LCICG

Low Carbon Innovation Co-ordination Group

Coordinating Low Carbon Technology Innovation Support

The LCICG's Strategic Framework

February 2014

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www.lowcarboninnovation.co.uk

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Foreword from Government

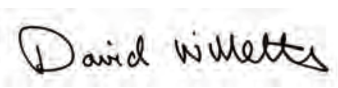
Since the coalition was formed in 2010, we have embarked upon a transformation of our energy system such that over the next 20 to 30 years we will see a profound shift from highly centralised fossil fuel burning power plants to a cleaner, low carbon, more distributed, interconnected and smarter energy market. There are major challenges to be addressed along the way to ensure security of energy supplies and, crucially, the affordability of energy for hard-pressed consumers as well as UK industry. Innovation in low carbon technologies will be key.

With the UK now sixth in the £3.4 trillion international low carbon goods and environmental services sector, the innovation that will continue to drive progress also presents a major opportunity for UK companies competing in the global race for green jobs and growth.

The UK has many strengths in research and development; we have world-class universities and a track record of innovative companies. We need to nurture and build on those strengths. We must forge partnerships between industry, government and the most innovative minds in business and academia to identify, develop and deploy technologies that will transform the ways in which we generate and use energy.

Government's role in this is to identify opportunities and provide targeted support where needed to ensure commercialisation of key technologies. This Strategic Framework sets out how the different parts of the UK government are coming together to do just that.

Rt Hon Gregory Barker MP
Minister of State, Department of Energy and Climate Change



Rt Hon David Willetts MP
Minister of State for Universities and Science

Document Overview

This document has been written by the members of the Low Carbon Innovation Coordination Group (LCICG).[1] It sets out a Strategic Framework for the future coordination of UK public-sector support to low carbon technology innovation.

The LCICG brings together the major public-sector backed organisations that invest in low carbon technology innovation in the UK. The Group's members are:

Department of Energy & Climate Change

The Scottish Government

Department for Business Innovation & Skills

CARBON TRUST

Scottish Enterprise

energy technologies institute

EPSRC
Pioneering research and skills

Technology Strategy Board
Driving Innovation

Core LCIGG Members

Department for Communities and Local Government

Department for Transport

Department for Environment Food & Rural Affairs

Llywodraeth Cymru
Welsh Government

UK Trade & Investment

THE CROWN ESTATE

Defence Infrastructure Organisation

ofgem

Department of Enterprise, Trade and Investment

Associate LCIGG Members

[1] The LCICG's website is at: www.lowcarboninnovation.co.uk

Innovation in low carbon technologies is key to the future affordability, security and sustainability of energy supply and use, and will help UK businesses of all sizes maximise the opportunities from the growing low carbon economy. The LCICG's aim is to enhance the focus, coordination and delivery of government-backed support for innovation in low carbon technologies, in order to maximise the economic benefits to the UK. By working closely together, we are increasing the collective impact of our programmes by leveraging each other's resources and expertise, avoiding duplication and providing a more comprehensive range of support than would otherwise be possible.

This document is structured in two parts. In Part 1, we describe how public-sector backed support for innovation in low carbon technologies is delivered in the UK, and we summarise the progress made to date in strengthening coordination. We then set out our shared aims and objectives and detail how we plan to work together to further strengthen our coordination and impact in the future.

A key challenge for the Group is focusing our resources on those innovations where the need is most pressing and where our investments can have the most impact. We have previously published Technology Innovation Needs Assessments (TINAs), which were compiled with significant input from industry and academia. The TINAs analyse and quantify the impact of technology innovation for eleven low carbon technology sectors (see Table 1 in Chapter 4). In Part 2 of this document we take that analysis a step further. Building on the TINA work, we set out what we believe are the key innovation needs in each of those eleven technology sectors over the remainder of the decade, and we assess the scale of support that would be required to address those needs.

This document provides insights into future innovation needs and a framework for future prioritisation. However, we do not make choices here between the individual technologies or their needs; nor do we describe our current or future work programmes. Individual LCICG members have published descriptions of current activities and plans up to 2015.[2] The shape of our work programmes for 2015 and beyond will be informed by various factors including the success or otherwise of current innovation programmes, the development of the technologies over the next few years, the development of wider energy policy and the availability of funding in future spending rounds. Our analysis to date suggests that for the UK Government alone to support all of the innovation needs identified would require substantially more funding than is likely to be available. It is clear therefore that difficult choices will have to be made as we develop our future work programmes. The analysis and principles set out in this document will be influential in guiding those choices and the future investment decisions made by members of the Group.

[2] See the LCICG website for links to members' websites.

Document Structure

Part 1 – Coordinating Innovation Support

Chapter 1: The Role of Innovation (Page 11) – summarises the reasons why the UK Government is supporting low carbon technology innovation;

Chapter 2: Supporting Innovation (Page 17) – describes the way in which support is currently provided and describes the LCICG, setting out our aims and objectives;

Chapter 3: Strengthening Coordination (Page 27) – details the LCICG's work programme, summarising our work to date and describing how we will go about ensuring that future support is well coordinated and prioritised to maximise impact;

Chapter 4: Prioritising Future Investments (Page 33) – outlines the conclusions of our work to identify the key innovation needs within each of eleven technology sectors and details how we plan to prioritise between those needs to develop future work programmes;

Chapter 5: Summary and Next Steps (Page 45) – summarises the conclusions drawn in the preceding chapters and sets out next steps.

Part 2 – The Innovation Needs of Key Technologies

(Page 47) – summarises the analysis of eleven technology families. The eleven technology families analysed are those which previous modelling and analysis suggested are of particular importance to government objectives and where significant and coordinated UK public-sector backed support is likely to be needed. They are:

Bioenergy (Page 50)	Carbon Capture and Storage (Page 54)	Domestic and Non-domestic Buildings (Page 56)
Electricity Networks (Page 59)	Electricity Storage (Page 62)	Heat (Page 64)
Hydrogen for Transport (Page 66)	Industrial Sector (Page 69)	Marine Energy (Page 71)
Nuclear Fission (Page 74)	Offshore Wind (Page 77)	

Annex: LCICG Members – provides a brief description of each LCICG member and their innovation focus.

Part 1 – Coordinating Innovation Support

PACT/Douglas Robertson

Chapter 1
The Role of Innovation

This chapter outlines the reasons why the UK Government supports low carbon technology innovation.

The Opportunities from Low Carbon Technology Innovation

The energy sector is a critical part of the UK economy and is an important driver of growth. However, our energy sector faces major challenges: tackling the threat of climate change; upgrading our aging infrastructure; maintaining energy security; minimising costs for industry and householders; and protecting the fuel poor. Addressing those challenges requires a major shift in the way we supply, use, and think about energy. They also present a unique opportunity for innovative UK businesses, both large and small, to benefit from the £110bn of investment in UK energy infrastructure needed by 2020[3] and to capture an increased share of the world market for low carbon and environmental goods and services, which was worth £3.4 trillion in 2011/12.[4]

The UK Government and the Governments of Scotland, Wales and Northern Ireland are taking action on multiple fronts to address these challenges. DECC's 2011 Carbon Plan[5] sets out how we will meet the requirements of the 2008 Climate Change Act, putting us on the right track to reduce our greenhouse gas emissions by 80% by 2050 against the 1990 baseline. The UK Government's Annual Energy Statement, published in October 2013,[6] provides up-to-date information on our principal energy policies and progress to date.

In 2013, a number of UK Government publications identified the opportunities from key low carbon technologies, such as Energy Storage which was highlighted in the context of the 'Eight Great Technologies',[7] and from key industrial sectors such as Offshore Wind and Nuclear Fission. The UK's Industrial Strategy is a new partnership between business and all parts of government; it has identified a range of opportunities to help create growth for the future, from developing new skills and securing critical investment, to commercialising our research and inventions. Sector Strategies in Offshore Wind[8] and Nuclear Fission[9]

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3 Electricity Market Reform Delivery Plan, December 2013 update. See: DECC, Delivery Plan Impact Assessment, December 2013: https://www.gov.uk/government/publications/electricity-market-reform-delivery-plan

4 BIS, Low Carbon Environmental Goods and Services, Report for 2011/12. July, 2013.

5 https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2

6 https://www.gov.uk/government/publications/annual-energy-statement-2013

7 http://news.bis.gov.uk/Press-Releases/-600-million-investment-in-the-eight-great-technologies-68680.aspx

8 https://www.gov.uk/government/publications/offshore-wind-industrial-strategy-business-and-government-action

9 https://www.gov.uk/government/publications/nuclear-industrial-strategy-the-uks-nuclear-future

were published in 2013 and highlighted the importance of research and development (R&D) in maximising the economic benefits for the UK from those sectors.

A consistent message in these and other relevant policy documents is that innovation in low carbon energy technologies has a critical part to play in delivering secure, affordable, low carbon energy. Innovation is needed to diversify the ways in which we generate and use energy – developing new technologies and enhancing the use of existing technologies. And, crucially, innovation is needed to reduce the cost of future energy supply. The LCICG's Technology Innovation Needs Assessment (TINA) project (see Chapter 4 for more details) analysed the potential for cost reduction in each of eleven technology families and concluded that, in all eleven cases, innovation could significantly reduce the costs that consumers and industry would have to pay for low carbon energy. For example, that analysis concluded that under a central scenario, investment in innovation could reduce costs up to 2050 by as much as: £28bn in Building Energy Efficiency; £22bn in Carbon Capture and Storage (CCS); and £30bn for Heat (see Part 2 of this document for further details and other examples).

Innovation in low carbon technologies also presents a significant opportunity for UK-based businesses. The UK is at the forefront of the shift to low carbon energy and we have technical and commercial strengths across a broad range of energy technologies. We have a world-leading academic base, innovative small and medium-sized enterprises (SMEs) and many companies with the skills and capabilities to develop UK supply chains

Box 1: The LCICG working in partnership – Energy Storage

Storage has the potential to revolutionise the way we think about electricity generation and supply. Increased storage capacity could facilitate a higher penetration of renewable electricity generation, a higher utilisation and efficiency of nuclear and fossil fuel plants, and the greater electrification of heat and vehicles.

The LCICG's core members expect to invest up to £75m between 2011 and 2015 in RD&D for energy storage technologies. That funding is supporting projects and programmes such as:

- **DECC's Energy Storage Technology Demonstration SBRI Competition**, which launched in 2013 and funded twelve organisations to carry out feasibility studies into innovative and diverse energy storage ideas that could address grid-scale storage and balancing needs in the UK electricity network. Four of those organisations have since been awarded total funding of up to £15m to take their designs to the grid-scale demonstration stage.
- **EPSRC's** investment of £30m in five centres to support new science capital facilities for grid-scale energy storage, to help accelerate the development of national-scale electricity storage.
- The **ETI's** £14m investment in a project led by Isentropic to develop and demonstrate a 1.5MW/6MWh grid-scale electricity storage unit, which will be deployed at a primary distribution substation in the Midlands.

for products that could be exported globally. Our TINA analysis estimated that investment in innovation could allow us to successfully win a greater share of global markets that could yield significant net contributions for the UK out to 2050. For example, in a central scenario: up to £18bn could be delivered by Offshore Wind; up to £8bn by CCS; and up to £11bn by Electricity Storage (see Part 2 of this document for further details and other examples).

Realising those benefits will require close working between industry, academia and government. This will help to deliver substantial and sustained investment targeted at those technologies where the UK can have most impact and achieve the most benefit.

The Role of Public Investment in Innovation

All technologies follow a path from concept through to commercialisation, though this is rarely linear and the nature of the innovation and support required changes throughout this journey. Figure 1 summarises the classic stages of the technology innovation journey.

At the early stages of basic research, government often fully funds innovation activity – in the UK it does so principally through its funding of the UK Research Councils. As technologies develop, the driving forces of innovation are the investments made by innovative private companies, and the competition between them.

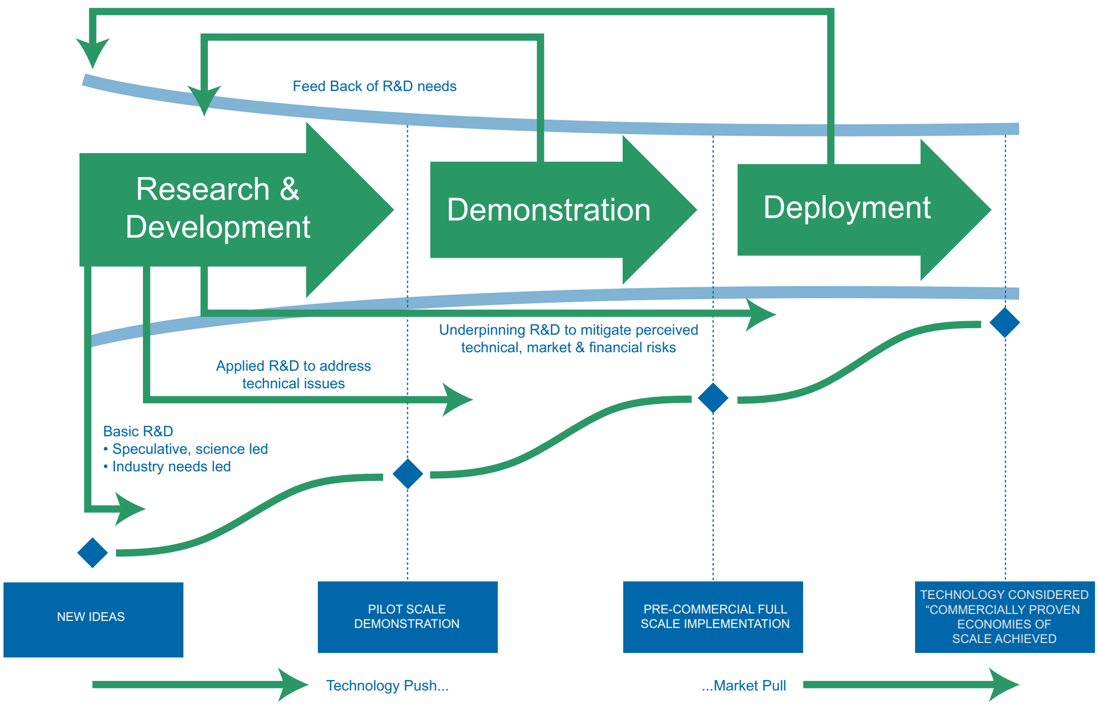
It is industry and other private-sector investments that are critical to the successful development and commercialisation of innovative ideas. However, there are a number of market failures and barriers which affect the level of private investment in low carbon innovation. These have been well documented elsewhere, including by the Committee on Climate Change[10] and the International Energy Agency.[11] These market failures and barriers include for example: spillover effects, where the benefits from innovation to society are greater than those that accrue to the original innovator; high upfront costs; limited access to finance; and path dependency of previous investments due to market power and dominant designs.

While these market failures and barriers can affect other innovative technologies, there are significant differences between energy markets and the markets for other

[10] The Committee on Climate Change, *Building a low-carbon economy – the UK's innovation challenge*, July 2010.

[11] International Energy Agency, *Energy Technology Perspectives 2012 – Pathways to a Clean Energy System*, June 2012.

Figure 1: The Technology Innovation Journey



[Source: Energy Research Partnership]

more familiar consumer products, such as computers or mobile phones, where innovation tends to occur at a rapid pace. Two key differences distinguishing the energy market are the large capital investments required and the long payback periods. Low carbon technologies can often take ten or twenty years, or longer, to successfully develop. The costs of developing an energy technology can run to many tens or hundreds of millions of pounds, and the required level of investment tends to increase substantially as technologies progress from early stage research through to the development, demonstration and initial deployment phases. Other factors hindering investment include risks around the public acceptability of certain technologies and their environmental impact, and under-developed supply chains.

Policy uncertainty and imperfect market signals can be particularly significant barriers in the energy sector. Market incentives such as Feed in Tariffs and Contracts for Difference can help provide confidence to technology developers that there will be a return on investment, but these need to be complemented by direct support to drive the required innovation.

Taken together, market failures and barriers can lead to low levels of innovation taking place in low carbon technologies. For most private-sector funders, which generally have a low appetite for risk, these issues coupled with the uncertainties inherent in the development of energy technologies will often be sufficient to dissuade investment.

The private sector needs to be the primary source of investment in technologies that are to be deployed in commercial markets. However, governments have a role to play in incentivising and de-risking that investment. Public funding can only ever be part of the equation, but direct public investment to part-fund research, development and demonstration (RD&D) mitigates some of the issues, by: reducing financial risk; enhancing the credibility of projects; and increasing the confidence of

Box 2: The LCICG working in partnership – Carbon Capture & Storage

CCS is applicable to both power generation and industrial emissions and could allow the flexibility and energy security benefits of fossil fuel combustion with vastly reduced greenhouse gas emissions. DECC is investing up to £1bn in integrated full-chain projects which bring together capture, transport and storage. Complementing this critical step, LCICG members expect to invest up to £125m over four years to support innovation in key component technologies which could improve future performance and reduce future costs.

That funding is supporting a range of projects and programmes including:

- **Ferrybridge CCPilot100+** which is a 5MWe post-combustion carbon capture pilot plant, constructed by SSE, Doosan Power and Vattenfall. This has successfully demonstrated a capture efficiency of 90% and is a key stage in the development of full-scale CCS. With a total size of over £20m, the project has received over £6m of co-funding from **DECC** and the **Technology Strategy Board**.
- The **UK Carbon Capture and Storage Research Centre**, which is receiving £10m from EPSRC. The Centre is a virtual hub that brings together leading UK CCS researchers, coordinates a programme of underpinning research and acts as an interface for government, industry and international collaboration.
- **CO_2 Stored**, which is a comprehensive web-enabled database of over 500 potential UK CO_2 storage locations. The database was developed as part of a £4m **ETI**-funded UK Storage Appraisal Project and is now licensed to The Crown Estate and British Geological Survey.

private-sector investors. These issues are not unique to the UK; in the low carbon technology sector, this use of direct public funding to mitigate investment risk alongside market incentives to mitigate market risk is the norm around the world. Historical evidence shows that those countries who have, in recent decades, been successful in developing energy technologies, such as Onshore Wind or Solar Photovoltaic energy, have used a mix of direct and indirect public-sector funding to do so.

It is for these reasons that the members of the LCICG provide direct financial support for low carbon technology innovation.

Sanne Berg/iStock/Thinkstock

Chapter 2
Supporting Innovation

This chapter describes the LCICG and its aims and objectives, and summarises the way in which support is currently provided.

The Low Carbon Innovation Coordination Group

The LCICG brings together the major public-sector backed organisations that invest in low carbon technology innovation in the UK. The Annex lists the Group's core and associate members and describes each member's role and innovation focus. Although each LCICG organisation has its own priorities for, and approach to, investment in low carbon technology innovation, we share many common objectives and we agree on the major outcomes we seek. Thus, the LCICG members' shared aim is:

To maximise the impact of UK public-sector funding for low carbon technologies, in order to:

- **Deliver affordable, secure, low carbon energy for the UK;**
- **Deliver UK economic growth; and**
- **Develop the UK's capabilities, knowledge and skills.**

The LCICG members are committed to working closely together to coordinate our innovation support activities. By doing so, we increase the collective impact of our programmes by leveraging each other's resources and expertise. We also avoid unproductive duplication and are able to provide a more comprehensive range of support than would otherwise be possible.

Government Support for Low Carbon Technology Innovation

Government-backed low carbon technology innovation policies and programmes support the RD&D of new and enhanced low carbon technologies and their subcomponents and processes. The aim of these policies and programmes is to take key technologies to the point at which they are sufficiently proven that the market, with the support of market-based policy mechanisms if necessary, can deploy them widely.

The energy system is highly complex, with multiple technologies interacting through multiple interfaces. Consequently, providing effective innovation support across the whole energy system and the full innovation journey can present challenges. Energy touches on many government policies and priorities across a range of departments, including industrial policy, regional economies, environment, housing and transport. A whole-systems approach to energy technology innovation is therefore crucial to understanding the social, environmental, and economic impacts of different energy technologies.

