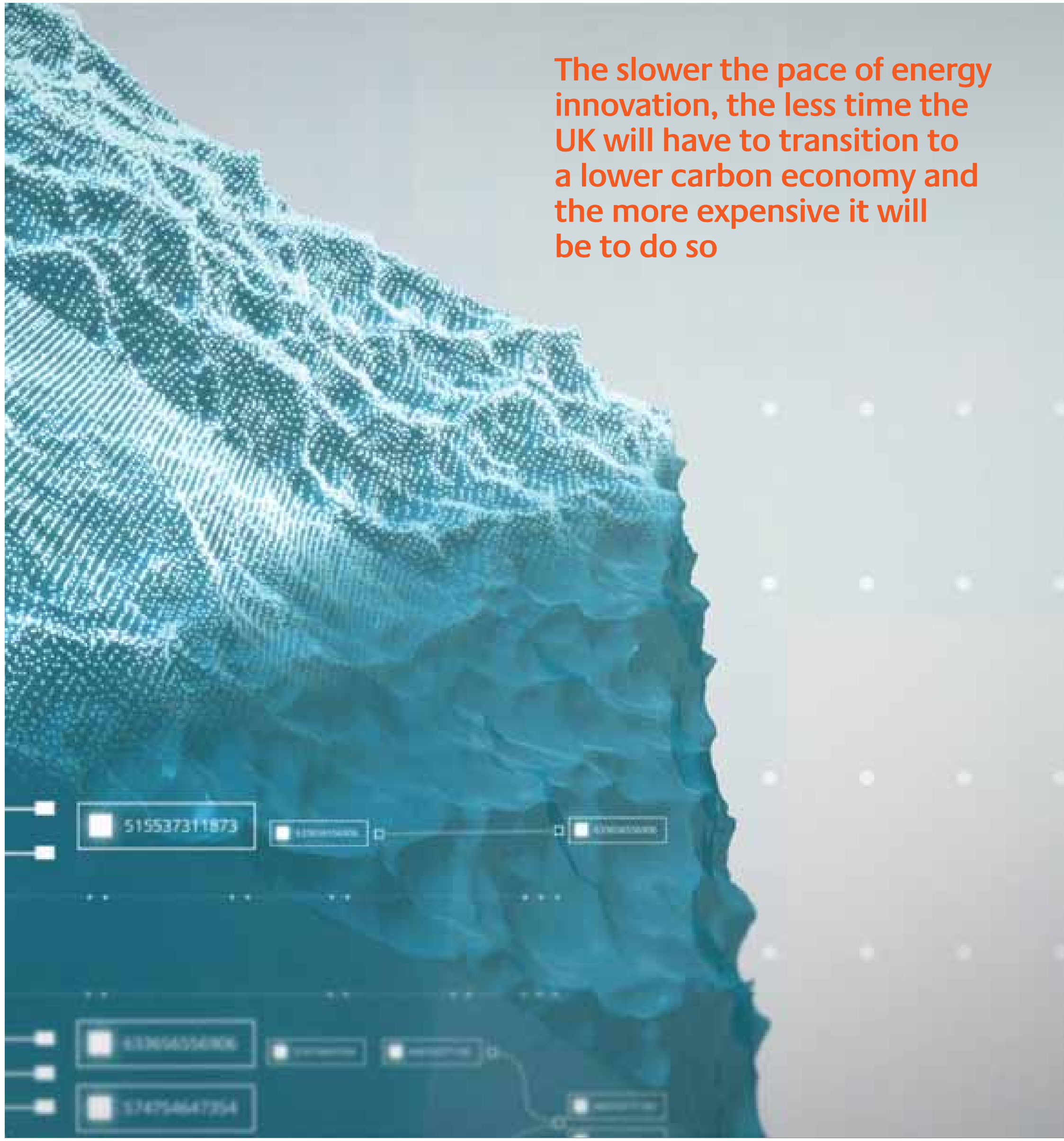
If we are to meet or even be close to our 2050 carbon targets at an affordable cost[1] we need attractive, commercially viable low carbon energy technologies to be available soon. Maximising the pace of innovation and its implementation in low carbon is hugely important to this.

Scenario analysis undertaken by the ETI[2] has shown that the slower the pace of energy innovation, the less time the UK will have to transition to a lower carbon economy and the more expensive it will be to do so. We have no more than 10 years to prepare for many key decisions. These include issues such as choice of power generation technology. Once built, these will be with us for 40-50 years. This means we have to understand the innovation process and make sure that all parts of the process work as quickly and effectively as possible. We need this to ensure all of the necessary conditions are in place for implementation to happen so that the UK can transition as cheaply as possible to a lower carbon economy.

It will be easier to achieve the transition to a lower carbon energy system, at the scale and pace required if there is a shared understanding of the drivers of new low carbon energy technologies, the barriers that can impede their development and the key interactions required to unlock opportunities in the UK. Better understanding of the specific needs of others and better communication between different players in the innovation process will help to remove unnecessary delays by ensuring all of the necessary pre-conditions for progress can be met.

[1] Coleman and Haslett. Targets, technologies, infrastructure and investments – preparing the UK for the energy transition. ETI, 2015.

[2] Milne. Options, Choices, Actions – UK scenarios for a low carbon energy system. ETI, 2015.



Specifics of low carbon innovation

Innovation delivers new products to market much quicker in some sectors than others. The low carbon energy sector faces particular challenges.

