Department for Business, Energy and Industrial Strategy
Building an Industrial Strategy Consultation

Response from the Energy Futures Lab and the Grantham Institute- Climate Change and the Environment, Imperial College London

13/04/2017

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Brief Introduction

Consistently rated amongst the world's best universities, Imperial College London is a science-based institution with a reputation for excellence in teaching and research that attracts 13,000 students and 6,000 staff of the highest international quality.

Within the College, the Grantham Institute is committed to driving research in climate change and the environment, and translating it into real world impact. Established in February 2007 with a £12.7 million donation over ten years from the Grantham Foundation for the Protection of the Environment, the Institute's researchers are developing both the fundamental scientific understanding of climate and environmental change, and the mitigation and adaptation responses to it. The research, policy and outreach work that the Institute carries out is based on, and backed up by, the world leading research by academic staff at Imperial.

Energy Futures Lab is a cross-discipline institute based at Imperial College London. Energy Futures Lab was founded in 2005 to develop multidisciplinary, cross-faculty collaborations to tackle the broad range of energy challenges that the world faces. The Institute is a small team of dedicated professional that assists in building connections, coordinating projects and highlighting successes.

This consultation response draws upon the expertise of academics and researchers at Imperial College London and has been prepared by the Grantham Institute and the Energy Futures Lab.

Response to the Consultation

General Comments
We welcome the government's industrial strategy and recognise its key aims to deliver economic growth and jobs to many different parts of the country, capitalising on technical skills and STEM expertise. (Q.34)

The commitment to developing the clean energy sector, the pledge to invest in new infrastructure and the potential to develop exports in the relevant, clean and green sectors of the economy are promising. This strategic outlook has the potential to deliver on the government's job creation agenda whilst contributing to the UK's climate change commitments, as enshrined in the Climate Change Act.

However, we believe that the strategy could be more direct and bold in making the case for economic growth through low carbon innovation. Every component of the industrial strategy must demonstrate how it contributes to the transition to a low carbon and resilient society. The opportunities for UK economic growth in creating this transition will be the basis for our future well being.

This submission addresses the consultation questions associated with the overall ambition set out in the consultation:

"We need to keep costs down for businesses, and secure the economic benefits of the transition to a low-carbon economy."

The current scientific evidence points clearly to the need to take urgent action on climate change, by reducing our greenhouse gases and preparing to adapt to the impacts of climate change. Spurred on by the strength of this evidence, our organisations would like to emphasise some of the most promising opportunities we see in your report:

1. **Affordable energy and clean growth:** the paper makes a commitment to affordable energy and clean growth. To deliver on these goals, the industrial strategy must be aligned with the forthcoming Green Growth Plan – previously the Emissions Reduction Plan. Providing long-term targets and policies that support these targets will create policy certainty that will keep costs down and encourage investment in the the low-carbon generation that the UK needs.

2. **Infrastructure development:** The focus on investment in long-term infrastructure (Q.16) can help support the development of a lower-carbon and more resilient economy. It is important for infrastructure projects to be developed in a way that contributes to the delivery of the UK's climate and environmental targets, rather than just minimising damage to our environment.

3. **Balancing costs**: The industrial strategy includes the challenging goal of supplying energy through competitive markets, without the need for ongoing subsidy (Q.28). Whilst we endorse the principle of competitive markets, we also recognise that all energy suppliers – even the most mature technologies – are likely to need some sort of certainty e.g. through long run contracts. In addition, more nascent low-carbon technologies, storage and carbon capture and storage (CCS) will need at certain times support to be enabled to enter the market, whilst one develops low carbon technologies or even more mature technologies will need some levels – albeit differential - of financial support to enter or thrive within these competitive markets. In addition, concerns about fuel poverty and capacity issues are not always effectively managed by competitive markets.

   It is important that growth strategies, and analyses such as cost and benefit analyses, include considerations of the value of less tangible assets, such as the natural environment. These considerations can be incorporated using natural capital calculations, social cost of carbon or carbon shadow prices or equivalent techniques.