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.

Figure 3 shows the main UK public-sector backed funders of low carbon technology innovation and describes their roles, how they interrelate and how funding flows to innovators. By working together, these bodies can deliver the breadth and depth of support innovators need, with strong coordination between the bodies being critical to avoiding duplication and strengthening delivery. The LCICG's role is to ensure that appropriate coordination happens and that together our programmes deliver on our shared objectives.

The diagram focuses on public-sector support but it is the private sector that is the primary funder of innovation at the later stages of the innovation journey. It is vital therefore that public funders work closely with industry, both large and small, and with other partners such as academia and the professional institutions. Public-private partnerships such as the Energy Technologies Institute (ETI) and the new Catapult Centres on Offshore Renewables and Energy Systems are a key part of that relationship. By working in partnership through these and other initiatives, we ensure that we better understand the needs, capabilities and drivers of industry and that we can tailor and target our support accordingly.

Similarly, the LCICG does not work in isolation from other bodies that analyse the energy sector and provide insights into energy innovation needs. The LCICG maintains close links with organisations such as the Committee on Climate Change, the UK Energy Research Centre and the Energy Research Partnership (see Box 3) and we consult with them to ensure our activities are informed by their expertise and the perspectives of their members.

Box 3: Energy Research Partnership

The Energy Research Partnership (ERP) brings together major funders from the public and private sectors to give strategic direction to energy innovation in the UK. Its aim is to increase the level, coherence and effectiveness of public and private investment, enabling the UK to become a world leader in the development of new energy technologies.

ERP's private sector members represent sectors from across the energy system, including: utilities; infrastructure; equipment; buildings; engineering; academia; and NGOs.

ERP projects in 2013/14 include: the importance of public engagement as the UK transitions to a low carbon energy system; managing flexibility of the electricity system; building technologies; and the UK's international engagement in energy innovation.

The LCICG's Scope

The focus of the LCICG's activities is on 'low carbon technology innovation'. Much of the discussion in this document is about the energy system and we particularly focus on technologies associated with electricity generation, energy supply and distribution, and the use of energy. In addition, our scope includes energy use in transport as well as industrial and agricultural processes that release greenhouse gases.

We consider 'low carbon technologies' to include technologies that can:

- Prevent or reduce the release of greenhouse gases into the atmosphere;
- Supply energy with substantially lower greenhouse gas emissions than the average of currently deployed processes;
- Enable such technologies to be deployed, for example transmission and distribution technologies or system balancing technologies;
- Reduce the amount of energy consumed;
- Help consumers to reduce their energy use, such as smart meters and demand management technologies; and
- Reduce the release of greenhouse gases from other processes, for example industry or agriculture.

The primary focus of the LCICG's activities is on the development of low carbon technologies. We use a relatively broad definition of 'technology innovation' that includes system and process innovations, provided they are closely linked with the deployment and use of a technology. However, innovation in individual technologies cannot progress without consideration of the whole energy system and wider economic, regulatory, social and environmental factors. Therefore, while it is beyond the scope of the Group's core coordination remit, LCICG members do also support research and innovation that considers the social, environmental and economic impacts of particular energy choices, as well as the challenges surrounding innovation in low carbon technologies.

Similarly, other considerations such as the policy and regulatory environment, or the availability of resources and skills, are crucial to the successful development of technologies. These factors are not considered in detail in this Strategic Framework as they have not been a major part of the Group's work so far. However, skills, for example, are a key consideration for the development and deployment of low carbon technologies. The Research Councils have a range of activities to help address the shortage of key skills. The Engineering and Physical Sciences Research Council (EPSRC) currently supports twelve Centres for Doctoral Training (CDTs) in energy (£82m investment), involving over a hundred industrial partners. A further twelve new EPSRC Energy CDTs were announced in late 2013, as part of a £350m investment in cohort-based PhD training.

In considering technology innovation needs, we have structured our analysis around individual technology families, to allow us to consider in detail the subcomponent elements where innovation is needed. That approach of breaking the problem into parts is necessary given the many complexities in the energy system and the uncertainties over its future development. It is very important however to recognise that we are dealing with a highly complex and interconnected system and that no technology can be developed or deployed in isolation. The risk of analysing individual technology families is that the relationships and interdependencies between components of the system are not adequately considered, and that cross-cutting or underpinning challenges and opportunities are not fully addressed. In our analytical processes we recognise that risk and seek to mitigate it by using a range of systems models and analysis tools (see Box 4) to provide insights into the role and interdependencies of any given technology, and by explicitly considering the interfaces between component technologies. As both our analysis of priorities and our understanding of the energy system evolve, we will continue to refine our assessment of innovation priorities to ensure we continue to target our resources to maximum effect.

Box 4: The Systems Perspective

As the UK moves towards a low carbon economy, the interdependencies between the different parts of the energy system across the heat, power and transport sectors and the infrastructure that links them will become increasingly important. System-level analysis and modelling is crucial to understanding these interactions and provides important evidence that is used by **DECC** in the formation of energy policy. LCICG members also use these tools and insights to inform the development of their innovation programmes and we are pursuing a range of activities to enhance our understanding of the energy system.

The **ETI** has developed the Energy Systems Modelling Environment (ESME) which is a least-cost optimisation model of the whole UK energy system. It finds least-cost energy system designs which meet stipulated sustainability and security targets, taking account of technology operation, peaks in energy demand, UK geography and uncertainty in costs. ESME, alongside other systems analysis tools, was used by the LCICG in developing the TINAs.

The **Research Councils UK** Energy Programme funds the UK Energy Research Centre (UKERC) which carries out world-class research into sustainable future energy systems. UKERC takes a whole-systems approach to energy options, supply, and usage in order to enhance understanding of their social, environmental, and economic implications. It is the hub of UK energy research and the gateway between the UK and the international energy research communities. The Centre's interdisciplinary, whole-systems research informs UK and international policy development and research strategy.

Complementing these activities, the **Technology Strategy Board** is funding the establishment of a Catapult Centre focused on Energy Systems.

Image: Massimiliano Agati/iStock/Thinkstock

Our Innovation Support Programmes

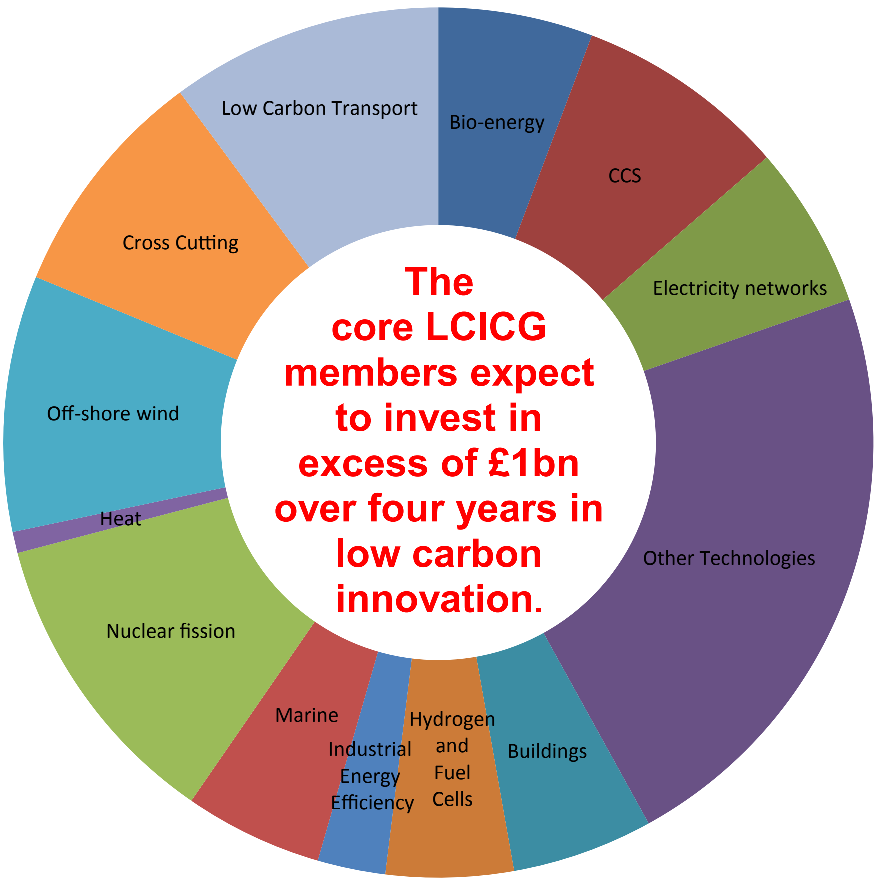
Supporting the breadth of innovation needs across a large and complex energy system requires a diversity of support activities. The members of the LCICG therefore provide support through a wide range of programmes and mechanisms. Our support activities address innovation needs across all of the technologies covered by the TINAs, as well as in other energy technology families and a wide range of innovative underpinning technologies.

The scale of support provided across government is substantial. In the four years up to March 2015 the core members of the LCICG expect to invest in excess of £1bn in low carbon technology RD&D.

Support is provided using a variety of tools. Most funding is provided in the form of grants or through direct investment in projects, but pre-commercial procurement mechanisms are increasingly used and other support mechanisms, such as loans and equity investments, can be part of the portfolio.

Pre-commercial procurement is a valuable mechanism for supporting innovation. It is most appropriate where there is a clearly defined need but no commercially available solution, and for technologies where a clear market has yet to be established. Under this mechanism public-sector funders procure an innovative solution to a particular challenge, paying 100% of the development costs in return for agreement to share the outputs of the R&D across the public sector. This approach helps to ensure that solutions are delivered at a competitive market rate. It is a particularly helpful mechanism for early-stage businesses and SMEs, which often struggle to secure private-sector investment for their R&D activities.

Figure 2: Approximate breakdown by technology family of expected LCICG investments in 2011-2015.



The Technology Strategy Board's Small Business Research Initiative (SBRI) programme operates on this principle and aims to connect public-sector challenges with innovative ideas from industry, leading to better public services and improved efficiency and effectiveness. DECC's Energy Storage Technology Demonstration Competition, launched in 2013 (see Box 1), is just one example of the value of this approach in meeting energy challenges.

Making progress against particular objectives often requires targeted funding to create a critical mass of investment and activity. However, it is important to remain open to ideas and innovations that come from unexpected directions. That is particularly true at the earlier stages of the innovation journey, which is why the Research Councils fund a portfolio of both targeted and investigator-led activities. Targeted activities through specific calls amount to approximately 60% of the current portfolio, with the remaining 40% comprising investigator-led awards, where proposals are submitted by the community in any area of energy research at any time. That flexibility is also important at the later stages; our programmes therefore deliberately provide a mix of open, flexible schemes and challenge-led targeted calls.

Typically our programmes are open to innovators from any organisation. We recognise however that SMEs, which are often the instigators and drivers of innovation and change, face particular challenges in funding R&D. As part of our portfolio we therefore have a range of mechanisms that aim, in particular, to address the funding gap often experienced

Box 5: The LCICG working in partnership – Energy Efficiency in Buildings

Improving energy efficiency within the buildings sector is critical. The energy used by domestic buildings accounts for approximately 25% of the UK's carbon emissions and non-domestic buildings' energy use accounts for approximately 18%. The LCICG's core members have current and planned investments worth up to £60m to fund a range of projects and programmes to help address that challenge. For example:

- The Research Councils are funding six **End-Use Energy Demand Centres** which will receive £30m from **EPSRC** and **ESRC**, with a further £13m from project partners. The Centres focus on food, technology transitions, sustainable materials use, heat, behaviour and the use of data.
- The **Technology Strategy Board** has allocated £8m to fund building performance evaluation studies on domestic and non-domestic buildings. The programme will help builders and developers deliver more efficient, higher performance buildings. One hundred projects have been accepted for evaluation, with a range of project teams including housing associations, commercial and public sector clients, architects and universities. The programme includes the evaluation of 1620 new homes at Centenary Quay (see image). The dwellings are constructed with efficient building fabric and are served by gas combined heat and power and mechanical ventilation.
- Investment is also available from cross-cutting schemes such as **DECC's Energy Entrepreneurs Fund.**

by small and early-stage companies with innovative ideas and high growth ambition and potential. One example of this is DECC's Energy Entrepreneurs Fund, which is broad in scope and open to all but is particularly suitable for early-stage businesses and SMEs. That Fund provides companies with co-funding of up to £1m for technology development, as well as additional funding to support the development of business skills that will help the company successfully commercialise their products. Another example is the Technology Strategy Board's Smart scheme. This offers funding to UK-based pre-start-ups, start-ups, micro businesses and SMEs, to carry out science, engineering and technology R&D projects, prove new concepts or new markets and develop prototypes which could lead to successful new products, processes and services.

These programmes and the case studies inserted throughout this document provide some examples of the types of projects and programmes that LCICG members are supporting. These are however just a small subset of the broad range of activities that LCICG members' funding is helping to deliver.

Office of Gas and Electricity Markets (Ofgem)
An associate LCICG member; an independent regulator; focuses on consumer protection through the promotion of competition and regulation of monopoly companies; its low carbon innovation focus is on the development, demonstration and uptake of innovation in energy networks.

Department for Communities and Local Government (DCLG)
An associate LCICG member; a UK government department; policy lead on housing, planning and the building regulations; its low carbon innovation focus is on improving energy efficiency in existing and new buildings.

Department of Energy and Climate Change - Innovation Programme
A core LCICG member; a programme delivered directly by a UK government department; its focus is on energy-policy-led innovation at the development and demonstration stages, with the aim of delivering secure, clean, affordable energy.

UK Trade and Investment (UKTI)
An associate LCICG member; a UK government department; its low carbon innovation focus in on helping UK-based companies succeed in the global economy, and on attracting high-quality investment from overseas by offering expertise and contacts through its UK and global network.

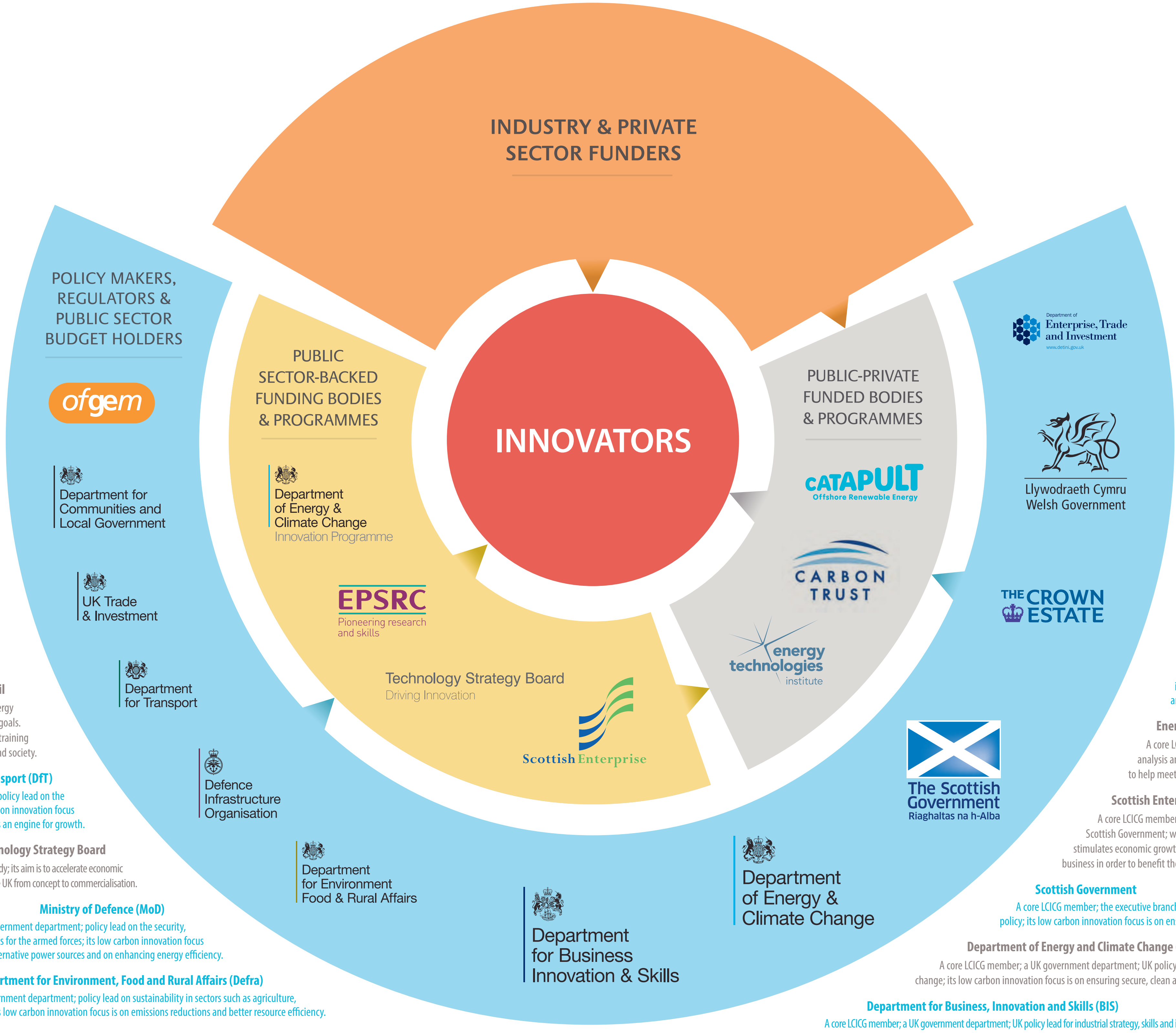
Engineering and Physical Sciences Research Council
A core LCICG member and represents the Research Councils' UK Energy Programme; its low carbon innovation focus is on UK energy policy goals. The Research Councils support world-class research, postgraduate training and activities to deliver impact for the UK economy and society.

Department for Transport (DfT)
An associate LCICG member; a UK government department; policy lead on the transport system including lower carbon transport. Its low carbon innovation focus is on delivering a greener transport system that is an engine for growth.

Technology Strategy Board
A core LCICG member; the UK innovation agency - a non-departmental public body; its aim is to accelerate economic growth by stimulating and supporting business-led innovation in the UK from concept to commercialisation.

Ministry of Defence (MoD)
An associate LCICG member; a UK government department; policy lead on the security, sustainability and affordability of energy supplies for the armed forces; its low carbon innovation focus is on research and demonstration of alternative power sources and on enhancing energy efficiency.

Department for Environment, Food and Rural Affairs (Defra)
An associate LCICG member; a UK government department; policy lead on sustainability in sectors such as agriculture, waste and forestry; its low carbon innovation focus is on emissions reductions and better resource efficiency.



Northern Ireland Executive
An associate LCICG member; the administrative branch of the Northern Ireland Assembly; its low carbon innovation support is channelled through Invest NI and its focus is on ensuring that innovation benefits Northern Ireland's economy.

Catapult Centres
Not LCICG members but some have close links with LCICG's work; centres of expertise for technology and innovation in particular sectors; established with government funding with an objective to accelerate the take-up of emerging technologies and drive economic growth.

Welsh Government
An associate LCICG member; the devolved government in Wales; its low carbon innovation focus is on enhancing economic, social and environmental wellbeing and improving quality of life for present and future generations.

Carbon Trust
A core LCICG member; a not-for-dividend company; provides expertise in low carbon innovation needs analysis, development and deployment; and partners with organisations to accelerate the commercialisation of low carbon technologies.

The Crown Estate
An associate LCICG member; a property portfolio owned by the Crown; manages the UK seabed to the benefit of the nation; its low carbon innovation focus is on exploiting the country's wind, wave and tidal energy resources.

Energy Technologies Institute (ETI)
A core LCICG member; a public-private partnership; its focus is on energy system analysis and investments in major engineering and technology demonstration projects to help meet energy targets at the lowest cost.