- The significant global externality of climate change makes it extremely difficult to create large-scale markets for low carbon technologies. Markets in carbon emissions are missing and the carbon price is volatile and a poor basis for decision-making.
- The risk of lock-in to sub-optimal technologies is high. The energy system is dependent on past investments in infrastructure that create inertia and make it difficult for alternative 'disruptive' technologies to succeed. Incumbents have a vested interest in maintaining the status quo.
- Some innovations will, in addition, require significant changes in business models and/or consumer behaviour.
- Lead times to development and deployment are unusually long and there is considerable risk and uncertainty, more so than for other areas of innovation, making it hard to attract the required level of private finance.
- Instability in environmental policymaking can add to the uncertainty as policies tend to vary with the electoral cycle and with changes in the national and world economy.
- Coordination failures: there are multiple funding bodies, research centres, government departments, agencies and commercial players ranging across many sectors of the economy, whose interests may not align.

We cannot remove all of the challenges, but a crucial one which can be addressed is the flow of information which links together the different aspects of the innovation process. This is important to minimising the risk of delay and dead ends.

Low carbon markets are almost entirely driven by public policy but delivered by private sector firms

There are numerous different parties involved in innovation, each providing a critical element of the total package needed to deliver a successful product to market. Better communication means alignment between them develops more quickly, if it is going to happen. More activities can be undertaken in parallel rather than sequentially. Tasks can be undertaken once, because the needs of all parties are designed in from the start, rather than having to be repeated to provide information critical to a party that wasn't considered at that stage. While better communication has a cost, primarily time, it should save resources in the long run and speed up the overall innovation process.

Successful innovation in low carbon energy requires new technology capabilities, new markets, new business models together with appropriate changes to the regulatory framework

The Paper

To assist in making the case for better communication, this paper outlines a high-level model of the UK low carbon energy innovation system. It aims to provide an accessible and consistent framework for engaging in dialogue on these issues, building a common understanding among stakeholders including industry, finance and government. It describes the key stages in the innovation process; the barriers, drivers and other factors required for successful deployment of new low carbon solutions commercially and at scale; and to help identify accelerated pathways for innovation.

The structure of the model (created for the ETI by Warwick Economics and Brian Titley Consulting Ltd) is necessarily stylised and generic. However, its application to the UK energy system and/or to low carbon technologies can reveal distinctive features of the low carbon energy innovation challenge and the specific issues that need to be addressed.

These issues include the need for radical innovation, requiring significant investment in both R&D and infrastructure; extended lead times; and the risks of locking-in to sub-optimal technological pathways. These problems are compounded by perceptions of a lack of stability in the policy environment and market signals which are often volatile or unclear. There are also questions of public and consumer acceptance of the new technologies. As a result of all these factors, new promising technologies will often appear economically inferior to incumbents for long periods.

Ultimately, ETI wishes to use the model to illustrate the key interactions between stakeholders involved in low carbon energy innovation. It then intends to use the understanding gained to accelerate the diffusion, deployment and commercialisation of the low carbon energy system options that it has helped to develop.

It is easier to achieve a transition with a shared understanding of the drivers of new low carbon energy technologies

Main findings from a review of the innovation literature

It is now widely accepted in the innovation literature that successful innovation systems involve open and iterative processes from which both incremental innovations and large-scale “disruptive” technologies can emerge. These processes are often complex and non-linear, seldom involving a straightforward progression from basic research through to deployment. The conclusions drawn from an extensive literature on non-linear models of innovation are:

- Successful innovation requires multiple interactions between different actors (individuals and organisations), to facilitate knowledge transfer and learning across science and industry.
- Collaboration is particularly important as few organisations will have sufficient internal resources – whether technical skills, financial or other – to develop and take an innovation from concept through to full commercialisation without external help.
- There is a key role for trial and error, whereby emerging technologies are assessed, rejected or refined and may be diffused at any stage. The process adds to the stock of knowledge, which in turn drives further innovation activity.
- It takes time for innovation systems, networks, relationships and expectations to form and mature and therefore for new technologies to be developed and deployed, especially more radical disruptive technologies.

Successful innovation systems often involve open and iterative processes, which are complex

Nevertheless, earlier linear or sequential models of innovation can be useful as a means:

- To analyse the key drivers of innovation, whether science-led (technology push) or demand-led (market pull);
- To chart and monitor the progression or life-cycle of a new technology from initial concept through to full commercialisation and market maturity;
- To identify gaps or barriers that can impede the movement of emerging technologies along the innovation chain and prevent their successful commercialisation; and
- To assist the design of policy to plug these gaps, for example, through financial support, knowledge sharing and the creation of appropriate market signals.

Key features of the model

The core elements from the existing literature have been captured and synthesised to build an initial conceptual model of the energy and low carbon innovation system in the UK. This is represented in Figure 1 and described in Table 1. The model borrows heavily from representations of low carbon innovation systems developed by Grubb[3] and the OECD[4] and the more generic framework of Crafts and Hughes[5] among others.