4. **Harnessing the right institutions**: The choice of institutions (Q.3) to deliver the industrial strategy is key. The UK already has a number of very effective and useful institutions and organisations that can contribute to the industrial strategy including universities. The government may need to consider new institutions at a more regional level to deliver on priorities for different parts of the country or institutions focussed on a specific technology focus e.g. energy storage. However, any investment in new institutions should take care to build upon existing legacy and not to duplicate capacity – particular in relation to educational institutions and institutions targetted at innovation and commercialisation. A number of approaches have been tried in the past and it is important to learn which institutions have been successful, and where they have succeeded.

   For the UK to become a world leader in developing and commercialising low-carbon innovation we need to develop low-carbon innovation clusters. Innovation hotspots already exist in London, the Thames Valley, Cambridge, Birmingham, Edinburgh and Glasgow, but growth rates of 4-6% gross value added (GVA) need to be doubled for the UK to be globally competitive. Enabling leading Universities to support existing and new businesses to accelerate innovation is an innovation clustering model that can and has delivered increased growth rates. The creation of a network of city-based low-carbon innovation clusters should be a key component of the industrial strategy.

5. **Joined up approaches:** Several pillars in the industrial strategy can support both decarbonisation and growth, for example using procurement to support new technologies which therefore help create new markets (and reduce risk for investors), support for SMEs and investment in infrastructure. It is vital that the pillars of the strategy also consider secondary objectives, such as supporting the UK emissions reduction plan, in a joined up manner.

Question 5: What should be the priority areas for science, research and innovation investment?

We welcome the strategy's recognition of the importance of clean energy, and its acknowldgement that industrial growth and job creation should also deliver the UK's climate change goals. Conversely, there are opportunities for job creation from the drivers to achieve these climate change targets, and deliver a low-carbon enegy system.

The specific focus on the development of new storage technologies is important in the context of developing our low carbon energy and transport systems, and offers the opportunities for continued jobs in the transport sector. For these reasons, prioritising storage technologies is logical.

However, we would encourage the government to keep support systems for technology priorities in relation to clean energy and climate change flexible. Storage will not be the only opportunity in this area. Indeed, a low-carbon economy will impact every existing sector and create some new ones. For example, food is a major contributor to greenhouse gas emissions and we would expect the UK to be at the forefront of innovations to reduce the sector's negative impats. Institutions and systems should be developed that are able to seize the next new opportunity as it arises.

8. How can we best support the next generation of research leaders and entrepreneurs?

We have already proposed that the UK should create innovation clusters for the low carbon economy. This has been the basis of discussions with the Department for Business, Energy and Industrial Strategy (BEIS). Such clusters are an essential environment for supporting leaders in research, innovation and entrepreneurship. The engagement of universities, research institutions and the private sector in the creation of dense networks of support for science, innovation and business creation is, from our perspective, a key catalyst for the development of a high-value low carbon economy.

These statements are based on our experiences as a founding partner of the EU-funded Climate-KIC. This has enabled us to successfully bring universities, research institutions, big businesses and start-ups together in the creation of new business and businesses. For example, in the space of 5 years we have been able to support the development of 34 new businesses, who have won $115M of investment and created over 350 jobs. We have a tested model that we believe can and should be replicated in other centres.

In the past the government has not focussed innovation resources into cluster hotspots. This is contraindicated by the well known benefits (to researchers, innovators and entrepreneurs) of clustering. Creating such innovation clusters will provide the potential for the UK to become one of the world's leaders in low-carbon business creation.

The support that would be required to create such innovation clusters would include:

- Support for innovation and coupled research that would be vested with the local cluster partners.
- Support for infrastructure that enables the proximity that the cluster needs.
- Support for the development and management of the networks that are the basis of a cluster.
- Support for national coordination between clusters to enable research, innovation and business development opportunities between clusters.