Scottish Enterprise
A core LCICG member; a sponsored non-departmental public body of the Scottish Government; which along with Highlands and Islands Enterprise stimulates economic growth, enterprise, innovation and investment in business in order to benefit the Scottish economy.

Scottish Government
A core LCICG member; the executive branch of the devolved government of Scotland; leads on Scotland's energy policy; its low carbon innovation focus is on ensuring that innovation benefits the Scottish economy.

Department of Energy and Climate Change (DECC)
A core LCICG member; a UK government department; UK policy lead for energy and climate change; its low carbon innovation focus is on ensuring secure, clean affordable energy supplies.

Department for Business, Innovation and Skills (BIS)
A core LCICG member; a UK government department; UK policy lead for industrial strategy, skills and innovation; its low carbon innovation focus is on driving sustained economic growth.

Figure 3: UK Public-Sector Support for Low Carbon Technology Innovation

The outer ring shows those UK public-sector bodies that have a policy or regulatory role that impacts low carbon technology innovation and/or have budget responsibility for low carbon technology innovation funding. These bodies typically route their financial support through the organisations and programmes in the inner ring, though they may occasionally fund innovation directly. The inner rings show those bodies which typically work directly with innovators. The left hand arc shows the major public-sector backed funding bodies or programmes that provide significant direct financial support to low carbon technology innovation (tens of millions of pounds per annum). The right hand arc shows the key organisations that are backed by both public and private funds to support or work with low carbon technology innovators. The arrows show the primary flows of funding or policy direction.

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Chapter 3
Strengthening Coordination

This chapter describes the LCICG's work programme and explains how we will ensure future support is well coordinated and prioritised to maximise impact.

The LCICG's Current Work Programme

Since its formation, the LCICG has pursued a range of activities designed to strengthen the coordination and delivery of public-sector backed low carbon technology innovation support.

Since 2011 we have:

- Developed and published a shared evidence base called the Technology Innovation Needs Assessments – described in more detail in Chapter 4;
- Established the 'Low Carbon Funding Landscape Navigator' – a single online portal for innovators to find funding (see Box 6);
- Developed complementary programmes and projects across the LCICG membership (see the 'LCICG working in partnership' breakout boxes);
- Leveraged the resources and expertise of our members to deliver a number of co-funded projects and programmes (see the 'LCICG working in partnership' breakout boxes); and,
- As set out in this document, agreed a shared plan for future collaboration and prioritisation.

Box 6: Energy Generation and Supply Knowledge Transfer Network

The Energy Generation and Supply Knowledge Transfer Network (KTN) manages the Low Carbon Funding Landscape Navigator, which helps innovators identify funding opportunities to progress their technologies to commercialisation.

The Navigator is an interactive portal that provides innovators with the opportunity to identify funding from both public and private sources. In addition, the KTN provides information and networking opportunities to innovators, including technical solution sourcing and insights about UK and international funding.

The Funding Landscape Navigator can be accessed at:
http://www.lowcarbonfunding.org.uk

We are also continuing work to pilot a shared approach to measuring the impact of the Group's innovation programmes, and to collate and maintain a detailed database of current public-sector funded innovation support activities.

As an integral part of delivering these activities, we have consulted with a wide range of industry and academic experts, innovators and end users to better understand their needs and to help ensure we provide the right support in the right way.

The LCICG's Future Plans

Innovators often highlight that the availability of consistent, sustained support is crucial if they are to have the confidence to make investments or secure commercial backers. A lack of transparency with respect to future plans, or a lack of certainty around future funding, can be a significant barrier to innovation. Innovators also emphasise the importance of avoiding gaps in funding. Addressing those challenges is a key priority for the LCICG. Our ambition is to work closely together to improve the technology journey for developers and investors – ensuring the right support is available at the right time and at the right scale to deliver a seamless progression to deployment.

During 2014 and 2015, we will build on our current work programme to deliver the following four priorities:

1. Coordinating planning of a prioritised portfolio for 2015-2020.

Our experience makes clear that different innovators need different types of support at different stages of the innovation journey. LCICG members support innovators right across that journey with a range of interventions and programmes. Harnessing our diversity while working in close partnership offers us the opportunity to provide a coordinated, prioritised portfolio of support that will give innovators the clarity, consistency and breadth of assistance they need.

To that end the LCICG will:

- Agree and implement a coordinated approach to identifying and prioritising public-sector backed support between 2015 and 2020 (Chapter 4 provides further details about how we will do this);
- Through coordination of our individual programmes, provide a range of funding mechanisms that offer a combination of targeted and flexible support throughout the innovation journey.
- Support co-funded projects and programmes where LCICG members can offer a combined response which is greater than the response offered by any one member. For example, subject to confirmation of funding, we are establishing an Energy Catalyst which will complement our targeted support programmes by providing an open, flexible funding stream that will help the best ideas move smoothly and quickly through to commercialisation (see Box 7 for more details);
- Publish details of the planned portfolio of LCICG members' programmes – demonstrating the alignment of our shared and individual activities, and providing clarity on the future availability of innovation funding opportunities for low carbon technologies.

2. Strengthening external communications to ensure innovators can find the right support.

Given the diversity of support available, innovators often need assistance in finding suitable funding opportunities. Innovators and investors also need the right environment and opportunities to form and develop collaborations, to identify and partner with investors and to broker access to facilities.

Strong communication links are also needed between public-sector funders and organisations that will develop, fund or deploy innovative technologies. These include the large multinational companies which can make significant investments, but also the SMEs who are often the pioneers of

Box 7: An Energy Catalyst Programme

Building on successful catalyst schemes in other sectors such as biomedical technology, the **Technology Strategy Board, EPSRC, DECC** and other LCICG partners are developing thinking on how an Energy Catalyst can accelerate the best UK energy innovation to market. The Energy Catalyst would provide a joined-up escalator of funding able to support the best research ideas or novel concepts all the way to commercial readiness. Open for innovators across the energy sector to apply to at any time and at any stage of technology development, a Catalyst aims to provide flexible support when technology developers require it, complementing more targeted, technology-specific funding streams.

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innovation. Such links are crucial in ensuring all parties have a good understanding of each other's needs and drivers and in ensuring that support programmes are tailored to both the requirements of developers of innovative technologies and the industries which will deploy them.

The LCICG members plan to work together to strengthen our communication activities to help address those needs. By doing so we aim to help developers and investors understand government and industry priorities and the public and private-sector innovation support opportunities open to them. By raising the profile of our activities we also hope to increase awareness of and confidence in UK public-sector support for innovation.

To that end the LCICG will:

- Help developers and investors navigate the technology journey by building on the online 'Low Carbon Funding Landscape Navigator' (see Box 6) to signpost and guide innovators to funding opportunities;
- Facilitate introductions to collaborators, access to facilities and networking opportunities, by continuing to support and utilise brokering and knowledge exchange services provided by LCICG members, such as: the Knowledge Transfer Networks;[12] the Research Councils offices in the European Union (EU), India, China and the USA; and the Catapults[13] (see Boxes 6 and 8). This work will also include developing online information provision, building on the Research Councils UK Gateway to Research, and the Technology Strategy Board's '_connect' service;
- Maintain a close dialogue with innovators, the private-sector funders who support them, and the companies, large and small, which will deploy new technologies. This will be achieved by making extensive use of existing government-industry forums; and arranging bespoke events, where necessary, to brief on developments and consult on developing plans;
- Increase awareness of and confidence in UK public-sector support to innovation. This will be achieved by: actively promoting the work of LCICG and its funding programmes through its website, conferences, workshops and press releases; and publishing details of the LCICG's portfolio of priorities and funding plans, as set out above.

[12] https://www.innovateuk.org/-/knowledge-transfer-networks

[13] https://www.innovateuk.org/-/catapult-centres

Box 8: Catapults – a new force for innovation and growth

A Catapult is a physical technology and innovation centre where the very best of the UK's businesses, scientists and engineers work side by side on late-stage R&D, transforming 'high potential' ideas into new products and services to generate economic growth. Established and overseen by the **Technology Strategy Board**, nine Catapults will receive more than £1bn of public and private-sector investment over the next few years.

The **Offshore Renewable Energy Catapult** has been set up to lead the transformation of the offshore renewable industry's approach to innovation, working with the sector to identify, develop and rapidly commercialise innovative technology solutions in emerging UK and overseas markets.

The **Energy Systems Catapult** will, when operational in mid-2015, help UK businesses to create systems capable of handling future energy demand and supply, both in domestic and overseas markets. It will play a part in accelerating the market viability of technologies that underpin whole energy systems, building on existing UK strengths in this area.

3. Maintaining and updating our shared analysis of innovation needs.

The TINAs are a valuable tool in prioritising and coordinating innovation support. They are essential to LCICG members' work and are valuable to others as a source of evidence. However, the energy system is constantly evolving and new data and insights continue to emerge. Any analysis can quickly become out of date. We will ensure that the TINA analysis is maintained, updated and broadened appropriately so it can continue to inform our investment decisions.

To that end the LCICG will:

- Monitor developments in each of the TINA technology sectors as well as in the wider energy system and, at least once a year, formally consider whether new developments or data warrant a new analysis of innovation needs;
- For those technologies identified as in need of a refresh, carry out a partial or full review of the underpinning data and assumptions, and issue a new or updated TINA Summary Report;
- Monitor developments in the energy system and, if evidence suggests that a particular technology sector or a cross-cutting challenge has new and significant needs that may require a coordinated, prioritised response from the public sector, we will commission TINA analysis for that technology area or challenge.

4. Strengthening our international engagement and leverage.

Many countries encounter similar issues to our own, and the scale of the challenges we face is often larger than any single country's budget can address. Partnering with other countries to share information, access skills and expertise, coordinate support programmes and to co-fund programmes of mutual interest can therefore deliver significant benefits to our national and international objectives. Partnering with other countries can also help UK businesses find, develop and access international markets for their products and expertise.

However, international collaborations can be complex and time consuming to arrange, and there is often a risk that the benefits will not flow equitably to the countries investing. Collaborative activities therefore need to be carefully chosen and managed.

The LCICG members are engaged in a range of international innovation support programmes, but there is scope to further broaden and deepen our international partnerships. The EU and its programmes provide a very significant opportunity to coordinate activities to benefit Europe's energy objectives and to leverage direct value for UK companies and the UK energy system. There are also valuable opportunities to partner on key technologies with countries outside the EU, among both established and emerging economies.

To that end the LCICG will:

- Continue to engage with and support the delivery of the EU's Strategic Energy Technologies Plan and contribute to the development of the EU Integrated Roadmap and Action Plan for energy technology development;
- Seek to increase the UK's share of the EU's innovation funding steams – in particular the Horizon 2020 Energy Programme;
- Conduct an analysis of partnership opportunities within and outside the EU to identify priorities for future joint action programmes, and to develop a shared, coordinated plan to build strategic partnerships on particular technologies with a number of prioritised countries.

Box 9: The European Union's SET Plan

The EU's Strategic Energy Technology (SET) Plan outlines what needs to be done, from an EU perspective, in terms of energy technology RD&D to achieve its 2020 energy and emissions targets, and its 2050 vision. The SET Plan's objectives are: sustainability; security of supply; and retaining EU competitiveness. Delivery of the Plan has been costed at up to €80bn over ten years.

As part of the delivery of the SET Plan, the EU has set up the European Energy Research Alliance (EERA). EERA aims to strengthen, expand and optimise EU energy research capabilities through the sharing of world-class national facilities in Europe and the joint realisation of pan-European research programmes (EERA Joint Programmes). EERA streamlines and coordinates national and European energy R&D.

Horizon 2020 is the EU's framework programme for research and innovation, aiming to fund the research necessary to achieve Europe's 2020 targets. Within Horizon 2020, at least €5.9bn will be spent on supporting non-nuclear energy technology development, with a main focus on facilitating SET Plan implementation.

The SET Plan and Horizon 2020 offer significant opportunities for the UK in terms of leadership, funding and the UK's direct involvement in the development of strategically important energy technologies.

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Chapter 4
Prioritising Future Investments

This chapter outlines the conclusions of our work to identify key innovation needs, and describes how we plan to prioritise between those needs to develop future work programmes.

The Need for Prioritisation

Significant public-sector investment in RD&D for low carbon technologies is needed to accelerate deployment, reduce costs and to capture economic gains. However, as the analysis summarised in Part 2 makes clear, the UK cannot afford to take a leading role in developing all major low carbon technologies. We need to target public-sector investment on those technology areas where we can have the most impact in achieving our energy and emissions targets and our economic growth objectives.

A core pillar of the LCICG's work to date has been the development of a common understanding of innovation priorities for delivering our energy and growth objectives. Over the last three years we have developed and published a detailed analysis of innovation needs – the TINAs. In this document we have summarised and updated the key findings from the TINAs and have developed the analysis further by considering in more detail the implications for future funding programmes.

As we prepare for the next public-sector Spending Review, which is likely to take place in 2015, difficult choices will need to be made about how much to invest and how to target that investment. The LCICG members are committed to working together to coordinate our analysis and prioritisation processes to ensure that future programmes are well aligned and that together we provide support where it can have the most impact.

In the following sections we detail our approach to prioritisation, the evidence we have collated to date and the principles we will follow in developing our programmes for the period 2015 to 2020.

The Technology Innovation Needs Assessments

A shared approach to prioritisation needs to be founded on a shared understanding of the problems to be addressed. The TINA project was launched in late 2010 as a collaborative effort between the LCICG members. The project's aim was to create a robust, shared knowledge base to inform coordinated programme planning and to support a portfolio approach to innovation investments. The output from that work to date has been TINA Summary Reports on ten technology families. A further TINA Summary Report, on Hydrogen for Transport, is due to be published early in 2014 and we expect to produce further reports and updates to existing reports later this year.

The TINA project built on existing research and experience from across government, industry and academia and applied a consistent methodology to identify and value the potential for innovation within a given technology sector. For each selected

Box 10: The LCICG working in partnership – Offshore Wind

The offshore wind industry is growing rapidly and the UK is a global leader in deployment. Innovation in this sector has a significant role to play in reducing the cost of energy from offshore wind and in creating opportunities for UK growth.

The LCICG's core members expect to invest in excess of £100m over four years to support RD&D of offshore wind technologies. That funding is supporting a number of multi-year LCICG programmes. **Scottish Enterprise** for example has, since 2011, run three funding calls to support projects with the potential to reduce the cost of offshore wind energy and/or accelerate deployment, with a fourth call due in early 2014. There have also been four calls under the **DECC-Technology Strategy Board Offshore Wind Component Technologies Scheme**, leading to the award of nearly £11m of DECC funding to fifteen projects by the end of 2013, with further projects to be announced later in 2014.

Complementing these schemes are collaborative programmes that leverage public and private investment. The **Carbon Trust's Offshore Wind Accelerator** is a £45m programme that involves nine offshore wind developers, and is two-thirds funded by industry and one-third funded by **DECC**. It focuses on foundations, access systems, wake effects, electrical systems and cable installations and aims to reduce the cost of offshore wind by at least 10% by 2015. The **ETI** public-private partnership has also made targeted investments in offshore wind, focused on accelerating levelised cost of electricity reduction (e.g. the development of low cost long blades) and enabling more of the UK's high-quality offshore wind resources to be accessed (e.g. floating platforms for deeper water applications).

LCICG members are also investing in the skills and knowledge needed to tackle current and future offshore renewable energy challenges. Jointly funded by the **ETI** and **EPSRC**, the **Industrial Doctorate Centre in Offshore Renewable Energy** is a multi-disciplinary centre that brings together diverse areas of expertise to train engineers and scientists.

technology area, the TINAs consider the principal components of that technology and identify the key innovation needs in the short and medium term necessary to meet our long-term objectives. Each TINA includes an assessment of:

- The value of the technology and the innovation in meeting emissions and other energy policy targets at lowest cost;
- The value of the technology and the innovation in aiding UK economic growth; and
- The case for UK public-sector support, including a review of international and private-sector activity and a consideration of market failures.

The conclusions reached in the TINA Summary Reports were informed and validated by extensive consultation with industry and academic experts, through workshops, individual discussions and peer review.

In deciding which technologies to analyse, we have focused our attention on those which previous modelling and analysis (in

Box 11: The LCICG working in partnership – Nuclear Energy

Innovation can play a significant role in reducing the cost of construction and operation of new-build nuclear power plants, and in the life extension and decommissioning of existing plant. The LCICG's core members expect to invest over £100m over four years in nuclear R&D.

One example of the sort of innovation we are keen to foster is the **LaserSnake** project (pictured) which combines advanced robotics and laser cutting technology to create an innovative, safe and cost-effective tool for the multibillion pound nuclear decommissioning market. The project is being delivered by a consortium led by UK SME OC Robotics and it received £6m of co-funding from the **Technology Strategy Board**, **DECC** and the **Nuclear Decommissioning Authority** to deliver a full-scale demonstration.

Our funding is also supporting infrastructure projects and programmes such as the **National Nuclear User Facility** which is receiving £15m of funding from **EPSRC** and **DECC** to bring together previously fragmented nuclear research facilities in the UK.

The LCICG will be working closely with the newly established **Nuclear Innovation Research Advisory Board** and the **Nuclear Innovation Research Office** to ensure nuclear R&D priority areas are addressed in a coordinated manner.

particular by individual LCICG members, the Energy Research Partnership and the Committee on Climate Change) suggested were of particular importance to government objectives, and where significant and coordinated UK public-sector backed support was likely to be needed. TINAs have been produced covering:

Bioenergy (Page 50)	Carbon Capture and Storage (Page 54)	Domestic Buildings (Page 56)
Electricity Networks and Storage (Page 59 & 62)	Heat (Page 64)	Hydrogen for Transport[14] (Page 66)
Industrial Sector (Page 69)	Marine (Page 71)	Non-domestic Buildings (Page 56)
Nuclear Fission (Page 74)	Offshore Wind (Page 77)	

This list of TINAs is not intended to be a comprehensive list of all technology families that could contribute to the UK's energy and growth objectives. We continue to monitor developments and will expand the evidence base to include other technologies if we identify a need for TINA analysis. For 2014, we have identified three areas for possible further work – Solar PV, Industrial CCS and Heat Networks.

[14] Publication of the Summary Report of the Hydrogen for Transport TINA is expected in early 2014.

Summary of TINA Conclusions

Table 1 below summarises the headline conclusions from the TINA analysis. Figures are presented in a format corresponding to the TINA deployment scenarios, with a leading central estimate followed by a low to high range in brackets. The deployment figures are based on scenarios, to inform our consideration of the innovation needs, but they are not forecasts or targets. More detail on individual technology areas can be found in Part 2 of this document and in the relevant TINA Summary Report.

Table 1: Summary of potential of innovation up to 2050 for all TINA technologies (cumulative, discounted)

Technology	Global deployment	UK deployment	Cost reduction potential for UK	Value creation potential for UK
Bioenergy	61 EJ (14-87 EJ)	963 PJ (278-2586 PJ)	£42bn (£6-101bn)	£19bn (£6-33bn)
Carbon Capture & Storage	431 GW (202-1011 GW)	30 GW (11-60 GW)	£22bn (£10-45bn)	£8bn (£3-16bn)
Domestic Buildings	–	–	£16bn (£4.5-37.5bn)	£1.7bn (£0.6-3.7bn)
Electricity Networks	–	–	£4.4bn (£2-8.6bn)	£5.1bn (£3-7.9bn)
Electricity Storage	–	27.4 GW (7.2-59.2 GW) 128 GWh (31-286 GWh)	£4.6bn (£1.9-10.1bn)	£11.5bn (£3.4-25.7bn)
Heat	-	-	£30bn (£14-66bn)	£6bn (£2-12bn)
Hydrogen for Transport	12% of LDVs (0-26% of LDVs)	20% of LDVs (0-50% of LDVs)	£35.7bn (£0-88.7bn)	£20.2bn (£0-48.1bn)
Industrial Sector	-	-	£20.3bn (£14.4-26.9bn)	£3.9bn (£1.5-6.5bn)
Marine – tidal stream	13 GW (0-52 GW)	2.5 GW (0-5 GW)	£1.2bn (£0-2bn)	£0.3bn (£0-1.3bn)
Marine – wave	46 GW (0-188 GW)	4 GW (0-8 GW)	£1.6bn (£0-3bn)	£0.9bn (£0-£3bn)
Non-domestic Buildings	-	-	£12.6bn (£3.9-23.8bn)	£1.7bn (£0.5-3bn)
Nuclear Fission	1223 GW (482-1973 GW)	40 GW (16-75 GW)	£5.7bn (£2-14.5bn)	£7.2bn (£1.5-13bn)
Offshore Wind	439 GW (119-1142 GW)	45 GW (20-100 GW)	£45bn (£18-89bn)	£18bn (£7-35bn)

Prioritising Future Public-Sector Support

Most of the LCICG members' existing programmes run until March 2015 or March 2016. Over the next 18 months, LCICG members will need to develop and secure funding for their innovation programmes for 2016/17 and beyond.