The model contains the following key elements which are explained in more detail on pages 12-13:

(A) The timescale over which an innovation system develops and different technologies emerge and mature;

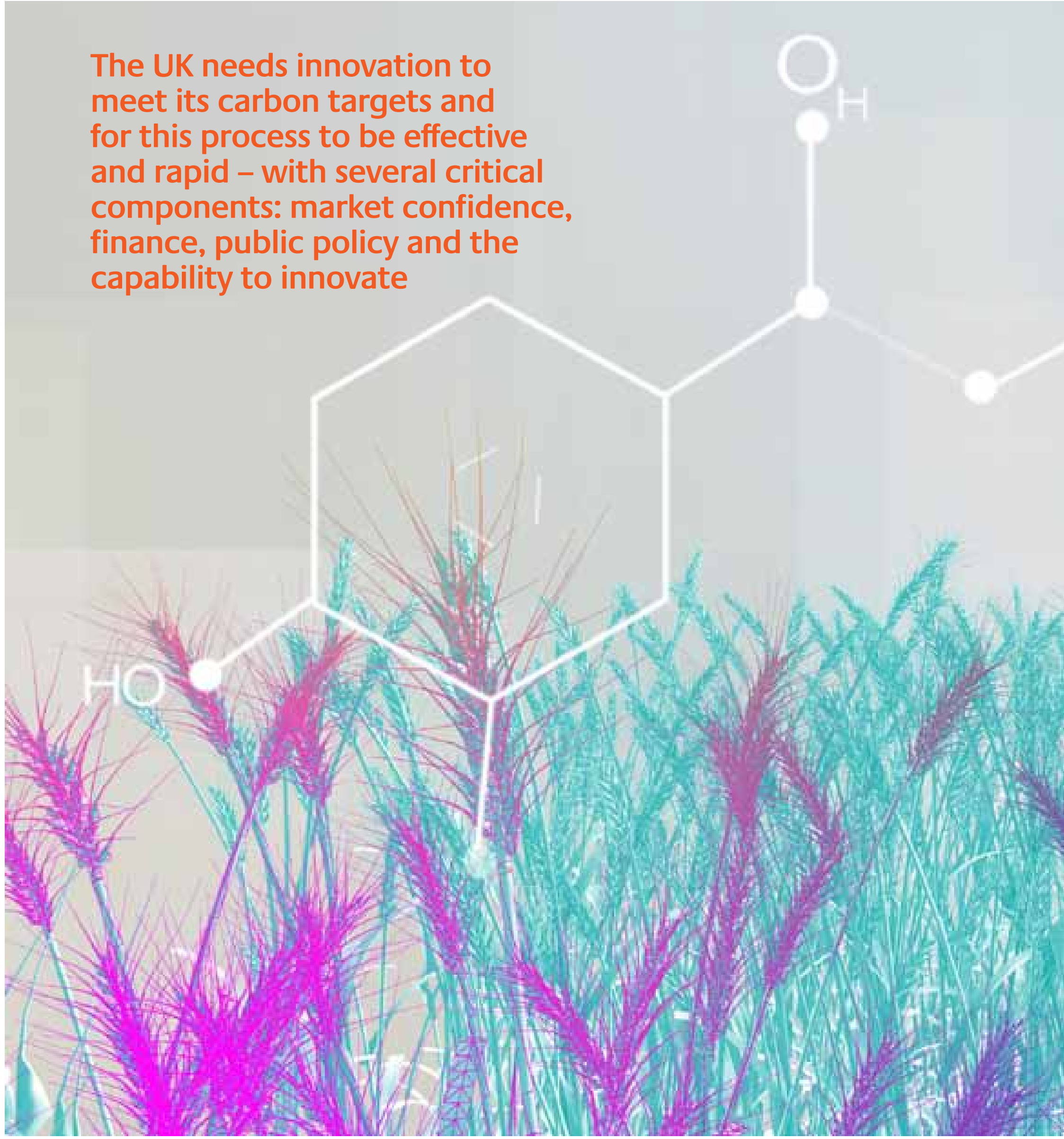
(B) An illustrative innovation chain consisting of the key stages through which a technology will typically need to progress to reach full commercialisation;

(C) The combined forces of technology-push and market-pull that drive forward innovations to develop and demonstrate safe and cost-effective low carbon technologies;

(D) An open, collaborative and iterative innovation process in which firms exchange and refine ideas and pursue multiple pathways to advance their technologies;

(E) A sustainable innovation process with critical components involving routes to market, sources of finance, a supportive policy environment and widespread innovation capabilities within UK firms and the innovation system more generally.

Many of these features would need to be present for an innovation system to work effectively for any sector or technology. However, innovation in new energy and low carbon technologies is particularly challenging compared to other sectors because of specific characteristics of the market outlined earlier.



The UK needs innovation to meet its carbon targets and for this process to be effective and rapid – with several critical components: market confidence, finance, public policy and the capability to innovate

[3] Grubb. Technology Innovation and Climate Change policy: an Overview of Issues and Options. Keio Economic studies, 2004.

[4] OECD. Fostering Innovation for Green Growth: Policy Considerations. OECD, 2011.

[5] Crafts & Hughes. Industrial Policy for the Medium to Long-term. Future of Manufacturing Evidence Paper 37, Foresight, GO Science, 2013.

Key features of the model

Continued »

FIGURE 1:

A conceptual model of the UK energy/low carbon innovation system (high-level schematic)

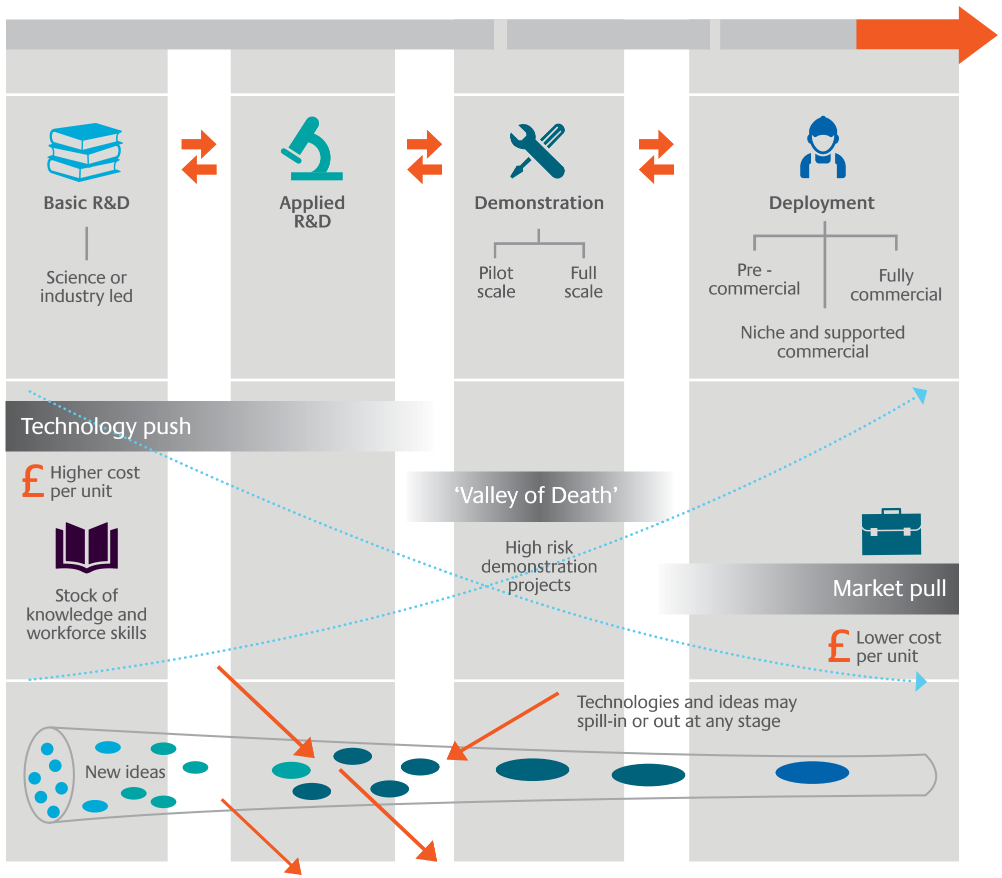
For more info please refer to Table 1, pages 18/19

(A) Timescale / innovation life cycle

(B) Innovation chain with multiple feedback mechanisms

(C) Key drivers

(D) An open, iterative innovation process to identify, develop, assess, select and refine the most promising technologies



(E) Critical components and challenges

Market confidence and expansion
- Missing markets in carbon etc
- Technological lock-in
- Novel low carbon technologies
- Multiple risk factors
- Need for demonstrators
- Consumer acceptance

Sources of finance
- Climate change externalities
- Path dependency in energy
- Coordination problems
- Unusually high risk uncertainty
- Long time horizons
- Leverage vs crowding out

Public Policy
- Holistic systems approach
- Overcoming technological roadblocks
- Modern industrial policy
- Promoting entrepreneurship
- Demand-side policies

Innovation Capability
- Vulnerability to swings in climate change policy
- Handling disruptive innovation
- New business models
- Skills gaps in low carbon
- Commercial skills

Key features of the model

Continued »

While the diagram in Figure 1 does not fully represent the complexity of the underlying conceptual model, it is intended to provide an accessible stakeholder engagement tool:

- To identify and build stakeholder networks around individual technologies or programmes to facilitate interaction, joint learning and the exchange and exploitation of accumulated knowledge;
- To develop a "strategic narrative" to help those involved to better define and understand their role in the low carbon innovation system and the transition to a low carbon economy;
- To use as a basis for developing "case studies" illustrating the innovation story to date or the innovation challenge ahead, in specific areas of low carbon technology.

The model provides a consistent but flexible framework that can be adapted for different technologies and innovation pathways or "journeys."[6] These can be from the perspective of the innovator, investor, policy maker or end user, etc. to show the different barriers or issues they will face and the interactions that must take place at the different stages of the innovation chain. These "journeys" are explored in more detail in Tables 2-6 on pages 20-31 below.

The model can be used as an evaluation tool, to build accessible and compelling innovation case studies or "stories", aimed at promoting further interactions amongst stakeholders or inspiring innovation in related areas. Alternatively, it can be used in appraisal mode, as a tool aimed to identify and help address specific innovation challenges. However it is used, there are likely to be significant differences according to the scale and complexity of the chosen technologies, the time required to progress them through each phase in their development and the number of different stakeholders, skills and capabilities required at each stage.

The model has been tested through interviews and at a workshop with a number of stakeholders drawn from industry, the research base and government. Together they helped to refine the initial model, prioritise key challenges and develop a number of specific technology case studies. Key issues from the case studies are summarised in Figure 2 on page 16.

The case studies (see Figure 2) serve to highlight that successful innovation in new energy and low carbon technologies requires the creation of new markets, the development of viable businesses and appropriate changes to the regulatory framework. In addition to technical progress, therefore, innovation requires new business models to support commercialisation, the removal of market barriers, new workforce and industrial capabilities and strong links to the development of government policy.