Each LCICG organisation has its own mission and particular focus, and each organisation will develop its own programme. However, the core LCICG members are committed to working together to ensure that those individual programmes are aligned and complementary and add up to a coherent whole that provides the right support for the most important innovation needs.

The first step in our shared prioritisation process was the TINA evidence base. This Strategic Framework is a key part of the next step. In the sections below and in the technology sections in Part 2, we build on the TINA evidence to identify specific innovation needs which the LCICG members view as priorities for investment in the remainder of this decade. The final step in our prioritisation process, which we will complete by 2015, will be to develop and agree an aligned portfolio of prioritised work programmes.

In order to identify those priority innovation needs, we have built on the already extensive analysis and consultation that went into the TINAs. We have pooled and compared the expertise and analysis conducted by all the LCICG members, and consulted with a wide range of academic and industry experts through workshops and bilateral discussions. The results of that analysis are 44 priority innovation needs across the eleven technology families. These needs are summarised in Table 2 below and outlined in more detail in Part 2.

Addressing these priority needs would help deliver the innovation that our analysis suggests will be of significant value to UK objectives but which will likely not happen, or not happen quickly enough, without UK public-sector investment. In other words, it is unlikely that industry investment alone or public-sector investment in other countries will deliver the UK's needs. The activities identified are those that require support in the short to medium term – roughly defined as before the end of this decade.

Box 12: The Sustainable Power Generation and Supply Programme

The Sustainable Power Generation and Supply Programme (SUPERGEN) is the focus of the **Research Councils UK** Energy Programme's investment in sustainable power generation and supply technologies, with over £76m currently invested in seven key areas: energy storage; hydrogen and fuel cells; sustainable power networks; wind; marine (wave and tidal); solar; and bioenergy. The SUPERGEN programme's mission is to bring the UK's academic community together in each field to address the underpinning research challenges holding back the deployment of low carbon technologies. The programme also provides an easily accessible point of contact for industry and government. The programme was renewed for a third phase in 2011, moving from large fixed consortia to a hub and spoke model that is more open and flexible, and easier to manage.

The 44 needs identified will be our primary focus when considering the development of future programmes. However, this list is not intended to be an exhaustive or fixed list of everything that the UK public sector might support. A wide range of factors could potentially impact on the translation of the priorities described here into operational investment programmes. These factors include but are not limited to: political changes and policy developments; shifts in the prevailing investment climate; socio-economic, environmental and regulatory influences; and the technical success or failure of individual technologies. This list of priorities therefore needs to be kept under regular review, and our programmes will need to be flexible to adapt to changing circumstances.

In addition to the priorities listed, LCICG members may choose to support other activities. For example, that may be in cases where UK companies have particular strengths in niche areas that if supported could create economic growth opportunities. At the earlier stages of the innovation journey, public-sector funding also needs to support a broad base of research, including highly speculative activities. Our list of priorities is therefore focused primarily on applied research and beyond.

Table 2: Summary of innovation priorities out to 2020 for all TINA technologies

Technology	Priorities for public-sector support	Indicative scale of funding required (£)
Bioenergy	• R&D to enhance crop yield on marginal land.	• High tens of millions
	• Demonstration of improved integrated syngas synthesis, clean-up and flexible reactor development.	• High tens of millions
	• RD&D on advanced biofuels from sustainable crops.	• Low tens of millions
	• Support for efficiency gains and component-level improvements for near commercial conversion technologies.	• High tens of millions
	• Biomass CCS research programme.	• High tens of millions
	• R&D into measuring and monitoring of compliance in sustainability criteria.	• Low millions
Carbon Capture & Storage	• Sub-sea storage, measurement, monitoring and verification.	• Low hundreds of millions
	• Advanced capture development.	• High tens of millions
	• CCS transport and storage network configuration	• Low millions
Domestic and non-domestic Buildings	• R&D aimed at bridging the gap between forecast and actual performance.	• High tens of millions
	• RD&D to identify and promote efficient operation.	• High millions
	• Establish a forum where manufacturers can collaborate to test their products in combination.	• High tens of millions
	• Dissemination of LCICG member programme results.	• Low tens of millions
Electricity Networks	• Demonstration of an integrated platform of technologies.	• High hundreds of millions
	• Increased knowledge sharing and coordination.	• Low millions
	• R&D in electric vehicle integration technologies and installation methods.	• High tens of millions
Electricity Storage	• Roadmap for grid-appropriate storage technologies.	• Low hundreds of thousands
	• R&D for grid-level storage concepts	• High tens of millions
	• Demonstration of an integrated platform of technologies.	• High tens of millions

Technology	Priorities for public-sector support	Indicative scale of funding required (£)
Heat	• System level integration and design solutions for renewable heating technologies. • RD&D for components, design, and installation of heat pumps. • RD&D for design, operation, and integration of heat/cold stores.	• Low tens of millions • Low tens of millions • Low tens of millions
Hydrogen for Transport	• Industrialisation of vehicle and component production. • RD&D of low carbon hydrogen production. • RD&D of refuelling infrastructure.	• Low tens of millions • High millions • Low tens of millions
Industrial Sector	• RD&D for the use of low carbon substitutes. • Programmes to identify and pilot alternative process technologies. • Industrial CCS.	• High tens of millions • High tens of millions • High tens of millions
Marine – wave & tidal stream	• Demonstration of wave devices. • Initial deployment of first arrays. • R&D to address challenges identified in first arrays. • Operational improvements: health and safety; resource characterisation; and standardisation. • R&D for pipeline of second generation tidal stream technologies and novel wave devices. • Towards deployment of first commercial-scale farms.	• High millions • High tens of millions • Low tens of millions • Low millions • High millions • High tens of millions
Nuclear Fission	• Future nuclear energy technologies. • Advanced component manufacturing. • Fuel cycle technologies. • Waste management and decommissioning. • Construction, installation and commissioning. • Small Modular Reactors.	• High tens of millions • High tens of millions • High tens of millions • High tens of millions • Low tens of millions • Low hundreds of millions
Offshore Wind	• Offshore demonstration sites and site pipeline. • Transmitting electricity from far-shore wind farms. • Reduce installation time per turbine. • R&D to improve wind farm yield and turbine reliability. • Cost-effective serial manufacturing and production of foundations.	• High tens of millions • Low millions • High tens of millions • High tens of millions • Low tens of millions

Funding for Future Innovation Support

For each innovation support activity, we have also estimated the level of public-sector investment likely to be required to fully address that innovation need. These figures were derived from a cross-cutting assessment of all the TINAs and reflect the costs associated with different technologies as they progress through the RD&D stages, drawing on the experience of LCICG members in developing and delivering innovation programmes. The public-sector figures assume that the private sector is co-investing in these projects, providing between 40% and 75% of the funding, depending on the stage of development.

We estimate that delivering all of the innovation support activities identified would require the UK Government to invest somewhere between £3bn and £4bn over the next 5-7 years. By comparison we estimate that the equivalent spend over the five years to 2016 is around £1-1.5bn.

There is a clear gap, therefore, between current investment levels and the amount of funding needed to support all of the technology families considered here. Levels of public-sector investment in low carbon technology innovation in 2015 and beyond will depend on a range of political and economic factors at the time. It is very likely though that UK public-sector funding alone will not be sufficient to address all the innovation activities identified in Table 2.

One approach that may help to address the gap is to leverage more investment from other sources. We will be exploring ways of working with partners to maximise the innovation impact of other public-sector budgets, as well as working to facilitate

Box 13: The LCICG working in partnership – Hydrogen and Fuel Cells

Hydrogen technologies have potentially important roles in the future UK energy system, with possible applications in transport, power and heat. The LCICG's core members have current and planned investments worth up to £60m to support innovation in hydrogen technologies. That funding is supporting projects such as:

- The **Aberdeen Hydrogen Bus Project** in which the **Technology Strategy Board**, **Scottish Enterprise** and the **Scottish Government** are working with key industry players to fund and deliver Europe's largest demonstration of hydrogen-fuelled buses;
- The **Zero Emission London Taxi Demonstration and Commercialisation** project, which is co-funded by the **Technology Strategy Board** and **DfT** with a grant of over £5m. This is accelerating the introduction of commercial fleets of zero emission hydrogen fuel cell hybrid taxis. These taxis have been trialled in London and were in use at the 2012 Olympic Games. The project has produced a fuel cell electric vehicle with a 250 mile range and a refuelling time of only a few minutes, capable of meeting the demanding duty cycle of one of the icons of London and British transport.
- **Carbon Trust's Polymer Fuel Cell Challenge.** This development programme is funded by **DECC** and is currently supporting four novel fuel cell technologies, with the aim of reducing the cost of automotive fuel cell stacks by one third to help make fuel cell electric vehicles cost competitive with internal combustion engines.

and encourage greater private-sector investment. We will also, as described in Chapter 3, be looking for ways of working in partnership with other countries to burden share and leverage each other's investments. It is clear however that, even with increased leverage for our investments, we will still need to make some tough choices over the next few years to avoid spreading our resources too thinly, and to prioritise our resources on a subset of technologies where we can have most impact on our objectives.

This means that some technologies are unlikely to develop in the way or at the pace we would wish. Those choices therefore need to be carefully considered and informed by strong evidence and analysis. The LCICG members will be working together to ensure a coordinated approach to making those choices. To help us do so consistently, we have agreed a common set of criteria for programme and project selection, as set out below.

Common Criteria for Programme and Project Selection

In developing our future programmes we will consider and weigh options against the following criteria:

- **Impact on energy policy objectives** – supporting projects that accelerate and broaden the availability of secure, low carbon energy supply, distribution or end-use technologies and/ or reduce the cost of energy from a low carbon energy system.
- **Impact on economic growth objectives** – supporting projects that: help build and sustain a strong UK supply chain; help UK-based companies, large and small, secure a greater share of energy investment; encourage inward investment; and help increase UK companies' exports.
- **Impact on knowledge, skills and capabilities** – supporting investments that create and sustain world-class research and innovation centres in the UK in our priority technologies, and that develop people with the capability to enable the UK to lead the RD&D of new technologies.

Different LCICG members may emphasise some of these criteria more than others. However, we value them all and our shared aim is to build a portfolio of programmes and projects that maximises the impact on all.

In addition, when selecting programmes or projects we will consider:

- **The additionality of government funding** – the likelihood that the innovation will happen without public-sector funding. We will only invest if UK public-sector funding looks to be essential to a project's success, i.e. investment by the private sector or by other countries on its own will not be sufficient.

- **The timing and availability of suitable projects** – this is a key consideration, particularly at the later stages of the innovation journey. No matter how pressing the innovation need, we cannot invest if innovators do not bring forward suitable projects.
- **The delivery risk** – innovation projects by their nature have significant delivery risks and the purpose of our programmes is to encourage some risk taking. Different programmes acting at different stages of the innovation journey will accept different risks, but all programmes need to consider the likelihood of success and to strike a balance.
- **Leverage and materiality** – in determining the level of support, we aim to maximise direct and indirect leverage whilst ensuring materiality and maintaining additionality. Appropriate leverage depends on the project type, the stage of development and the extent of market failures. At later stages, industry co-funding of projects is important evidence that a genuine market opportunity exists.
- **The likelihood of subsequent successful commercialisation** – for an innovation to contribute to our objectives, it needs to be commercialised and deployed. We therefore consider: the availability of a future market; the likelihood of sufficient subsequent investment; and the availability of the skills, resources and infrastructure necessary to enable commercialisation.

Box 14: The LCICG working in partnership – Marine Energy

The UK has a large natural resource of marine energy and there are more wave and tidal stream devices being tested in the UK than anywhere else in the world. However, there are significant challenges to overcome before full commercialisation can be achieved. The LCICG's core members expect to invest up to £60m between 2011 & 2015 to support marine energy technology innovation projects and programmes.

A total of £38m has been made available to support the very first marine energy arrays in UK waters, and array-level infrastructure, through **DECC's Marine Energy Array Deployment** fund and the **Scottish Government's Marine Renewables Commercialisation Fund** (MRCF), managed by the **Carbon Trust**.

LCICG members are supporting the design, construction and installation of individual full scale devices. For example: Scotrenewables' 2MW full-scale SR2000 floating tidal turbine (pictured) is being supported by the **WATERS** (Wave & Tidal Energy RD&D Support) Programme, a joint venture between **Scottish Enterprise, Highlands & Islands Enterprise** and the **Scottish Government**; the **ReDAPT** project – an innovative 1MW buoyant tidal turbine being installed and tested by Alstom with funding from the **ETI**, building on earlier demonstration support from the **Technology Strategy Board**; and the deployment and testing of full-scale wave prototypes by Aquamarine Power Ltd and Pelamis Wave Power, co-funded by the MRCF.

Array-level infrastructure innovation is being supported by the **Marine Energy Array Technology Programme** – a collaborative venture between the **Technology Strategy Board** and **Scottish Enterprise**. Projects include the development of a buoyant Marine Energy Subsea Hub that offers rapid deployment and retrieval by low cost marine vessels, and the Synthetic Mooring Rope Technology project. These projects and others like them could feed into the Marine Farm Accelerator, a consortium of marine energy project developers being established and supported by the **Offshore Renewable Energy Catapult** and the **Carbon Trust**.

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Chapter 5
Summary and Next Steps

This chapter summarises the conclusions drawn in the preceding chapters and sets out the next steps.

The Role of the LCICG

This document has set out the LCICG's Strategic Framework for the coordination, and the future prioritisation, of UK public-sector support for low carbon technology innovation. It has described our shared aims and objectives and reviewed the ways in which public-sector backed support for innovation in low carbon technologies is delivered in the UK. It has also summarised the progress LCICG members have made to date in strengthening coordination, while outlining how we plan to work together to further improve our coordination and impact in the future.

Building on the previous TINA analysis, we have put forward a shared LCICG assessment of the key innovation needs that, if they are to be addressed, will likely require government support in the remainder of this decade, together with an assessment of the scale of support that would be required to address those needs. We have set out current LCICG views on priorities, but these may need to be refined in the months and years ahead if new evidence emerges. The exact role and deployment of each technology in the energy system up to 2050 cannot be predicted. A portfolio approach is required that uses a range of mechanisms to support innovation across a variety of technologies, in a way that maintains options for realising the optimal future energy system.

Future Prioritisation and Programme Planning

Significant public-sector investment in low carbon technology RD&D is needed to accelerate deployment and to capture economic gains. However, the UK government alone cannot support all the innovation needs identified, and difficult choices will have to be made about how much to invest and how to target that investment. LCICG members will continue to focus their resources on those innovations where the need is most compelling and where our investment can have the most impact.

The next step, to be completed in 2014 and 2015, is for the core LCICG members to work in partnership with industry and innovators to develop an aligned and complementary portfolio of prioritised innovation support, including co-funded projects and programmes. Those future investment decisions by LCICG members will build on the analysis and principles in this Strategic Framework. LCICG members will also be working together to strengthen external communications, to foster wider understanding of technology priorities, and to help innovators and investors access appropriate funding and collaboration opportunities. In addition, further work will be undertaken with partners in the public and private sector to promote increased investment in low carbon innovation, including by capitalising on international partnerships.

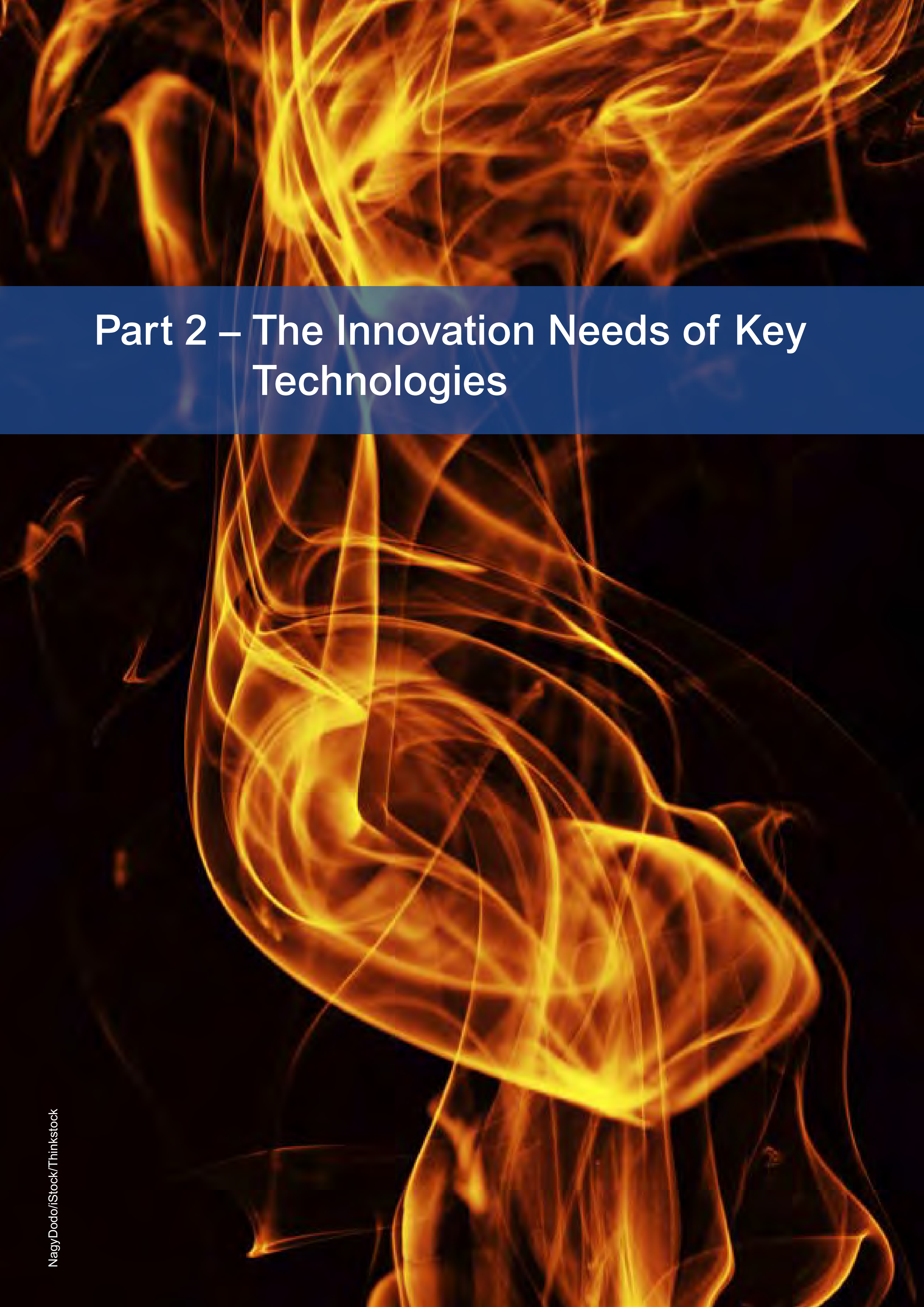
The Innovation Opportunity

Energy innovation is difficult, costly and takes time. But investing in low carbon technology innovation now will help us to meet our future emissions targets and energy needs cost effectively, while enabling the UK to keep pace with international competitors, to access global markets and deliver on the promise of sustainable economic growth.

There remains substantial unrealised potential for UK innovation, especially given our world-class research base, our innovative companies, and the attractiveness of our skilled science and engineering workforce to foreign investors. The UK is well placed to capitalise on its strengths and competitive advantages by leading the future development of key low carbon technologies.

By continuing to work together, LCICG members will enhance their contribution to the creation of a low carbon, energy-efficient future, and help put the UK on the path to becoming a more prosperous and globally competitive economy.

Part 2 – The Innovation Needs of Key Technologies



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Introduction

In the following technology sections, this document updates and develops the TINA evidence to identify areas within technology families that LCICG members consider to be key innovation needs out to 2020, and assesses the scale of public investment likely to be required to address those needs. Each section is structured as follows:

- Context: introduction to the technology and the TINA, including commentary on current status and market conditions;
- Potential for innovation: summary of TINA-identified value of innovation in meeting emissions and energy policy targets, and for UK economic growth;
- Vision: our shared view of what could be achieved by 2020; and
- Priorities for public sector support: our current view of priority areas for future or continued support by LCICG members.

Building on the stakeholder consultations undertaken for the original TINAs, in spring 2013 workshops were held to inform the preparation of this document, involving relevant experts from industry, academia and LCICG organisations.

In assessing the scale of public investment, comparative analysis has been undertaken across all the TINAs, considering the development stage of each technology, the type of intervention needed and the likely cost of delivering all the required cost and efficiency improvements. These funding level assessments are by their nature imprecise and are only intended to be indicative.

Our assessment of the public investment required takes into account the leverage that could be achieved at each RD&D stage from the private sector and other sources. While LCICG members may fully fund the most uncertain phases of primary research, as technologies progress our role is increasingly one of enabling industry investment by co-funding and sharing risk.

The technology sections here broadly align with the TINA technology families. However, Electricity Networks and Storage has been split into two sections to allow a fuller discussion, while the two areas of Buildings technologies have been combined into one section. All the technology discussions build on the TINAs and the analysis of innovation needs is therefore presented in a technology-specific manner. However, it is important to remember that low carbon technologies also need to be considered from the perspective of the UK's whole energy system, and that socio-economic, environmental and regulatory factors also have a bearing.

The following sections include extracts from the TINA documents, but for brevity much of the background and supporting analysis has been excluded. Unless otherwise cited, the figures quoted are derived from the TINAs and can be found in the published Summary Reports.[15] For this reason, these figures are not referenced

[15] All of the TINA Summary Reports published to date can be found on the LCICG website.

again in this document; the only sources quoted are for those data which are not from the TINAs.

Figures are presented in a format that corresponds to the TINA deployment scenarios, with a leading central estimate followed by a low to high range in brackets. These scenarios are not predictions, but are intended to illustrate the potential for cost reduction and value creation at different deployment levels. They draw on modelling of both technology and market parameters between now and 2050, and we present here a low to high range of outcomes that are considered possible, with a central scenario quoted as a point of comparison. However, this should not be taken to imply that the central scenario for a particular technology is the most likely outcome. Similarly, while some of the high scenarios are potentially achievable, there may be factors that limit the prospect of these outcomes being realised. The technologies with the greatest potential are those that promise to deliver significant value in terms of cost reductions and economic benefits under a range of scenarios.

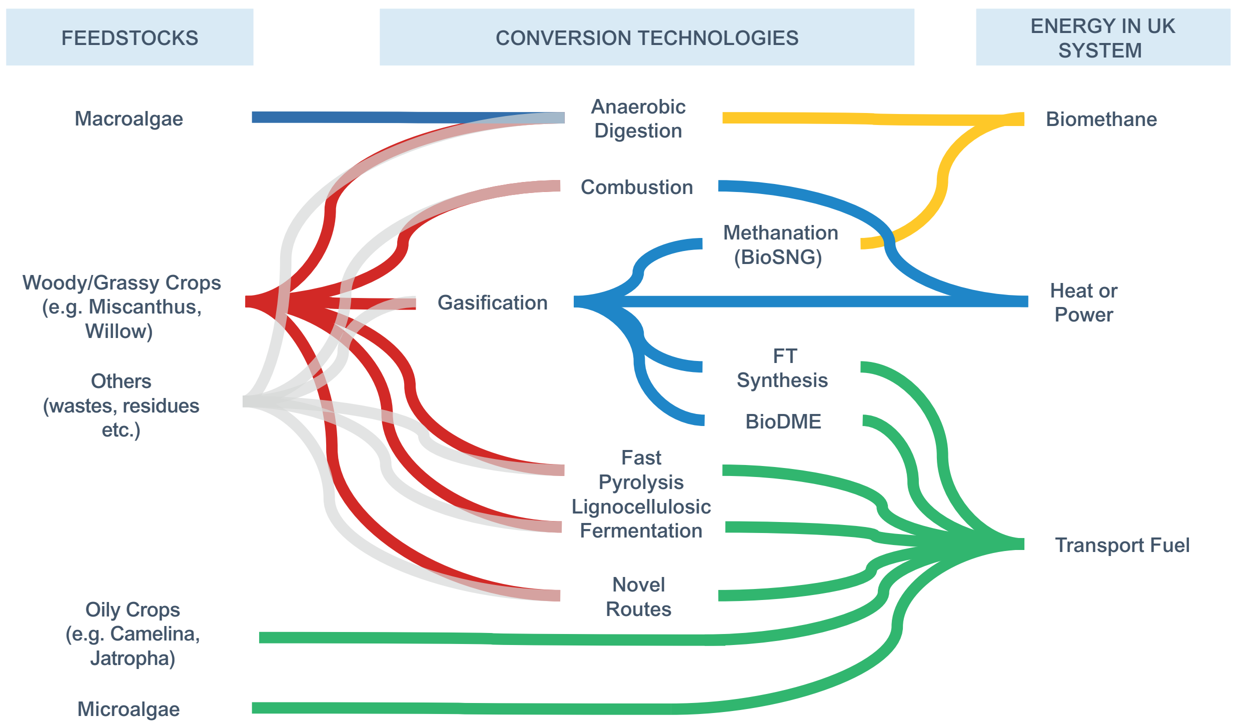
1. Bioenergy

Sustainably sourced biomass is a renewable energy source which could contribute significantly to meeting the demands of all sectors of the UK energy system (power, transport fuel and heat). Bioenergy resources are valuable to the UK energy system because of their flexibility, cost, compatibility with existing infrastructure, and their potential to generate negative emissions via CCS. They could also play a role in contributing to UK energy security. Successfully harnessing sustainably-sourced bioenergy could meet c. 8-21% of the UK's total primary energy supply by 2050.[16]

A subset of bioenergy technologies was chosen for detailed TINA analysis. Selection was based on a high-level review of plausible future deployment levels, technological maturity, ability to use sustainable feedstocks, and innovation potential (Figure 4).

Bioenergy is a broad term covering a wide variety of non-fossil fuel energy sources. The bioenergy sector is currently characterised by large-scale deployment of first generation liquid biofuel technologies, using annual starch or oil crops for the feedstock, and co-firing of biomass for electricity generation using woody pellets. However, the bioenergy value chain is highly complex and questions remain regarding the sustainability and sufficiency of feedstock supply, particularly in the context of potential competition with food production. There is a need to characterise the impacts of each fuel and feedstock and what they are replacing in the energy chain. This drives a need to develop the future sector around sustainable domestic feedstock grown on non-prime agricultural land, instead of imports. The industry is also looking to adapt existing supply chains to introduce more sustainable crop residues and other wastes, feeding into advanced process technologies to overcome these concerns.

Figure 4: Bioenergy value chain for routes included in TINA



[16] HM Government, *UK Bioenergy Strategy*, April 2012.

Potential for Innovation

It is essential that short and medium-term innovation in bioenergy helps to develop and establish a long-term supply chain, positioning the UK for longer-term decarbonisation. The greatest short-term gains for the UK will come from investment in more efficient and reliable operation of early conversion technologies and making better use of agricultural by-products. Medium-term gains will come from improved energy crops and more efficient production of advanced biofuels. Innovation in sustainable feedstocks could generate cost reductions in the range of 53-77% and save the UK c. £12bn (range of £2-40bn[17]) to 2050. Conversion technologies, particularly gasification systems and advanced biofuel conversion technologies, could generate cost reductions of 48-80% by 2050, cumulatively saving the UK energy system c. £23bn (range of £0-78bn).

Global bioenergy markets are estimated to have a cumulative turnover of c. £10tn (range of £2-17tn), which the UK could capitalise on by building on its world-class academic, industrial and commercial strengths. The UK has the potential to be world leading in the whole system analysis of the environmental and cost impacts of the bioenergy ecosystem. By 2050, successful innovation in targeted technologies could save the UK energy system c. £42bn (range of £6-101bn) and help create a UK industry that could contribute an estimated c. £19bn (range of £6–33bn) to GDP up to 2050 (Table 3).

Objectives

A foundation for future bioenergy deployment in the UK will be the development of new sustainable energy feedstocks adapted to UK conditions. Another near-term step towards viable deployment would be successful demonstration of gasification technologies. Deployment of gasification for electricity generation (biopower) pre-2020 would help establish the bioenergy value chain for future deployment of bioheat (through biomethane) and biotransport fuels (including shipping and aviation fuels). Furthermore, successful deployment of CCS could help incentivise bioenergy by enabling negative emissions. However, scaling up deployment of biopower and biofuels between 2020 and 2030 is dependent on the availability of UK-based sustainable feedstocks. In order to position the UK to take maximum advantage of these two developments, more work is needed to establish the potential future scale of sustainable domestic biomass and waste feedstock, while continuing to develop advanced conversion and CCS technologies.

Table 3: Potential of innovation in bioenergy up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Global deployment by 2050[18]	14 EJ	61 EJ	87 EJ
UK deployment by 2050	278 PJ	963 PJ	2586 PJ
Cost reduction potential for UK	£6bn	£42bn	£101bn
Value creation potential for UK	£6bn	£19bn	£33bn

[17] The high estimate for all the technologies' potential combined is not the same as the sum of their individual high estimates, as they could not all be realised simultaneously due to feedstock constraints.

[18] These figures refer to the energy out, not the total energy content of the feedstock.

Table 4: Potential of cost reduction and deployment of selected bioenergy technologies (cumulative)

Category		Current LCOE	Cost reduction 2020	UK Deployment 2020 (PJ)	Cost reduction 2050	UK Deployment 2050 (PJ)
New Energy Feedstocks	Woody/ Grassy Crops	7 £/GJ	14%	33 (12-47)	54%	217 (160-304)
	Macroalgae	47 £/GJ	37%	0 (0-0)	77%	8 (0-79)
Biomethane	Anaerobic Digestion	14 £/GJ	19%	8 (8-15)	33%	103 (58-156)
	BioSNG	21 £/GJ	55%	0 (0-1)	77%	41 (0-204)
Advanced Biofuel Conversion	Gasification, pyrolysis oil, novel fuels, etc.	33-43 £/GJ	32-52%	0 (0-9)	59-80%	18 (0-324)
Biopower	Gasification	89 £/MWhe	14%	0 (0-0)	48%	38 (0-136)
Bioheat	Small scale	55-120 £/MWhth	5-8%	40 (4-40)	11-15%	18 (0-164)
	Large scale	35-46 £/MWhth	6-7%	0 (0-0)	12-17%	38 (0-102)

Priorities for Public-Sector Support

In order to drive short and medium-term gains in innovation and provide a platform for the long-term competitiveness of the UK bioenergy industry, the most important areas for innovation support from LCICG members have been identified as follows:

RD&D to enhance crop yield on marginal land

This programme would invest in developing the long-term supply of adequate sustainable biomass and new dedicated energy feedstocks on marginal land, and in ensuring the measurement and monitoring of their compliance with sustainability criteria. It could also include RD&D focused on the more rapid establishment of crops. Combined, these could help minimise resource inputs, maximise sequestration and ensure adequate disease resistance to reduce pressure on the agricultural supply chain. Delivery of this priority would require public funding in the high tens of £ millions.

Demonstration of improved integrated syngas synthesis, clean-up and flexible reactor development

Building on the Energy Technologies Institute's Energy from Waste project, significant benefit can be achieved through proof of concept that syngas can be produced, converted and used reliably at scale. Flexible gasification reactor or boiler development would reduce the cost of bioenergy by increasing the variety of usable feedstocks. Delivery of this priority would require public funding in the high tens of £ millions.

RD&D on advanced biofuels from sustainable crops

RD&D on new production techniques for novel and pyrolysis-derived fuels would include pre-treatment technologies, lignocellulosic treatment, and optimisation of biological (enzymatic) or chemical (catalytic) conversion of crops to advanced biofuels and robust fast pyrolysis techniques. In August 2013, the Government announced that it was committing £25m of capital funding, delivered over three years from 2015, to enable the construction of demonstration-scale waste-to-fuel and other advanced biofuel plants. DECC is already funding the £2m Wetland Biomass to Bioenergy SBRI[19] to demonstrate how wetland biomass can be efficiently and sustainably used to provide energy, and is also playing a leading role in EU bioenergy demonstrations worth €73m.[20] Given the level of existing public and private investment, delivery of this innovation priority would require public funding in the low tens of £ millions.

Support for efficiency gains and component-level improvements for near-commercial conversion technologies

Efficiency gains and improvements in near-commercial combustion and gasification for heat, combustion-for-power and anaerobic digestion for biomethane would drive significant system-level cost reductions and support an increase in near-term deployment of bioenergy technologies. Delivery of this priority would require public funding in the high tens of £ millions.

Biomass CCS research programme

This would continue the work of the ETI's 'Biomass to Power with CCS' activities on the adaptation of biomass combustion technology to CCS applications. Delivery of this priority would require public funding in the high tens of £ millions.

R&D into measuring and monitoring of compliance in sustainability criteria

There is scope to improve approaches for measuring and monitoring of compliance in sustainability criteria, including data gathering, sharing and use of associated data. Delivery of the basic R&D associated with this priority would require public funding in the low £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Bioenergy Summary Report* (published September 2012) and the *UK Bioenergy Strategy* (published April 2012).

[19] SBRI is a procurement-based approach, which enables the public sector to engage with industry during the early stages of technology development.

[20] Via two ERANET Plus programmes: 'Bioenergy Sustaining the Future' 1 and 2.

2. Carbon Capture and Storage

There is a broad body of evidence and analysis from organisations such as the Committee on Climate Change[21] and the International Energy Agency[22] which underlines the importance of CCS in reducing carbon emissions. CCS offers many benefits to a low carbon energy and economic system: it allows the flexibility and energy security benefits of fossil fuel combustion with vastly reduced greenhouse gas emissions; when applied to biomass firing it serves as a source of negative emissions; and it is applicable to both power generation and industrial emissions. While many of the innovation challenges presented by CCS for power and industrial applications are similar, the TINA focuses specifically on power sector applications.

The individual technological components of carbon capture, transport, injection and storage have been largely demonstrated at commercial scale. However, component costs and efficiency penalties remain high and key challenges remain around the integration of all these technologies across the CCS chain, which the Government's CCS Commercialisation Programme is now seeking to address. The lack of fully characterised and appraised carbon dioxide (CO_2) storage sites will also jeopardise the optimal (and hence lowest cost) deployment of CCS.

Potential for Innovation

Innovation is critical not only to reducing the cost of deployment but also to making CCS a viable option for the UK energy system. The impact of having CCS available is expected to save the UK hundreds of billions of pounds in cumulative value to 2050. This is in addition to technology-specific savings of c. £22bn (range of £10-45bn) as a result of focused innovation. The UK has the capabilities required to become a strong player in the global market for CCS technology, particularly in offshore transport, storage, engineering and contracting services built on the expertise developed to exploit North Sea oil and gas. Investment in innovation would support the growth of an industry and supply chain that could serve both UK and global markets and contribute an estimated £8bn (range of £3-16bn) to GDP up to 2050 (Table 5).

Objectives

CCS creates a significant opportunity to save energy system costs if adopted early, through the mitigation of technical and economic risk and the introduction of flexible generation based on existing fossil fuel infrastructure. While current estimates show the costs of CCS are relatively high, work by the industry-led Cost Reduction Task Force (CRTF) has suggested that power stations equipped with CCS have the potential to be cost competitive with other forms of low carbon

Table 5: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Global deployment by 2050	202 GW	431 GW	1011 GW
UK deployment by 2050	11 GW	30 GW	60 GW
Cost reduction potential for UK	£10bn	£22bn	£45bn
Value creation potential for UK	£3bn	£8bn	£16bn

21 Element Energy for the Committee on Climate Change, *Potential for the application of CCS to UK industry and natural gas power generation*, May 2010.

22 International Energy Agency, *Technology Roadmap: Carbon Capture and Storage*, June 2013.

power generation, delivering electricity at a levelised cost in the region of £100/MWh in the 2020s.[23] Innovation is required to support this reduction, driving c. 40% reductions in cost to 2050, with sizable savings in novel CCS-specific subcomponents such as CO_2 transport and storage, and enabling the effective delivery of c. 10-35% of total UK power generation by 2050. The recent Government response to the CRTF's recommendations[24] reaffirmed its commitment to supporting research, development and innovation in CCS. In line with the CRTF's recommendations, we anticipate that the Advanced Power Generation Technology Forum will, in consultation with the UK CCS Research Centre (see Box 2 in Part 1), publish an updated analysis of future CCS R&D requirements. This will supersede the research needs set out in DECC's 2012 CCS Roadmap, and will be considered when developing future policy in this area.

Priorities for Public-Sector Investment

The priority areas for continued or future innovation investment led by LCICG members are outlined below, focusing on 'lynch pin' technologies which include critical technology obstacles to deployment and system availability. In addition, on the path to commercialisation, integrated full-chain projects will be needed which bring together capture, transport and storage. This is currently the focus of DECC's CCS Commercialisation Competition, which has been allocated capital funding of up to £1bn.

Sub-sea storage, measurement, monitoring and verification

Public-sector investment is needed to identify, assess and characterise potential storage sites, and assemble best practice measurement, monitoring, and verification protocols. Building on the early work undertaken by the CO_2 Stored database (see Box 2 in Part 1), this would open opportunities for potential collaboration with other North Sea countries and the private sector. Delivery of this priority would require public funding in the low hundreds of £ millions.

Advanced capture development

There are specific leadership opportunities for the UK in the development of certain aspects of CO_2 capture, such as integration with industrial emitters, with coal, load-following gas and, in the future, biomass power generation. These opportunities include existing concepts already at the pilot or demonstration stage, and 'breakthrough' technologies that are currently at an earlier stage of development. Development and pilot demonstration in this area will require public investment to accelerate promising technologies to commercial readiness. There is strong potential for international collaboration with countries that host capture testing pilot and demonstration projects. Delivery of this priority would require public funding in the high tens of £ millions.

CCS transport and storage network configuration

Collaborative studies to identify options for developing configurations for the CCS transport and storage system for both early and future CCS projects would help minimise long-run costs. Attention should also be given to options for the potential to capture industrial process emissions. Delivery of this priority would require public funding in the low £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Carbon Capture and Storage in the Power Sector Summary Report* (published August 2012).

[23] UK CCS Cost Reduction Task Force, *CCS Cost Reduction Taskforce Final Report*, May 2013.

[24] DECC, *CCS in the UK – The Government response to the CCS Cost Reduction Task Force*, October 2013.

3. Domestic and Non-domestic Buildings

TINAs have been published for both domestic and non-domestic buildings. Both assessments examined opportunities in:

- Pre-construction and design, including modelling and software tools for design, retrofit, and district heating;
- Build process, including smart manufacturing and retrofit techniques;
- Building operation, including smart controls and behaviour change;
- Materials and components, including advanced fenestration, insulation, and cooling/ventilation.