[6] Carbon Trust. Low Carbon Technologies in a Green Economy - Energy and Climate Change. Memorandum submitted to Energy and Climate Change Commons Select Committee, 2009.

Key features of the model

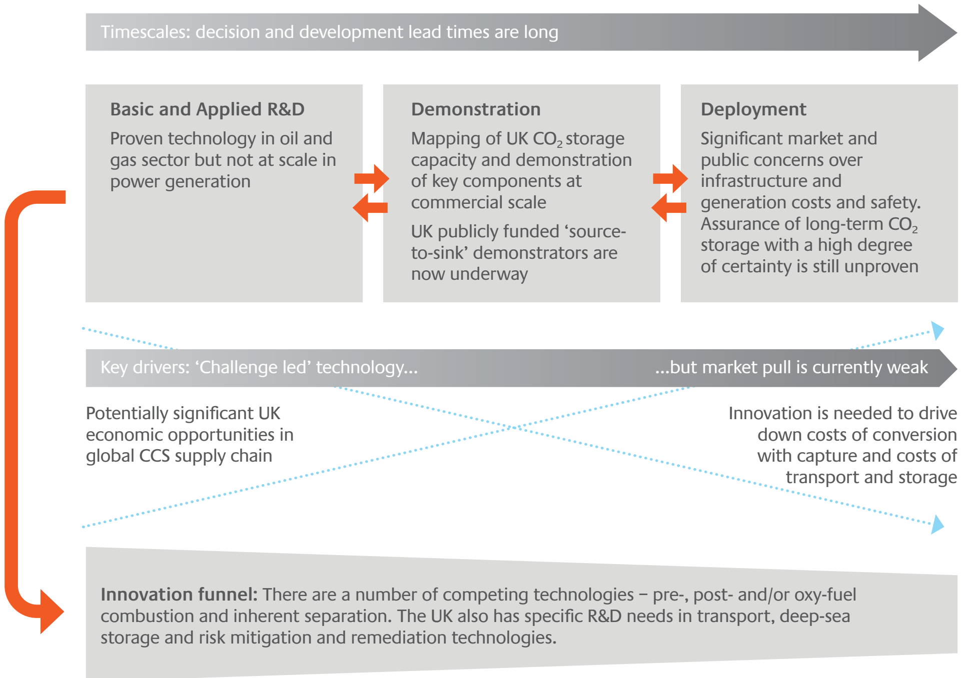
Continued »

FIGURE 2 :

Workshop case study summaries

1. Carbon Capture and Storage (CCS)

CCS offers the potential for near-zero greenhouse gas emissions from continued fossil fuel combustion. However, the UK innovation system for CCS is relativity immature. Investment costs are high and market appetite is low.



Critical components:

Government policy seen as critical to continued innovation in CCS, to the development of market and public confidence and the leverage of private finance.

2. Hydrogen fuel cell Micro CHP (Combined Heat and Power)

Key issues:

- Fuel cells are a proven technology and micro-CHP has become more cost effective due to rising energy costs but cannot sell at volume at present;
- Pilot scale demonstrations required – local community solutions, business parks, etc.;
- New business models are required to build scale and consumer / market confidence, and to reduce installation costs for domestic consumers, e.g. through "power by the hour" type contracts;
- Hydrogen in the energy system can supply up to 15% of energy supply without need to change grid infrastructure - but higher content in the mix will require new gas pipework, burners and turbines;
- Critical issues: what type of network will the UK need / want in 10 – 30 years? How to manage costs of transition?

3. Low carbon domestic heat

Key issues:

- Housing stock has poor thermal performance - c20% of UK carbon emissions generated by domestic heating;
- Elimination of emissions from buildings potentially more cost effective than deeper cuts in energy intensity of other sectors;
- Innovations in heat pumps, heat networks and heat storage could reduce UK energy system costs and create new business opportunities;
- Clear need for demonstrators at community, regional and national level;
- Community solutions, e.g. shared heat network installations can play important role;
- Need for behaviour change: compelling consumer propositions and business models are needed;
- Installation issues: scale, availability of skills, technology integration;
- Socio-economic factors important: affordability, patterns of home ownership, etc.

Model of UK energy/low carbon innovation system

TABLE 1:

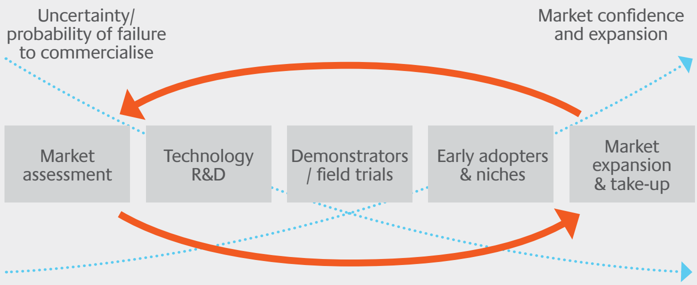
Model of UK energy/low carbon innovation system (underpinning conceptual framework)