Improving energy efficiency within this sector is critical, as the energy used by domestic buildings alone accounts for approximately 25% of the UK's carbon emissions. Non-domestic buildings' energy use accounts for an additional c. 18% of UK carbon emissions.

The UK's non-domestic building floor area is expected to increase by a third by 2050, with 60% of building space already built. Similarly, three-quarters of the domestic building stock for 2050 has already been built. Therefore, in addition to the development of new technologies and high performance new buildings, serious attention needs to be given to better understanding and improving the performance of existing building stock through efficient operation, refurbishment, retrofit of technologies and tackling the gap between intended and actual performance.

Building Regulations set minimum requirements for energy efficiency at the point of construction and when building work is carried out on existing properties. The regulations set technology neutral performance requirements and have been progressively strengthened over the years to help promote innovation in the energy efficiency and low carbon energy sectors.[25] However they do not control the operation or maintenance of buildings, which can result in a gap between forecasted and actual performance.

DECC's 2012 *Energy Efficiency Strategy*, and the more recent 2013 *Update* to this document identify the main market barriers to the adoption of wide-scale energy efficiency, and the policies being introduced to overcome them. The Government's publication *Construction 2025* highlights the potential that exists in renovating our existing building stock; global growth in green and sustainable building construction is forecast to be, on average, nearly 23% a year between 2012 and 2017.

Potential for Innovation

A carbon reduction of 75% by 2050 is achievable in the non-domestic building stock at no net cost. However these, and corresponding domestic sector reductions, will be challenging to achieve without upfront investment in innovation. Additionally, successful innovation in the domestic sector could reduce UK energy system costs by c. £16bn (range of £4.5-37.5bn) and create opportunities for UK industry with the potential to contribute £1.7bn (range of £0.6-3.7bn) to GDP to 2050 (Table 6). Similar innovation in the non-domestic sector could reduce UK energy system costs by c. £12.6bn (range of £3.9-23.8bn) and create opportunities for UK industry with the potential to contribute c. £1.7bn (range of £0.5-3.0bn) to GDP to 2050 (Table 6). This is in addition to carbon reductions and energy efficiency

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[25] To demonstrate compliance with the regulations, the performance of innovative technologies should be verified through testing to, for example, relevant British or European Standards, or third party certification.

gains achieved as a result of policies which support the uptake of existing cost-effective measures, or system level integration and innovation with electricity, gas, or heat networks.

Objectives

Innovative energy saving measures could reduce emissions from domestic buildings by c. 11 $MtCO_2$ (range of 1-26 $MtCO_2$) and from non-domestic buildings by c. 18 $MtCO_2$ (range of 4-35 $MtCO_2$) by 2020. These carbon reductions come almost entirely from innovation in building operation, assuming a 10% uptake of energy-saving measures across the entire building stock over the next decade. Encouraging uptake is in itself a critical area for research and innovation. Innovations in pre-construction and design, and build process, in both new build and major refurbishment, could yield significant value between 2020 and 2050. Post-2030, these areas are predicted to be the dominant source of innovation-driven carbon savings in new buildings. Underpinning all innovations is a need for more data regarding the multitude of factors affecting building performance.

Priorities for Public-Sector Investment

The priority areas for continued or future innovation investment led by LCICG members are outlined below. In addition to these specific activities, public-sector intervention will aim to increase collaboration and integration of RD&D and join up innovation programmes with supply chain, infrastructure, and policy development through the continued efforts of the Green Construction Board and LCICG member programmes.

R&D aimed at bridging the gap between forecast and actual performance

The difference between as-designed forecasted and actual performance is a major barrier to market confidence in the achievement of energy reduction in buildings. This requires analysis of real building performance, from the perspective of both technology performance and behaviour of designers, builders, installers and users. Solving the performance gap is critical for delivering the energy and cost savings and supporting uptake, and a number of initiatives are currently underway, including research by the Zero Carbon Hub, the Green Construction Board's Buildings Working Group, the Technology Strategy Board's Building Performance Evaluation programme, and DECC's research into the real-world performance of insulation and heating systems. An appropriate level of public funding for this area would be in the high tens £ millions.

RD&D to identify and promote efficient operation

Significant energy and carbon savings can be achieved through innovation in efficient building operation, control, and management. Collaborative RD&D that cuts across technology development, behavioural change, and management systems could unlock these savings and maximise the performance of existing building stock. Activity should build on

Table 6: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Cost reduction potential: Domestic	£4.5bn	£16.0bn	£37.5bn
Cost reduction potential: Non-domestic	£3.9bn	£12.6bn	£23.8bn
Value creation potential: Domestic	£0.6bn	£1.7bn	£3.7bn
Value creation potential: Non-domestic	£0.5bn	£1.7bn	£3.0bn

the Technology Strategy Board's 'Future Energy Management for Buildings' programme and the EPSRC's 'Energy Management in Non-Domestic Buildings' and 'Transforming Energy Demand through Digital Innovation' calls. An appropriate level of public funding for this area would be in the high £ millions.

Establish a forum where manufacturers can collaborate to test their products in combination

Public-sector investment is required to establish a collaborative forum and facilities for manufacturers to test their products. This would result in better understanding of the interplay between technologies and real-world performance. Activity could build on sponsorship by LCICG members of initiatives such as the Sustainable Building Envelope Centre and the Future Cities Catapult centre. An appropriate level of public funding for this area would be in the high tens of £ millions.

Dissemination of LCICG member programme results

There are tens of millions of property owners, renters and developers in the UK. This, combined with the conservative nature of the building sector, means that it is imperative that LCICG members actively disseminate the results of innovation programmes to influence behaviour and reduce demand. Improved dissemination could occur through the development of case studies and better utilisation of existing channels. An appropriate level of public funding for this area would be in the low tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Domestic Buildings Summary Report* (published November 2012), the *Technology Innovation Needs Assessment: Non-Domestic Buildings Summary Report* (published November 2012), *The Energy Efficiency Strategy 2013 Update* (published December 2013), and *Construction 2025* (published July 2013).

4. Electricity Networks

Electricity network technologies are expected to play an important enabling role in the future of the UK energy system, supporting the deployment of renewable electricity generation, renewable heat, electric vehicles, rail electrification, and other low carbon technologies. Assessment of a comprehensive list of technologies against criteria of abatement potential and impact of innovation intervention yielded five areas for TINA analysis:

- Advanced transmission – primarily high-voltage direct current technologies which can be used to provide vital offshore connections and reinforce the core transmission system;
- Smart distribution – technologies such as fault current limiters, dynamic line rating, and active distribution voltage control, which help distribution networks manage strains placed on them by new loads and distributed generation;
- Home hub – networked infrastructure including home area networks and in-home displays on the customer side of the energy meter, enabling the control of energy use and data;
- Electric vehicle (EV) integration – controllers to coordinate the charging of electric vehicles;
- Demand response (DR) – control systems for the active adjustment of energy-consuming equipment, including the control of micro and distributed generation.

Some advanced electricity network components are already commercial or near-commercial, specifically those in the areas of smart distribution, demand response, and home hub. While the fundamental technology is available, lack of certainty and confidence in integrated solutions, combined with varying objectives between the different suppliers within the electricity value chain, have resulted in only modest deployment to date.

Potential for Innovation

While demand reduction from increased energy efficiency can reduce the need for network reinforcement, networks will still need to evolve to manage increasing electricity load. Deployment of many key low carbon technologies, such as EVs and distributed generation, and their successful integration at a system level with other areas such as buildings, heat and gas, is critically dependent on innovation in electricity network technologies. Advanced electricity network technologies have the potential to meet future stresses placed on the electricity system more cost effectively than traditional methods of grid reinforcement and fossil fuel-powered system balancing capacity. Moreover, successful innovation could save the energy system c. £4.4bn (range of £2.0-8.6bn) and support the growth of a UK industry that could contribute an estimated £5.1bn (range of £3.0-7.9bn) to GDP up to 2050 (Table 7).[26]

Objectives

The costs of different electricity technologies vary greatly between domestic and grid-level applications. For example, the total installed costs for the full set of home hub technologies (home area network, in-home display, wide-area network, and energy management system) are estimated to be c. £765 per home while the total costs to install 1km of advanced

[26] The Smart Grid Forum estimates savings of in the order of 25-30% of total investment costs in the period to 2050 arising from smarter electricity distribution networks: https://www.ofgem.gov.uk/publications-and-updates/analysis-least-regrets-investments-riio-ed1-wrapper

transmission cables is c. £0.9m. Investment in innovation could achieve an average cost reduction across the identified technologies of 13% by 2020, with the potential for cost reduction in domestic technologies closer to 20% due to greater opportunities for economies of scale. An enabler for home hub technologies is the current roll-out of the Government's vision for every home in Great Britain to be fitted with a smart meter by 2020. Combined with an increase in grid-connected renewable generation and a more developed understanding of some of the technical challenges, electricity network innovation would pave the way for the foundation for a UK-wide smart grid.

Priorities for Public-Sector Investment

The priority areas for continued or future innovation investment led by LCICG members are outlined below. Investment is most important in those areas with distinct synergies across electricity network technologies and the supply value chain, in order to maximise cost reduction and increase deployment at a system level.

Demonstration of an integrated platform of technologies

Electricity network technologies are mutually dependent and reinforcing. Large-scale trials of several integrated technologies, continuing and expanding on those of the Ofgem Low Carbon Networks Fund (LCNF), are needed to test and develop functioning solutions and prove system benefits. This includes cross-energy vector initiatives (e.g. heat, hydrogen, biomethane). Delivery of this priority would require public funding in the high hundreds of £ millions.

Increased knowledge sharing and coordination

A lack of clear understanding among industry about innovation developments in electricity networks provides an opening for increased knowledge sharing and coordination. Increasing awareness of the Smart Grid Forum and the LCNF would potentially provide uniform coordinated information about the future of advanced

Table 7: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario		Low	Medium	High
UK Deployment by 2050	Advanced transmission	601 km	1,663 km	2,307 km
	Number of smart distribution systems[27]	28	42	70
	Home Energy Management System penetration	11%	28%	70%
	DR penetration	53%	70%	100%
	EV controllers	5m	19m	36m
Cost reduction potential for UK		£2.0bn	£4.4bn	£8.6bn
Value creation potential for UK		£3.0bn	£5.1bn	£7.9bn

[27] Assumes one central control system per Distribution Network Operator licence area (of which there are fourteen in Great Britain), plus an additional one (low scenario), two (medium) or three (high) at the 32kV level in each area.

grid development, highlighting the progress and lessons of successful programmes, identifying areas for further development, and building confidence in their results. The development of the Energy Networks Association portal, which shares the findings of the LCNF projects, will contribute significantly to increasing this knowledge.[28] Delivery of this innovation priority would require public funding in the low £ millions.

R&D in EV integration technologies and installation methods

In enabling the electrification of transport, a key challenge will be developing sophisticated EV control systems. Building on early LCNF trials, the opportunities highlighted in the strategy published by the Office for Low Emissions Vehicles,[29] and the recent EPSRC UK China Smart Grids and Electric Vehicles call, R&D is required to deliver the benefits of dynamic charging and vehicle-to-grid control while providing consumer acceptability. Delivery of this priority would require public funding in the high tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Electricity Networks and Storage Summary Report* (published August 2012).

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[28] http://www.smarternetworks.org

[29] Office for Low Emissions Vehicles, *Driving the Future Today – A strategy for ultra low emission vehicles in the UK*, September 2013.

5. Electricity Storage

Storage has the potential to revolutionise the way we think of electricity generation and supply. At present, almost all electricity is generated when required and networks are designed to accommodate highest demands, even if they are of very short duration. Storage technologies offer the opportunity to store surplus electricity capacity and then make it available when the system has a shortage. Storage capacity can be installed anywhere in the system, from next to power plants and substations, to within houses and vehicles. Electricity storage can facilitate a higher penetration of variable renewable electricity generation and higher utilisation and efficiency of nuclear and fossil fuel plants. It can also support greater electrification of heat and vehicles, and can enable energy system savings through grid optimisation such as peak load management, reduced network reinforcement costs, frequency and reactive power support, and improved end-user energy management.

More broadly, energy storage technologies are increasing in profile, having been highlighted in the context of the 'Eight Great Technologies'.[30]

Assessment of a comprehensive list of storage technologies against criteria of abatement potential and impact of innovation intervention yielded seven areas for TINA analysis, focusing primarily on relatively advanced technologies with grid-level applications:

Pumped hydroelectric storage	Sodium-sulphur batteries
Compressed air energy storage	Redox flow batteries
Flywheels	Lithium-ion batteries
Thermal-to-electric storage	Supercapacitors

Storage innovation in personal electronic devices, uninterruptible power supplies, vehicles, and other energy vectors such as hydrogen, were not included in the scope of the TINA analysis. Electricity storage in vehicles has been identified as a key research theme by the Automotive Council UK,[31] and in September 2013 it published an electricity storage and electrochemistry technology roadmap.[32] Heat storage is covered in Part 2, Section 6 of this document.

Pumped hydroelectric storage is mature and widely deployed, making up almost all existing storage capacity worldwide. While some other technologies are not new, there is very little existing deployment of those technologies in grid-supporting applications. Participants in the energy value chain – including regulators, network operators, and technology providers – are unsure of the exact role that storage will play in the future energy system. Which storage technologies will become dominant, or indeed whether there will be a broad mix of technologies applied to different circumstances, and the resulting infrastructural impact, remain to be determined. This creates barriers to innovation, deployment and investment.

Potential for Innovation

The enabling benefits of electricity storage technologies are high, and innovation in storage is important to realising those benefits. Successful innovation could save the energy system c. £4.6bn (range of £1.9-10.1bn) by 2050. Additionally, the global market for storage technologies, specifically the basic science and corresponding engineering applications, is highly tradable and innovation could support the growth of a UK industry contributing an estimated £11.5bn (range of £3.4-25.7bn) to GDP up to 2050 (Table 8).

30 https://www.gov.uk/government/speeches/eight-great-technologies

31 BIS, *Driving success: a strategy for growth and sustainability in the UK automotive sector*, July 2013.

32 http://www.automotivecouncil.co.uk/2013/09/automotive-technology-roadmaps

Objectives

The greatest benefit for the UK is expected to arise through improved storage technologies in a relatively small set of promising sub-areas such as: thermal-to-electric storage, redox flow batteries and novel pumped hydro storage. The current costs of these technologies are approximately £200/kWh, £400/kWh and £150-200/kWh, respectively. Through applied R&D there is the potential to reduce the cost of each of these storage options by an average of c. 20% by 2020. Combined with an increase in grid-connected low carbon renewable generation and demand response controllers, this would pave the way for widespread deployment and integration of complementary electricity network technologies and create the foundation for a UK-wide smart grid.

Priorities for Public-Sector Investment

LCICG members are in a position to provide coordination and leadership to the development and commercialisation of energy storage technologies, working to connect UK industry with the science base required to invest in the required RD&D. Priority areas for continued or future innovation investment led by LCICG members are outlined below.

Roadmap for grid-appropriate storage technologies

It is essential that the manufacturing and application of energy storage technologies advances in partnership with the fundamental scientific research. An energy storage roadmap is required to support these activities, identify specific areas of focus based on UK strengths, and highlight goals and objectives for corresponding programmes. This would also help to provide insight and perspective on the role of storage in the future of the UK energy grid. Delivery of this priority would require public funding in the low hundreds of £ thousands.

RD&D for grid-level storage concepts

Public investment would build on existing activity, such as DECC's Energy Storage Technology Demonstration and Component Research and Feasibility Study competitions, EPSRC's Energy Storage for Low Carbon Grids programme, and ETI's development and demonstration project with Isentropic Ltd. Further investment would support focused research on key technical challenges, improving durability and operational lifetime to identify and deliver cost-effective grid-appropriate storage. Delivery of this priority would require public funding in the high tens of £ millions.

Demonstration of an integrated platform of technologies

Electricity storage is mutually dependent on, and reinforcing with, other advanced electricity networks technologies. Trials which continue and expand on those of the LCNF to operate several integrated technologies at scale are needed to test and develop functioning solutions and prove system benefits. Delivery of this priority would require public funding in the high tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Electricity Networks and Storage Summary Report* (published August 2012).

Table 8: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
UK deployment to 2050	7.2 GW	27.4 GW	59.2 GW
Cost reduction potential for UK	£1.9bn	£4.6bn	£10.1bn
Value creation potential for UK	£3.4bn	£11.5bn	£25.7bn

6. Heat

Space and water heating are the primary sources of non-industrial UK heat demand. Various technologies could potentially supply this demand for low-temperature heat, and the TINA focused on three core technology areas which appear to be consistently important to the UK heating system across a variety of future scenarios: heat pumps (air and ground source); heat networks (and waste heat recovery); and heat storage. Direct substitutes for natural gas (including hydrogen or biogas) within the current heating system were not included in the scope of the TINA analysis, and nor were other potential heat delivery systems such as water source heat pumps, micro combined heat and power, or solar thermal.

Space and water heating (excluding industrial process heat) account for about a quarter of UK energy consumption today. This demand is highly 'peaky' compared to other energy end uses, with much higher demand for heat during the coldest months and days of the year and during specific times of day. This high variability has important implications for the technologies that can meet heat demand cost effectively. Depending on the efficacy of energy efficiency and demand reduction measures, heat is expected to constitute between 12-25% of energy demand through to 2050.

There are limited low carbon technology options for meeting the UK's heat needs, and all of these technologies face major challenges if they are to be widely deployed. Even relatively mature and cost-effective technologies such as heat pumps are not yet proven to be ready for broad adoption in the UK context. Moreover, the provision of heat is closely linked to the thermal performance of buildings where the use and retention of heat varies greatly. The transition from traditional gas boilers to low carbon heating options requires not only technology changes but also corresponding operational and behavioural changes.

Potential for Innovation

Innovation in low carbon heat technologies could reduce UK energy system costs by c. £30bn (range of £14-66bn) through lower deployment costs and help create a UK industry with the potential to contribute further economic value of c. £6bn (range of £2-12bn) to 2050 (Table 9).

Objectives

Heat pump and heat network technologies have well understood costs, corresponding to levelised costs which range from £83/MWh for networks to £115/MWh and £200/MWh for air and ground source heat pumps, respectively. Investment in innovation is estimated to yield cost reductions of 25% in heat networks and 30% in heat pumps by 2020. Advanced heat storage technologies have yet to be proven at scale; however, it is estimated that 24% and 30% cost reductions could be achieved through innovation for interseasonal and daily heat storage, respectively. Supplementing

Table 9: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario		Low	Medium	High
Deployment by 2050	Heat pumps	100 TWh	180 TWh	340 TWh
	Heat networks	22 TWh	77 TWh	208 TWh
	Heat storage	6.1 GW	44.8 GW	192.9 GW
Cost reduction potential		£14bn	£30bn	£66bn
Value creation potential		£2bn	£6bn	£12bn

the introduction of the Renewable Heat Incentive (RHI), successful innovation could help support 124,000 renewable heat installations by 2020.

Priorities for Public-Sector Investment

The priority areas for continued or future innovation investment led by LCICG members are outlined below. In addition to these specific activities, public intervention will aim to increase collaboration and integration of RD&D and join up innovation programmes with supply chain and infrastructure development.

System-level integration and design solutions for renewable heating technologies

Building and network-level demonstration of integrated renewable heating systems would be paired with targeted R&D. Research will examine system performance and real mass-market consumer behaviour, requirements and profiles. This will inform the design of effective products, influence RD&D on network components and encourage the replacement of old and inefficient boilers. Cost reductions can be achieved by building upon the insights generated through the RHI and the ETI's Smart Systems and Heat Programme to promote the installation of renewable heat technologies on a broad scale. An appropriate level of public funding for this area would be in the low tens of £ millions.

RD&D for components, design, and installation of heat pumps

Technology cost reductions and increased levels of deployment can be achieved with more efficient, reliable, and quieter heat pumps which are easy to install and integrate with existing heating systems and networks. Public investment for RD&D will be required to target these improvements in key components and processes. An appropriate level of public funding for this area would be in the low tens of £ millions.

RD&D for design, operation, and integration of heat/cold stores

Higher density, smaller heat stores with a higher rate of heat exchange which are suited to domestic consumer or large-scale network operation are required in order to achieve cost reduction and key performance improvements. Targeted RD&D could focus on optimising the performance of integrated systems through early demonstration and related storage and network component R&D. This programme could leverage the outcome of the DECC Advanced Heat Storage competition and operate as part of the forthcoming SUPERGEN Energy Storage hub and other EPSRC programmes such as the Interdisciplinary Centre for Storage, Transformation and Upgrading of Thermal Energy. An appropriate level of public funding for this area would be in the low tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Heat Summary Report* (published September 2012) and *The Future of Heating: Meeting the challenge* (published March 2013).

7. Hydrogen for Transport

Hydrogen technologies have potentially important roles in the future UK energy system, with possible applications in transport, power and heat. The use of hydrogen across these applications could be interconnected, providing additional options and flexibility for energy storage and demand balancing across sectors. The TINA limits itself to transport applications, partly because the full role of hydrogen in the UK's energy system is very difficult to estimate at this time. However, hydrogen derived from renewable sources is one of the few credible solutions for ultra-low emission vehicles, as the technology is available, works and is nearing roll-out readiness. There are a number of ways that hydrogen could be incorporated in light duty vehicle (LDV) transport, and in recent years development work has overwhelmingly focussed on fuel cell electric vehicles (FCEVs) as the technology of choice. The TINA focuses on the technologies needed for hydrogen transport using FCEVs, due to their potential to deliver UK LDV transport needs with near-zero greenhouse gas emissions while reducing dependence on imported oil and the need for curtailment of renewable generation. The TINA does not make judgements about other possible uses of hydrogen in transport, for example directly in internal combustion engines.

Potential for Innovation

Short-term innovation priorities focus on readying hydrogen technology for a potential pre-2020 initial deployment. Long-term priorities focus on step-change innovations to significantly reduce cost and position the UK to capture economic value. The global market for hydrogen transport technologies is estimated to reach £428bn (range of £0-807bn) in annual turnover by 2050. While it is unlikely that the UK will play a dominant role in any specific part of the global supply chain, there are niche leadership opportunities - the most valuable being within FCEV and hydrogen production. There are short-term opportunities in FCEVs to industrialise manufacturing and open up long-term opportunities in the supply of advanced components, leveraging strengths in the UK automotive sector and recent successful policies supporting it. Within hydrogen production, there are opportunities to build upon academic and industrial strengths in both electrolysis and hydrocarbon reforming with consequential benefit from 'on-shoring' transport fuel

Table 10: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario		Low	Medium	High
Global deployment by 2050		0%	12% of LDVs	26% of LDVs
UK deployment by 2050		0%	20% of LDVs	50% of LDVs
Cost reduction potential for UK	with CCS[33]	–	–	£76.8bn
	without CCS	£0	£35.7bn	£88.7bn
Value creation potential for UK	with CCS	–	–	£36.0bn
	without CCS	£0	£20.2bn	£48.1bn

[33] Outcome of high scenario is dependent on success and adoption of CCS technology. If CCS succeeds it will dominate large-scale centralised hydrogen production in later years; if not, large-scale centralised electrolysers will be developed to fill the gap.

production. Successful innovation in hydrogen transport technologies could reduce UK energy system costs by c. £35.7bn (range of £0-88.7bn) and could help create a UK industry with the potential to contribute further economic value of c. £20.2bn (range of £0-48.1bn) to 2050 (Table 10). The flexibility and broad applicability of hydrogen – including outside of transport applications – means that innovation in relevant technologies could support options for the future energy system, thereby reducing overall system risks arising from uncertainties in other key technologies.

Objectives

The automotive industry commonly considers costs in terms of the total cost of ownership (TCO) of a vehicle: the capital cost of buying the vehicle plus the 15-year operation cost. TCO for a FCEV is currently estimated to be c. £170k, substantially higher than the c. £29k for a typical petrol LDV.[34] Innovation can play a significant role in reducing this cost through the economies of scale associated with a shift to industrialised volume manufacturing of vehicles. Furthermore, activity between now and 2020 can provide the base for a pipeline of advanced technology innovations in FCEV components which will enable UK leadership in future vehicle production. Short-term innovations are also needed before 2020 to lead to a functioning and scalable distribution and refuelling station network in order to enable successful roll-out of FCEVs, reducing potential for early adoption range anxiety, and encouraging the investment required for vehicle-oriented innovation.

Priorities for Public-Sector Investment

LCICG members will work with the Automotive Council UK, the Office for Low Emissions Vehicles, the UK H_2Mobility project, and the new Advanced Propulsion Centre to leverage existing investments and understand the opportunities for innovation. In parallel, LCICG members will work with others to determine the impact that decisions within other parts of the energy system will have on the role of hydrogen in transport. Priority areas for continued or future innovation investment led by LCICG members are outlined below.

Industrialisation of vehicle and component production

The largest opportunities for innovation are in the components of FCEVs such as the fuel cell stack and periphery, the integration of these with the electric drive train, and hydrogen storage. Investment in partnership with automotive original equipment manufacturers would support the industrialisation of early FCEV manufacturing, driving significant reductions in vehicle cost. This could also generate short-term economic growth by making the UK a more attractive place for the first global FCEV production facilities. Continued support for early stage R&D into the technology innovations for future generations of FCEVs through programmes such as the Polymer Fuel Cell Challenge would help to maintain the UK's competitive position in the automotive sector in the long term. Delivery of this priority would require public funding in the low tens of £ millions.

[34] Average of €32k at €1.15:£1 exchange rate. McKinsey & Company, *A Portfolio of Power-Trains for Europe: A Fact-Based Analysis*, November 2010

RD&D of low carbon hydrogen production

Pivotal to the introduction of FCEVs is the low carbon production of hydrogen. It is currently too early to predict which technologies will be most important in the long term, so a programme of support is needed to develop, demonstrate, and improve multiple options for low carbon hydrogen production, including electrolysis and reformed hydrocarbons. Improved electrolyser efficiency and durability with reduced capital and maintenance costs would greatly reduce the cost of hydrogen fuel, and flexible electrolyser operation could also support the future UK electricity system, reducing the cost of integrating variable renewable generation. Delivery of this priority would require public funding in the high £ millions.

RD&D of refuelling infrastructure

Successful roll-out of FCEVs is dependent on the development of a supporting hydrogen infrastructure, particularly refuelling stations, and UK H2Mobility has mapped out a potential pathway for this. Targeted short-term investment in RD&D is required to improve the cost and performance of refuelling stations to achieve a roll-out ready hydrogen refuelling system that is compatible with existing infrastructure. Delivery of this priority would require public funding in the low tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Hydrogen for Transport Summary Report* (publication expected in early 2014).

8. Industrial Sector

Emissions abatement opportunities in UK industry offer the potential to reduce greenhouse gas emissions and the cost of operations. Industrial sector emissions are driven largely by the use of heat and electricity. Direct emissions from industries were responsible for approximately one quarter of UK greenhouse gas emissions in 2008 and just under one-fifth of final energy consumed. Total emissions from UK industry came to c. 190 $MtCO_2$, with over 50% from the eight most emitting industries.

The Industrial Sector TINA began with a comparative review of the key emitting sectors to identify those which offer the greatest innovation benefits to the UK. Based on the importance of carbon abatement, economic growth potential and the need for UK public-sector support, the sectors selected for detailed analysis were: chemicals; food and drink; iron and steel; and cement. In each of the focus sectors, innovation opportunities were identified in the areas of: efficiency improvements; alternative process technologies; low carbon substitutes; and recovery and recycling. The cross-learning potential of these technologies across a broader range of sectors than those analysed in the TINA needs to be investigated further. This could identify the full potential of these sectors and inform further prioritisation of public-sector activities. Additional related work has now been commissioned by LCICG members on a broader range of sectors.[35]

Potential for Innovation

Industrial sector opportunities for innovation and investment are frequently driven by a combination of sustainability of raw material and energy supply, long-term visibility of input costs, and capital expenditure associated with the opening new facilities or significant refurbishments. The industries that are the focus of the TINA could provide abatement opportunities totalling 270-500 $MtCO_2$ by 2050. With innovation, the total UK industrial emissions to 2050 could be reduced by 38-68% relative to business as usual. While innovation can sometimes be disruptive to established business models, the TINA suggests that innovation in the shortlisted technologies could save the UK a total of c. £20.3bn (range of £14.4-26.9bn) in energy and carbon savings and contribute an additional c. £3.9bn (range of £1.5-6.5bn) to GDP up to 2050 (Table 11). Additionally, successful innovation has the potential to generate even greater energy savings and economic benefit, due to the cross-sectoral applicability of some technologies.

Objectives

Innovation could help to ensure industry's contribution to meeting the Government's 2020 carbon target of reducing emissions by 34% compared to 1990 levels, reducing emissions in the four focus sectors by c. 9.8 $MtCO_2$ (range of 7.6-16.2 $MtCO_2$). There is also an immediate need for innovation to ensure that abatement technologies are successfully deployed

Table 11: Potential of innovation[36] up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Cost reduction potential	£14.4bn	£20.3bn	£26.9bn
Value creation potential	£1.5bn	£3.9bn	£6.5bn

[35] Further relevant LCICG studies currently in progress include a feasibility study on improving the evidence base for industrial energy efficiency (DECC) and 2050 roadmaps for key UK industrial sectors (DECC and BIS).

[36] In the shortlisted TINA technologies.

in the limited window of opportunity that exists at the time of plant refurbishment or replacement and new builds. For example, early programmatic support for low carbon substitutes could save £506m (range of £460-552m) through the adoption of alternative heat in the food and drink sector, £58m (range of £21-96m) through the development of biocatalysts in the chemicals industry, and £295m (range of £221-369m) with clinker substitution in the cement industry by 2020.[37] Wherever possible, new technologies should be deployed in conjunction with plant refurbishment and replacement, to minimise 'lock-in' to less efficient, higher carbon technologies.

Priorities for Public-Sector Investment

The priority areas for continued or future innovation investment led by LCICG members are outlined below. In addition to these activities, LCICG members will have an important role to play in facilitating collaboration between industrial competitors and identifying opportunities for technology transfer between sectors.

RD&D for the use of low carbon substitutes

Low carbon substitutes could deliver significant benefits, due to the high energy and carbon savings potential in sectors where opportunities exist and the ability to derive value from export of the resulting intellectual property. Examples of potential low carbon substitutes include: the development of biocatalysts in the chemical industry; low carbon cement and clinker substitution in the cement industry; and alternative heat generation (e.g. biomass) in the food and drink industry. Research is also needed to identify and demonstrate low carbon sources of high temperature heat, including for direct-fired heat applications. Activities such as the EPSRC's UK Indemand Centre and the Carbon Trust's Industrial Energy Efficiency Accelerator are expected to help drive change in this area. An appropriate level of public funding, to support the prioritised interventions outlined in the TINA, would be in the high tens of £ millions.

Programmes to identify and pilot alternative process technologies

Innovation can unlock low carbon step changes in production across a variety of industries. Examples of alternative process technologies to explore include: improved separation technologies in the chemicals industry; smelt reduction in the iron and steel sector; and improvements to electrochemical processes in the steel industry. An appropriate level of public funding for this area, to support the prioritised interventions outlined in the TINA, would be in the high tens of £ millions.

Industrial CCS

CCS in the cement sector, and in iron and steel (combined with top gas recycling), has high carbon saving potential, potentially allowing energy intensive industries to continue using fossil fuels while significantly reducing emissions. Industrial CCS also benefits from cross-sector applicability beyond the sectors analysed in the TINA. Programmes should maximise collaboration and cross-learning from CCS in the power sector and develop industry-specific capture technologies to support the prioritised interventions outlined in the TINA. An appropriate level of public funding for this area would be in the high tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Industrial Sector Summary Report* (published November 2012), *The Energy Efficiency Strategy 2013 Update* (published December 2013), and *The Future of Heating: Meeting the challenge* (published March 2013).

[37] Savings are a combination of energy and carbon savings.

9. Marine Energy

The UK has a large natural resource of marine energy which, if harnessed using cost-effective wave and tidal stream devices, has the potential to deliver over 10% of the UK's forecast electricity needs in 2050. A third marine energy technology, tidal range, is comparatively mature and is not considered to be a strategic priority for public innovation support.

There are more wave and tidal stream devices being tested in the UK than anywhere else in the world. The UK is home to world-class marine energy test facilities, including the European Marine Energy Centre, the National Renewable Energy Centre, Wave Hub, the Falmouth Bay Test Site, and the wave tanks at Plymouth University's Marine Building. However, marine energy systems are still at the relatively early stages of development and there are significant challenges to overcome, including cost reductions, before full commercialisation can be achieved. Increased confidence in the industry is needed to attract sufficient commercial funding. Wave and tidal stream technologies are at different levels of maturity: leading tidal stream devices are reaching first deployment in small-scale arrays, while wave energy requires further optimisation and testing of devices to build confidence on costs, reliability and operation.

Potential for Innovation

Innovation to reduce costs and improve performance is crucial for marine energy technologies. With cost-competitive technology and a supportive international policy framework, a global market in marine energy could emerge. The UK is currently well positioned to capture a sizable share of this potential market, by capitalising on our strong R&D and supply base and leveraging our early investment in infrastructure and industrial capacity. Success in marine energy could save the energy system £2.8bn (range of £0-5bn) and contribute £1.4bn (range of £0-4.3bn) to GDP by 2050 (Table 12).

Objectives

The TINA estimated that the current costs of marine energy are of the order of £200-300/MWh for tidal stream and £350-400/MWh for wave energy.[38] Investment in innovation, including an increasing scale of demonstration combined with targeted R&D, is required to enable the delivery of

Table 12: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario		Low	Medium	High
Global deployment by 2050	Wave	0 GW	46 GW	188 GW
	Tidal	0 GW	13 GW	52 GW
UK deployment by 2050	Wave	0 GW	4 GW	8 GW
	Tidal	0 GW	2.5 GW	5 GW
Cost reduction potential for UK	Wave	£0	£1.6bn	£3.0bn
	Tidal	£0	£1.2bn	£2.0bn
Value creation potential for UK	Wave	£0	£0.9bn	£3.0bn
	Tidal	£0	£0.5bn	£1.3bn

[38] In the Electricity Market Reform Delivery Plan (published December 2013), the Contracts for Difference (CfD) Strike Prices for both tidal stream and wave energy were set at £305/MWh (in 2012 prices). This reflected the treatment of Strike Prices across the Renewables Obligation (RO) technologies, which used prices equivalent to RO levels adjusted for system efficiency savings from the CfD.

cost reductions and thereby build industry confidence. While very ambitious given current costs, the industry considers that array-scale installations of at least 200 MW could potentially achieve £100/MWh in typical UK resource locations by 2025 for tidal stream, and by 2030 for wave energy. At this cost, marine energy could begin to make a meaningful contribution to the UK energy mix. A medium deployment scenario suggests that, if costs fall, the UK could install around 4 GW (range of 0–8 GW) of wave energy and 2.5 GW (range of 0–5 GW) of tidal stream by 2050 (Table 12).

Reaching the desired cost reduction will require an increasing scale of demonstration, combined with targeted R&D. LCICG members have worked to identify areas where public support will be critical to removing barriers to innovation and supporting the breakthroughs required to drive the necessary cost reduction.

Priorities for Public-Sector Investment

The priority areas for continued or future actions led by LCICG members are outlined below. In addition to these specific activities, public intervention will aim to increase collaboration and integration of RD&D and join up innovation programmes with supply chain and infrastructure development.

Demonstration of wave devices

Public investment is required to build confidence in operation and reliability, and to attract inward commercial investment, continuing the progress of the Wave Hub testing facility, the Scottish Marine Renewables Commercialisation Fund (MRCF) and WATERS[39] programmes. Continued or enhanced delivery of this priority would require public funding in the high £ millions.

Initial deployment of first arrays

First arrays are a critical step in demonstrating a viable cost reduction pathway. Public investment would build on the work of DECC's Marine Energy Array Demonstrator (MEAD), NER300 and similar programmes. Initial arrays will be tidal stream demonstrators with wave energy and second generation tidal stream expected to follow. Delivery of this priority would require public funding in the high tens of £ millions.

R&D to address challenges identified in first arrays

Opportunities for cost reduction will arise in supporting sub-technology areas. These include cabling, installation, deployment and device interaction, which can all be improved for future devices and deployment. Public investment in collaborative R&D will be required to fully capture these cost reduction opportunities. The Marine Energy: Supporting Array Technologies programme, which is supported by the Technology Strategy Board, Scottish Enterprise and the Natural Environment Research Council, is investigating some of these areas along with the MRCF. The Marine Farm Accelerator and Offshore Renewable Energy Catapult will provide a platform for further collaboration. Delivery of this priority would require public funding in the low tens of £ millions.

Operational improvements: health and safety, resource characterisation, and standardisation

These areas are critical to building a safe, mature and commercially viable industry; improvement would promote general confidence in marine energy. Without specific public sector investment, immaturity in these areas could become a barrier to technology development. More effective operations and maintenance also

[39] Wave and Tidal Energy: Research, Development and Demonstration Support.

has the potential to increase yield and reduce the cost of energy. Delivery of this priority would require public funding in the low £ millions.

R&D for pipeline of second generation tidal stream technologies and novel wave devices

On-going R&D is required to drive the step changes critical to meeting the full cost reduction potential of marine energy. Activity would build on the SUPERGEN UK Centre for Marine Energy Research. For tidal stream energy, R&D is required on platform and second generation deep-water technologies, as well as first generation scale up. For wave energy, novel concepts could drive future cost reductions at the component and device level. Delivery of this priority would require public funding in the high £ millions.

Towards deployment of first commercial-scale farms

Investment would be required to build on the successful demonstration of early arrays, to prove commercial viability and de-risk deployment at scale. Activities could include on-going testing, related shore and sub-sea infrastructure, and associated R&D activities to reduce costs and encourage deployment. This would build on the outcomes of MEAD, NER300 and other support for early-stage arrays. Delivery of this priority would require public funding in the high tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Marine Energy Summary Report* (published August 2012).

10. Nuclear Fission

The UK has considerable experience in nuclear power and a history of world-leading technology development. However, over the past three decades it has moved from being a developer and leader in aspects of technology associated with new nuclear build to being a buyer of technology developed overseas. Nuclear fission can play a key part in the energy system of the UK. Nuclear generation has the potential to help the UK replace aging power plants, reduce reliance on gas, and meet greenhouse gas emissions targets and energy needs. In 2011, 19% of the UK's electricity was produced by nuclear power, down from a peak of 25% in 1997.

The nuclear industry in the UK faces a number of key challenges, including: to safely and cost effectively clean-up the UK's nuclear legacy; to operate and eventually decommission the aging reactor fleet; to kick-start an ambitious new build programme; and to identify and support collaborative efforts to develop future nuclear energy technologies.

The Government has set out its ambitions in the *Nuclear Industrial Strategy – The UK's Nuclear Future*, identifying priorities that government and industry will work on together in a long-term partnership.[40] The strategy includes:

- A new Nuclear Industry Council, that brings together Government ministers and all the key players across the nuclear supply chain;
- Coordination of R&D and innovation through new bodies that advise Ministers and government departments: the Nuclear Innovation and Research Advisory Board (NIRAB) and a Nuclear Innovation and Research Office (NIRO);
- A cost reduction initiative to investigate the scope for reducing costs across all aspects of the nuclear industry;
- Development of an export strategy to grow UK opportunities overseas; and
- A long-term plan to ensure the UK has the skills required for the future.