Key element	Description
(A) Timescale / innovation life cycle	» It takes time for an innovation system, networks, relationships and expectations to form and mature and therefore for new technologies to be developed and deployed, especially more radical disruptive technologies. » Weak or immature innovation systems may delay the progress of an innovation, or decrease the likelihood of its success. » Risk of lock-in to sub-optimal technological pathways can lengthen timescales. » Aspects of all of these issues can be seen with low carbon energy innovation.
(B) Innovation chain with multiple feedback mechanisms	» While a new technology can be observed to pass through distinct stages in its evolution – from concept (basic research) to commercialisation (deployment) – the process of innovation is seldom linear. It will involve both forward and backward multi-disciplinary interactions across science, business/commerce and government to facilitate knowledge transfer and learning. Innovation may therefore occur at any stage in the process and need not involve all stages. » Innovation may result in competing technologies and networks. Each network will try to make the case and build political legitimacy for its particular technology. This in turn can create or increase entry barriers for alternative technologies.
(C) Key drivers	» Innovations may be idea-led and/or demand-led. The forces of technology push and market pull combine to provide continuous challenge to the innovation system to develop and demonstrate safe and cost-effective low carbon technologies (in terms of levelised cost per unit of energy produced and/or product unit cost). The strength of market-pull is critically dependent on the price of carbon and the stance of environmental policy. » Promising low carbon energy solutions may fail to attract sufficient risk capital and other resources necessary to support full-scale demonstration and cost reduction to make it across a “valley of death” between applied research and commercial deployment due to significant market uncertainty.
(C) Key drivers - continued	» Successful innovation requires collaboration and networking between different actors. This is particularly true with low carbon energy, where very few organisations in isolation will have access to the knowledge, skills, finance and other resources to develop and move from initial concept to commercialisation. Coordination may however be difficult, nationally and internationally. » The stock of knowledge and workforce skills is increased through innovative activity and interactions. Knowledge can be fed back into the innovation process at any stage to stimulate further discovery and innovation.
(D) Open, iterative innovation process	» Innovation involves ‘trial and error’. Emerging solutions are continually assessed, refined or rejected and may be diffused at any stage in the process. Failures nevertheless create useful knowledge able to stimulate further innovation. » Firms will import useful technologies as well as developing their own ideas throughout the innovation process, and will use different pathways to market, both internal and external, in an attempt to advance their technologies.
(E) Critical components and challenges	» The development and deployment of new, low carbon energy products critically requires access to markets and sources of finance, a supportive public policy environment and widespread innovation capabilities. Socio-economic barriers can prevent these. » The probability of failure along the innovation chain and the cost of activities at different stages are fundamental risk factors for developing commercial products. Policy risk is also significant in the low carbon energy sector. » The innovation process must de-risk propositions over time to build investor, industry and user confidence. Equally, governments need to use their available policy levers at different stages in the innovation process to manage industry and public expectations and the transition to a new low carbon energy system.

Market confidence and expansion

TABLE 2:

Market confidence and expansion

Critical component	Market confidence and expansion
Innovation chain “Market journey”	
Key stakeholders	» Public sector funders (see sources of finance), who have a key role in providing finance in early stages when uncertainty is high, and returns less appropriable. » Potential private sector investors (see sources of finance) who have a key role in investment appraisal and whose engagement is crucial to securing sustainable expansion. » Policymakers (see public policy) and regulators whose decisions can shape the development of the market or in some cases create a new market and can themselves be a source of instability. » Incumbents who have a vested interest in resisting new technology, particularly disruptive technology. » Manufacturers, energy companies and service providers who need to provide facilities, establish supply chains and become engaged in the commercialisation process. » Final consumers and other users, whose needs should be understood and met and whose acceptance of new products and technology is a prerequisite for successful commercialisation. » Opinion formers (politicians, scientists, media and others) who can provide thought leadership and influence public attitudes towards the acceptance and adoption of new technology.

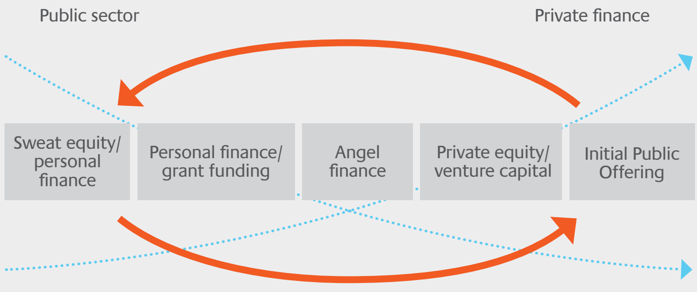
Critical component	Market confidence and expansion
Key challenges	“Overall, maturity or deployment of a given technology appear to be the dominant intrinsic factor that define the overall risk perception for that technology. Furthermore, all low-carbon technologies are exposed to policy risk, to such an extent that several survey participants responded to the effect that they were unable to rank risk factors due to the uncertainty surrounding future energy policy.”[7] » Missing markets for new low carbon energy products and uncertainty over the future price of carbon. » Technological lock-in: the challenge of breaking away from existing energy models and building critical mass for disruptive technologies, while avoiding lock-in to sub-optimal pathways. » Novel low carbon technologies without a track record need successful pilot testing at scale. » Multiple risk factors include price levels and volatility (wholesale electricity; carbon); energy demand; government policy; value of subsidies; public acceptance/perceptions; capex and opex; construction lead times; availability of technical skills; maturity of technologies; etc. » Need for demonstrators: bridging the valley of death before market/investor confidence established. » Need to win public and consumer acceptance of novel low carbon solutions.

[7] OXERA. Discount rates for low carbon and renewable generation technologies. Paper prepared for the Climate Change Committee, 2014.