Potential for Innovation

Innovation can play a significant role in the growth, cost reduction, and deployment of nuclear fission technology. Innovation could reduce operating costs of the existing stock, extend plant life and substantially reduce the future costs of decommissioning. Development and deployment of future nuclear energy technology (including advanced Generation IV systems, Small Modular Reactors, and associated advanced fuel cycles) depends on innovation. The successful deployment of these technologies could have a significant impact on cost reduction via corresponding improvements in waste management and fuel efficiency. Furthermore, innovation can potentially reduce the associated cost of capital and help avoid costly construction delays. Successful innovation could save the energy system c. £5.7bn (range of £2-14.5bn) to 2050 (Table 13).

The global market for nuclear fission is expected grow to some £1,348bn (range of £286bn – £2,485bn) in turnover by 2050. While the UK is not currently a nuclear reactor vendor, there are specific opportunities for UK leadership in a number of technology areas. The best opportunities for the value creation at home and overseas are represented by niches in component manufacture, monitoring and testing, and in decommissioning, which would respectively leverage the

[40] The *Nuclear Industrial Strategy* builds on the review undertaken in 2012 to respond to the report *Nuclear Research and Development Capabilities*, published by the House of Lords Select Committee on Science and Technology. The *Strategy*, and the *Nuclear Energy Research and Development Roadmap* published alongside it, both informed the development of the *Nuclear Fission TINA*.

supply chain expertise of the advanced manufacturing sector, our extensive industry experience in operations and maintenance, and the Nuclear Decommissioning Authority (NDA). Innovation could support the growth of an industry that could contribute an estimated £7.2bn (range of £1.5-13bn) to GDP up to 2050 (Table 13).

Objectives

Industry has set out initial plans to develop approximately 16 GW of new nuclear power in the UK, and the Carbon Plan[41] recognises that nuclear has the potential to provide up to 60% of the UK's electricity base by 2050.[42] Nuclear is cost competitive with other generation technologies and in the future it is expected to remain one of the cheapest large-scale low carbon source of electricity.

Independent estimates for DECC suggest that a First of a Kind (FOAK) new nuclear plant is expected to have a levelised cost of between £79-102/MWh, with a central estimate of £89/MWh.[43] As nuclear reaches Nth of a Kind (NOAK) status, levelised costs are projected to fall to between £67-89/MWh with a central estimate of £77/MWh, making it a cost-effective large-scale low carbon technology.[44]

However, this transition to NOAK is unlikely to happen without significant innovation. Public investment in innovation has the potential to reduce these costs, potentially bringing down the overall cost of operating and decommissioning the UK's existing nuclear stock by 5%, with the levelised cost of energy from new Generation III plants falling by ~20% and, for Generation IV plants, by more than 35% between now and 2050.

Priorities for Public Sector Investment

In line with the 'Building a Future: Innovation and R&D' section of the *Nuclear Industrial Strategy*, LCICG members will support the establishment and mission of NIRAB and NIRO to coordinate the UK's nuclear R&D and innovation activities by providing expert input, maximising synergies across member programmes, and encouraging technology transfer from outside of the nuclear industry. This activity will build on and complement existing initiatives such as the £15m National Nuclear Users Facility for universities and companies carrying out research into nuclear technology (see Box 11 in Part 1). The current thinking of LCICG members on priority areas for continued or future innovation investment is outlined below.

Table 13: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Global deployment by 2050	482 GW	1,223 GW	1,973 GW
UK deployment by 2050	16 GW	40 GW	75 GW
Cost reduction potential for UK	£2bn	£5.7bn	£14.5bn
Value creation potential for UK	£1.5bn	£7.2bn	£13bn

41 HM Government, *The Carbon Plan: Delivering our low carbon future*, December 2011.

42 AEA for DECC, *Pathways to 2050 – Key Results*, May 2011.

43 These generic cost estimates are broadly in line with the £89.50-92.50/MWh Contracts for Difference Strike Price agreed between the Government and EDF Group for the construction and operation of Hinkley Point C, which was announced in October 2013.

44 These are generic cost estimates that do not necessarily reflect site-specific cost information held by the Government.

Future nuclear energy technologies

Public-sector investment is crucial to support R&D of options for future nuclear energy technologies, given the estimated 20+ year timeline to commercialisation of technologies such as Generation IV or other advanced reactor types and associated fuel cycles. On-going support would open up international collaboration opportunities and ensure the UK develops the skills and supply chain necessary to capture future benefits. Delivery of this priority would require public funding in the high tens of £ millions.

Advanced component manufacturing

The UK has specific expertise in advanced component manufacturing. A programme of public-sector investment would support UK manufacturers developing innovative components and processes and meet the demanding requirements of the nuclear industry. This would continue the investment made in the Nuclear Advanced Manufacturing Research Centre. Delivery of this priority would require public funding in the high tens of £ millions.

Fuel cycle technologies

Through the operation of facilities such as Urenco and Springfields, the UK has leading capability in the areas of fuel enrichment, manufacture, management of separated plutonium, and reprocessing. There is high potential value in retaining this expertise and developing advanced fuel cycle technologies for future nuclear reactor types. Delivery of this priority would require public funding in the high tens of £ millions.

Waste management and decommissioning

The UK has a large and diverse radioactive waste inventory which represents a considerable liability, making cost reductions through innovation a strong priority. Furthermore, innovation opportunities exist in decommissioning, which would save time and money. As a result of limited private-sector incentives in this area, public investment is required to encourage innovation in delivering the mandate of the NDA as well as to support the export of UK supply chain expertise to overseas markets. The NDA presently funds research in this area directly and through its Site Licence Companies, and the Research Councils have recently announced the £5m DISTINCTIVE programme, to address nuclear waste and decommissioning. Delivery of this priority would require public funding in the high tens of £ millions.

Construction, installation and commissioning

Construction, installation and commissioning are important areas for successful delivery of a new build programme. Public-sector intervention in this area could support technical assistance and coordination to help align basic RD&D with the private sector and international markets, giving companies the certainty they need to invest in capacity and capability improvements. Delivery of this priority would require public funding in the low tens of £ millions.

Small Modular Reactors (SMRs)

Further work is needed to fully understand the benefits of SMRs, but their development is gathering momentum worldwide. Public investment could enable the UK to become engaged with international R&D programmes, and act as a stimulus to create commercial incentives for RD&D, regulatory acceptance, and deployment. Delivery of this priority would require public funding in the low hundreds of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Nuclear Fission Summary Report* (published April 2013) and the *Nuclear Industrial Strategy: the UK's nuclear future* (Published March 2013).

11. Offshore Wind

The UK has a large natural resource of wind power around its coast, and offshore wind power is a commercially available, proven technology to capture this resource. The offshore wind industry is growing rapidly and the UK is a global leader in deployment. Over the next decade, offshore wind could contribute to our energy needs and greenhouse gas emissions targets while reducing our reliance on gas and fuel imports. Successful deployment of offshore wind has the potential to deliver 20-50% of the UK's forecast electricity generation by 2050, with the level depending primarily on economic or technical constraints to grid development, alternative generation sources and their costs, and overall energy demand.

Offshore wind has been deployed at scale since 2002 and at the time of writing the UK has approximately 3.8 GW installed, with up to an additional 8.4 GW under construction or with planning approval, and up to a further 10.6 GW awaiting planning decisions.

Potential for Innovation

Innovation in offshore wind has a significant role to play in improving technology and reducing the cost of energy, both of which are critical to ensuring continued and expanded deployment. The global offshore wind market is expected to reach £56bn (range of £16-£168bn) annual turnover in 2050. The UK could become a leader in this market, especially in the areas of assembly, installation, and operation, building on our existing leadership position and nascent supply chains by leveraging our RD&D capability and skills from the North Sea oil and gas industry. By 2050, successful innovation in offshore wind could save the energy system £45bn (range of £18-89bn) and help create a UK industry that could contribute an estimated £18bn (range of £7-35bn) to GDP (Table 14).

Objectives

The UK has an earlier and greater need for offshore wind than other countries, and UK farms are further out to sea and in deeper water than other early adopters. This typically means higher wind speeds and increased energy generation, but requires new technologies and operational approaches to deliver the necessary cost savings.

Offshore wind power currently costs over £140/MWh for a typical Round 2 site.[45] The TINA, which was published in February 2012, concluded that innovation had the potential to drive down costs by 25% by

Table 14: Potential of innovation up to 2050 (cumulative, discounted)

Deployment scenario	Low	Medium	High
Global deployment by 2050	119 GW	439 GW	1142 GW
UK deployment by 2050[46]	20 GW	45 GW	100 GW
Cost reduction potential for UK	£18bn	£45bn	£89bn
Value creation potential for UK	£7bn	£18bn	£35bn

[45] Round 2 of the offshore wind licensing process coordinated by The Crown Estate was issued in 2003. Compared to Round 1, Round 2 sites were further offshore and in deeper waters.

[46] These figures do not take into account the results of more recent modelling done for the December 2013 Electricity Market Reform (EMR) Delivery Plan, which suggest that a range of 8-15 GW by 2020 is consistent with the Levy Control Framework. The EMR modelling also projects that later phases of offshore wind projects signing contracts up to 2020 will add a further 5.3 GW of deployment shortly after 2020.

2020[47] and perhaps by 60% by 2050. It also indicated that, by 2020, successful innovation-supported cost reduction could help the UK reach some 18 GW of installed capacity, encouraging the development of the UK supply chain and growth in exports. In common with the other TINAs, the deployment scenarios in the Offshore Wind TINA were based on the Committee on Climate Change's MARKAL (Market Allocation) model runs for the fourth Carbon Budget, DECC's 2050 calculator, and customised runs of the ETI's Energy Systems Modelling Environment. The TINA offshore wind figures are not constrained by available spend or a specific renewables ambition.[48]

Priorities for Public-Sector Investment

Innovation is needed to bring down the costs of offshore wind technologies, make them ready for wide deployment, and attract the inward investment required to build a world-leading UK industry. There are also wider system implications, in terms of the need to reduce costs and improve performance in areas such as storage and high-voltage direct current (HVDC) technologies. In addition to the activities outlined below, LCICG members have a critical role to play in encouraging and enabling collaborative working and the sharing of testing and monitoring data through key initiatives such as the Offshore Wind Accelerator, the Offshore Renewable Energy Catapult, and the National Renewable Energy Centre.

Offshore demonstration sites and site pipeline

A critical barrier delaying cost reduction is the lack of demonstration of new turbine and foundation designs; until designs have been proven operating offshore, developers will be reluctant to use them in their commercial projects. In addition to current large offshore test sites under development at the Blyth Offshore Demonstrator and the European Offshore Wind Deployment Centre, sites will be needed to test a sufficient number of innovative new turbines, foundations, electrical systems and operation, maintenance and service approaches. This would encourage continued cost reduction through better design and build investor confidence in operational reliability. New sites could come from either specific commercial models, from project variations to existing developments, or from other novel methods such as off-grid locations or specific testing and demonstration leasing rounds by The Crown Estate. Delivery of this priority would require public funding in the high tens of £ millions.

Transmitting electricity from far-shore wind farms

This programme would improve electrical infrastructure systems for sites far from shore, to reduce system costs by leveraging the advantages of HVDC over traditional alternating current. Development of optimised HVDC substations based on standard codes and designs would help drive cost reductions in all offshore wind farms. With early support from the Carbon Trust's Offshore Wind Accelerator 66kV Cable Qualification Competition, higher

[47] TINA figure corroborated by The Crown Estate, *Offshore Wind Cost Reduction Pathways Study*, May 2012.

[48] More recent modelling done for the December 2013 Electricity Market Reform Delivery Plan has used DECC's Dynamic Dispatch Model to assess technology deployment in the electricity sector, mainly out to 2030. These scenarios result in a range of offshore wind deployment of 8-15 GW by 2020. Later phases of offshore wind projects signing contracts up to 2020 add a further 5.3 GW of deployment shortly after 2020. This modelling and its outputs are set up to be consistent with the Levy Control Framework, which places an upper limit on the levies that the Government can impose on electricity suppliers to fund low carbon electricity policies.

voltage systems would support yield improvement, improve grid connectivity, and reduce the costs of generation through the need for fewer substations, reduced system losses and reduced overall cable requirements. Delivery of this priority would require public funding in the low £ millions.

Reduce installation time per turbine

A programme of improvements to make the installation of offshore wind farms faster and less sensitive to weather would reduce cost and address supply chain bottlenecks. This could be achieved by increased levels of onshore assembly and the use of floating vessels, in addition to exploring novel installation techniques such as 'float out and sink'. This would support a reduction in the time and risk involved in turbine installation. Delivery of this priority would require public funding in the high tens of £ millions.

R&D to improve wind farm yield and turbine reliability

Complementing existing initiatives, such as the Research Councils' SUPERGEN Wind Energy Technologies Consortium,[49] this R&D programme would focus on improving wind farm yields by increasing turbine efficiency, availability, and blade and drivetrain reliability. This could be achieved through better turbine control and monitoring systems for predictive maintenance, layout optimisation, yield prediction and wind resource assessment tools. The programme could boost wind farm yields and decrease cost. Delivery of this priority would require public funding in the high tens of £ millions.

Cost-effective serial manufacturing and production of foundations

A programme of support is required for the development, demonstration and testing of foundations, to unlock efficiencies of scale. Manufacturing thousands of foundations cost effectively will require a transition from low-volume batch processes to serial production. Funding would be required to develop these foundations and to implement serial production methods. Delivery of this priority would require public funding in the low tens of £ millions.

For a more in-depth discussion, please see the *Technology Innovation Needs Assessment: Offshore Wind Power Summary Report* (published February 2012) and the *Offshore Wind Industrial Strategy: Business and Government Action* (Published August 2013).

[49] Including the new £3m Wind Hub, and the £5m Towards the Offshore Wind Power Station project.

Annex
LCIGG Members

Core Members

These are organisations that provide substantial funding for low carbon innovation and have a broad policy or delivery role, supporting multiple low carbon technologies. The eight core members are involved in all aspects of the Group's work.

Department for Business, Innovation and Skills (BIS)

BIS invests in skills, reduces regulation, promotes trade and boosts innovation to help drive sustained economic growth – aiming to make Britain the best place in the world to run an innovative business or service. BIS provides a range of practical support for business innovation, including direct support through partner organisations such as the Technology Strategy Board and the Research Councils, and indirect support such as the R&D tax credit.

Department of Energy and Climate Change (DECC)

DECC's mission is to ensure secure, clean and affordable energy supplies and to promote international action to mitigate climate change. DECC supports low carbon innovation in a number of ways, including direct funding for demonstration and pre-commercial deployment of low carbon technologies.

Scottish Government

The transition to a low carbon economy is one of the Scottish Government's strategic priorities. The Scottish Government works with a variety of organisations to establish new technology hubs and alliances to act as focal points for low carbon innovation in the energy sector. These initiatives link to EU and UK funding programmes and attract overseas R&D investment. The Scottish Government also supports low carbon innovation through direct funding to the Energy Technology Partnership and Scottish Enterprise.

Scottish Enterprise

Scottish Enterprise identifies and exploits opportunities for Scotland's economic growth by supporting Scottish companies to compete, helping to build globally competitive sectors, attracting new investment and creating a world-class business environment. Scottish Enterprise sees company and sector innovation as a key driver of productivity and competitiveness. With its partners, Scottish Enterprise is taking a more integrated approach to stimulating innovation, knowledge transfer and commercialisation, with a focus on getting more new products and services into global markets.

Engineering and Physical Sciences Research Council (EPSRC)

EPSRC is a member of the LCICG on behalf of the RCUK Energy Programme, which aims to position the UK to meet its energy and environmental targets and policy goals through the support of world-class research and doctoral training. Led by EPSRC, the Energy Programme brings together the work of EPSRC with that of the Biotechnology and Biological Sciences Research Council, the Economic and Social Research Council, the Natural Environment Research Council, and the Science and Technology Facilities Council.

Technology Strategy Board

The Technology Strategy Board is a non-departmental public body which works with partners in industry and government to invest in business-led innovation, with the aim of stimulating UK economic growth. Priority investment theme areas with a low carbon focus include energy, transport and the built environment. The Technology Strategy Board is also creating a network of nine Catapult Centres, with the aim of transforming the UK's innovation capability in specific fields, including offshore renewable energy, transport systems, energy systems and future cities.

Energy Technologies Institute (ETI)

The ETI is a public-private partnership between six global energy and engineering companies and the UK Government. It carries out modelling and strategic analysis of the UK energy system to identify the key challenges and potential solutions for meeting the UK's 2020 and 2050 targets at the lowest cost. It also invests in major engineering and technology demonstration projects which address these challenges. The ETI's mission is to accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals.

Carbon Trust

The Carbon Trust is an independent company that works with businesses and governments to help them make the move to a low carbon economy and to benefit from business opportunities in sustainable green growth. It also partners with organisations to accelerate low carbon technologies through the process of commercialisation.

Associate Members

These are organisations that have a role in public-sector backed funding of low carbon technology innovation but the scope of their role is limited to particular technologies. Associate members choose which aspects of the Group's work they engage with.

The Crown Estate

The Crown Estate manages the seabed out to a distance of 12 nautical miles from the shore and has certain commercial rights beyond that, in particular relating to renewable energy. Its goal is to make a profit for the benefit of the nation. It is a key player in supporting the delivery of a diverse and secure energy supply for the UK, particularly by seeking to successfully exploit the country's significant wind, wave and tidal energy resources. The Crown Estate also has a significant onshore portfolio of which low carbon renewable energy is a part.

Department for Communities and Local Government (DCLG)

DCLG has an important role to play in protecting and enhancing the environment and supporting sustainable economic growth, through its responsibilities for housing, planning and the building regulations. Energy Performance Certificates promote improved energy efficiency in existing homes, while building regulations contain provisions for ensuring energy efficiency in new or altered buildings.

Department for Environment, Food and Rural Affairs (Defra)

Defra aims to drive emissions reductions in the agriculture, waste and forestry sectors and to support the sustainable deployment of low carbon and renewable energy. A portfolio of research and delivery programmes sets out to achieve emissions reductions and better resource efficiency in sectors such as agriculture, food, forestry and waste.

Department for Transport (DfT)

DfT is responsible for overall transport strategy, with a vision for a transport system that is an engine for growth, is greener, safer and improves quality of life. DfT promotes lower carbon transport and provides funding to support the uptake of the next-generation of ultra-low emission vehicle technologies and to support local sustainable transport projects.

Ministry of Defence (MoD)

Secure, sustainable and affordable supplies of energy support the continued operational effectiveness of the armed forces. MoD undertakes research and demonstration of a range of technologies with a view to developing alternative power sources and enhancing energy efficiency. The MoD Estate accounts for around 1% of the country's landmass, and includes nearly 50,000 Service personnel houses, with over 80% of Estate electricity provided by renewable or CHP suppliers.

Department of Enterprise, Trade and Industry (DETI)

DETI has responsibility, within the Northern Ireland Executive, for energy policy and priorities including security of supply and enhancing sustainability. Support for energy innovation is channelled through Invest NI, which regularly engages with over 400 businesses, promotes inward investment and has developed a Competence Research Centre for Sustainable Energy.

Ofgem

Ofgem is the Office of Gas and Electricity Markets, and focuses on consumer protection in these sectors through the promotion of competition and regulation of monopoly companies. Low carbon innovation is supported through Ofgem's Low Carbon Networks Fund, as well as through the new price control regime which has innovation and efficiency at its core.

Welsh Government

The Welsh Government works to enhance economic, social and environmental wellbeing, improving quality of life for present and future generations, including through making the transition to a low carbon economy. The Welsh Government offers innovation support for businesses and academia, and funds a National Research Network.

UK Trade and Investment (UKTI)

UKTI works with UK-based businesses to ensure their success in international markets, and helps overseas companies to bring their high quality investment to the UK. Low carbon funding support is a valuable tool that UKTI utilises when presenting the benefits to overseas companies of establishing an R&D presence and developing their technologies in the UK.

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