Sources of finance

TABLE 3:

Sources of finance

<table>
<tr><th>Critical component</th><th colspan="2">Sources of finance</th></tr>
<tr><td>Innovation chain
“Finance journey”</td><td colspan="2">

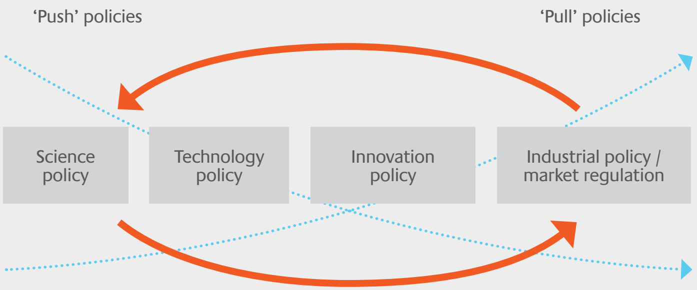
Financial/company journeys may differ, often depending on the type of technology. The journey shown is stylised to illustrate potential sources of finance available.</td></tr>
<tr><td>Key stakeholders</td><td>Public sector sources:
» Research Councils
» Innovate UK & Catapults
» The Carbon Trust
» DECC and other Central and Local Government Direct Support
» Office for Renewable Energy Development (ORED)
» Tax credits (R&D, Patent Box)
» Ofgem (Network Innovation Allowance and Competition)
» Green Investment Bank
» Public procurement programmes
» EC Framework Research & Technology
» EU-Emissions Trading Scheme</td><td>Private sector sources/ representatives:
» Energy and Clean-Tech Venture Capital organisations (e.g. Low Carbon Accelerator, Oxford Capital Partners, Environmental Tech Fund, Good Energies)
» UK Business Angel Association
» British Private Equity and Venture Capital Association (BVCA)
» Major Corporates (as R&D investors)
» Major Corporates (as tech users)
» Low Carbon Innovation Fund
» ‘Brokers’, for example, Green Industry Business Network, Greenbackers</td></tr>
<tr><td>Key challenges</td><td colspan="2">“The iterative evolutionary process from research to economic impacts and the open innovation funnel will typically involve multiple investments beyond the original public and private sector research investments. The transition from early stage activities funded by the public sector to final commercialisation will, in particular, require private sector investments which are usually many multiples of the original science base investment.”[8]
» Climate change externalities: make it more difficult for firms to fully appropriate the returns from their investments, which typically results in under-investment in innovation.
» Path dependency in energy systems and long lead times of many energy/ low carbon technologies create significant uncertainty: investors cannot quantify the likelihood of successful investment. Coordination problems and network failures are also pervasive.
» Unusually high risk and uncertainty: Financial risk in part reflects lack of experience and lack of understanding of specific risk return characteristics of low carbon investments. Funding is also particularly challenging for technologies transitioning from R&D across to deployment – referred to as ‘the valley of death’.
» Long time horizons: Risks at early development stages are exacerbated for low carbon energy technologies due to their long timeframes to deployment and requirements for capital expenditure intensive investment – especially challenging for VC funds.
» Leverage vs crowding out: Does public funding crowd in or crowd out private investment? How best to structure public funding to leverage (i) the ability of Venture Capital firms to successfully screen, develop and commercialise companies; and (ii) the ability of corporates to invest to longer timeframes based on strategic motives, using their significant internal resources and engineering ability?</td></tr>
</table>

[8] Crafts & Hughes. Industrial Policy for the Medium to Long-term. Future of Manufacturing Evidence Paper 37, Foresight, GO Science, 2013.

Public policy

TABLE 4:

Public policy

Critical component	Public policy
Innovation chain “Policy journey”	
Key stakeholders	Department of Energy and Climate Change (+DEFRA, DCLG) GO-Science and Research Councils Department for Business Innovation and Skills Council for Science and Technology Ofgem Local and Devolved Administrations European Union
Key challenges	“Just as no single technology can be considered entirely in isolation, no single support mechanism or programme could provide the range of support needed to deliver the diversity and scale of technology innovation required across the system. Government support needs to follow the same systems approach and should be provided in a range of ways by a range of bodies.”[9] **Science Policy** Focus: Production of scientific knowledge Instruments: » Public research funds granted in competition » (Semi-) public research institutions (e.g. laboratories, universities, research centres...) » Tax incentives to firms » Higher education » Intellectual property rights **Technology policy** Focus: Advancement and commercialisation of sectoral technical knowledge Instruments: » Public procurement » Public aid to strategic sectors » Bridging institutions (between the research world and industry) » Labour force training and improvement of technical skills » Standardisation » Technology road-mapping » Benchmarking industrial sectors

[9] Low Carbon Innovation Coordination Group (LCICG). Coordinating Low Carbon Technology Innovation Support - The LCICG's Strategic Framework. LCICG, 2014.

Public policy
Continued »

Critical component	Public policy
Key challenges continued	**Innovation Policy** Focus: Overall innovative performance of the economy Instruments: » Improving industrial skills and learning abilities (through general education system and labour training) » Improving organisational performance and learning (e.g. ISO 9000 standards, quality control, etc.) » Improving access to information: Information Society » Environmental regulation » Bioethical regulation » Corporate law » Competition regulations » Consumer protection » Improving social capital for regional development: clusters and industrial districts » Intellectual benchmarking » Intelligent, reflexive and democratic forecasting[10]
	» **Holistic systems approach:** There are inherent policy conflicts in addressing the energy trilemma: security, affordability and sustainability. Overriding importance of stable environmental policy framework and an integrated, holistic approach - investors require stable, long-term policy frameworks and markets. » **Overcoming technological roadblocks:** Governments need to use their available policy levers to overcome technological lock-in, build innovation capability and facilitate the transition to new low carbon outcomes.

[10] Lundvall & Borrás. Science, Technology, and Innovation Policy. In Fagerberg, Mowery & Nelson (eds), The Oxford Handbook of Innovation, Oxford University Press, 2005.

Critical component	Public policy
Key challenges – continued	» **Modern industrial policy** requires strategic collaboration between the private sector and Government[11]. Industry and Government should work together to set strategic priorities, deal with coordination problems, allow for experimentation, avoid capture by vested interests and improve innovation performance. » **Promoting entrepreneurship:** SMEs in the green economy need help to link to knowledge networks, access finance, develop skills and overcome regulatory barriers. » **Demand-side policies:** including the use of market-based instruments, standards and public procurement, as well as policies to promote consumer and public acceptance.

[11] Rodrik. Normalizing Industrial Policy. Paper prepared for the Commission on Growth and Development, 2006.

Public policy

Continued »

TABLE 5:

Public policy: Possible policies to foster green innovation[12]

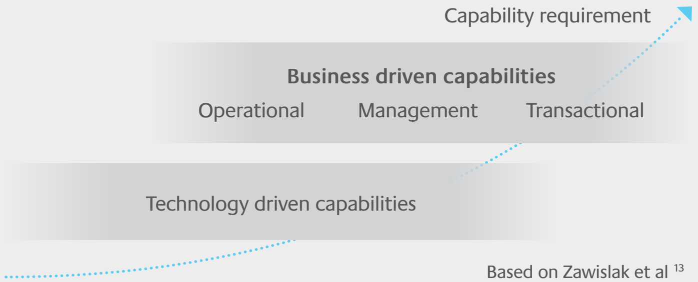
Policy challenge	Policy options
Insufficient demand for green innovation	» Taxes and market-based instruments to price externalities and enhance incentives » Demand side policies, such as procurement, standards and regulations, in specific markets and circumstances
Lack of innovation capability	» Broad based policies to strengthen innovation
Technological roadblocks and lack of radical innovation	» Investment in relevant R&D, including thematic and mission-oriented research » International cooperation
Research and investment biases to incumbent technology	» R&D support, tax incentives » Adoption incentives/subsidies » Technology prizes
Lack of finance	» Co-investment funds » Market development
Regulatory barriers to new firms	» Regulatory reform » Competition policy » Front-runner approaches
Lack of capabilities in SMEs to adopt green innovation	» Access to finance » Skills development » Linking SMEs to knowledge networks » Improving information supply » Reducing regulatory burdens
Non-technological innovation	» City and transport planning » Regulatory reform

[12] OECD. Fostering Innovation for Green Growth: Policy Considerations. OECD, 2011.

Innovation capability

TABLE 6:

Innovation capability

Critical component	Innovation capability
Innovation chain "Capability journey"	 Based on Zawislak et al [13]
Key stakeholders	» Department for Business Innovation and Skills » Department of Energy and Climate Change (incl. ORED) » Office for Nuclear Development » Devolved Administrations » Confederation of British Industry » Energy and Utility Skills Group » Sector Skills Councils and Bodies / Federation for Industry Sector Skills and Standards
Key challenges	"Achieving innovation requires the coordinated efforts of many different actors and the integration of activities across specialist functions, knowledge domains and contexts of application. Thus, organisational creation is fundamental to the process of innovation"[14]. "The ability of an organisation to innovate is a pre-condition for the successful utilization of inventive resources and new technologies."[15]

[13] Zawislak, Alves, Tello-Gamarra, Barbieux & Reichert. Innovation Capability: From Technology Development to Transaction Capability. Journal of Technology Management & Innovation, Vol.7 (2), 2012.

[14] Van de Ven, Polley, Garud & Venkataraman; The Innovation Journey; OUP, 1999

[15] Lam. Innovative Organizations: Structure, Learning and Adaptation. Innovative Perspectives for the 21st Century, BBVA, Spain 2010.

Critical component	Innovation capability
Key challenges – continued	» **Vulnerability to policy swings:** Environmental markets are almost entirely driven by public policy which, in turn, will affect the willingness to invest in low carbon skills in the UK. » **Handling disruptive innovation:** Many large corporations fail to develop disruptive innovations... basic constraints to creating successful disruptive innovation stem in large part from several inhibiting factors: the inability to unlearn obsolete mental models, a successful dominant design or business concept, a risk averse corporate climate, innovation process mismanagement, lack of adequate follow through competencies and the inability to develop mandatory internal or external infrastructure.[15] » **New business models:** Many innovative firms lack the business models that enable them to capture value. As a result, they have lower growth and profits and therefore lower returns, reducing the incentives to invest in the UK innovation system despite its ability to create value.[16] » **Skills gap:** Some take the view that the UK does not have the necessary skills to make the transition to a low-carbon economy at the pace required to meet mandatory targets - or the training arrangements in place to fill the gap.[17]; Developing the skills... necessary for the transition to the low carbon economy have wider environmental, economic and technological benefits which are not captured by employers or employees participating in the training... This can result in widespread underinvestment in the generic skills required to make the transition.[18] » **Commercialisation skills:** Overall, the UK energy sector is better at accessing and building innovation than commercialising it.[19]

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