15. Are there further actions we could take to support private investment in infrastructure?

There are a range of infrastructure investments that are vital to delivering the UK's decarbonisation and energy security goals. These priorities include public transport, energy infrastructure and networks, including interconnectors. Each of these infrastructure types have different funding models, and therefore different approaches are needed to support or leverage private sector investments.

Government also has a critical role in supporting technology innovation by helping to provide infrastructure where businesses would not necessarily be able to do so on their own. An electric vehicle charging infrastructure, or hydrogen and CO_2 transport networks, might be examples.

Interconnectors are a vital part of cost-effectively delivering the UK's decarbonisation agenda by enabling flexibility in the system (see answer to question 28) and some more detail on this particular type of infrastructure investment is provided here.

Interconnector costs are favourable compared with new power plants and other storage options. Based on a cost-benefit analysis of a number of future planned interconnectors (NSN, Viking Link, IFA2, FAB Link and Greenlink), linking GB energy markets to Norway, Denmark and France, the consumer welfare benefits are significant (Ofgem, 2014). They connect GB to markets with lower average price levels, leading to large net imports into GB. These benefits are weakened by lower GB producer surplus however (i.e. profitability of British generators). Furthermore, France and Norway are particularly well hedged against fossil fuel price increases and higher carbon prices as a result of their large shares of nuclear and hydro generation capacity, respectively.

While the business case and operating models were consistent, the social welfare impacts between different interconnector projects are driven by (1) the capacity (i.e. MW) of the interconnector; (2) the length of the interconnector (cost increases with length); and (3) the scale of the average price differences between markets.

The costs of development could drastically change after Brexit, resulting in the reassessment of planned projects (REA, 2015). Exchange rate fluctuations, import costs, restrictions on the movement of foreign expertise, financial regulation, passporting arrangements, and the introduction of trade tariffs on energy related components, could all impact investor appetite. The Weighted Average Cost of Capital (WACC) would also be expected to rise as a result of the increase in these perceived risk factors.

Losses of EU funding for interconnection should also be considered. The UK has been the fourth highest recipient of funds for infrastructure projects that benefit at least two member states. These Projects of Common Interest (PCIs) have facilitated investment on internal lines and interconnection with Belgium, France, ROI and Norway, helping the UK in achieving the 10% interconnection target by 2020. The European Energy Programme for Recovery (EEPR) has awarded over €100 million to support GB interconnection with ROI (12% of all EEPR funding awarded) (European Commission, 2012).

National Grid, along with other stakeholders, claim that supply security, flexibility, price competition, renewables integration and decarbonisation will all benefit from the continued free trade of energy in the Internal Energy Market (Energy and Climate Change Select Committee, 2015). Furthermore, they favour an ongoing implementation of EU energy packages, network codes, and market design. The UK would then have to ensure Ofgem and the National Grid remain contributing members of ACER and ENTSO-E, respectively.

The Government will need to consider securing, or replacing the comprehensive financing options currently available at the EU level (e.g. EEPR, PCIs, EIB loans, etc.) that currently help make a convincing case for interconnector investors.

24. What further steps can be taken to use public procurement to drive the industrial strategy in areas where government is the main client, such as:

Public procurement is an important driver of clean energy and low carbon growth, as well as supporting the other goals of the industrial strategy. The public sector should be leading in adopting the new technologies, or processes, many of which may be developed or manufactured in the UK, to deliver a clean and affordable energy system.

During the solar flat plate array project in the USA over the period 1975-1985, the US DoE purchased several blocks of different solar PV module designs to help field test them and arrive at the most durable, cheapest and highest efficiency designs. During this period alone, the cost of solar PV modules decreased by a factor of 10, and the current PV panel materials and designs that we see on roofs today were largely arrived at by 1985 (Gambhir, 2014).

27. What are the most important steps the Government should take to limit energy costs over the long-term?

As the cost of several leading low carbon sources of energy falls, focus is shifting from technology cost reduction to emerging energy system challenges. Through innovation, tensions between cost effectiveness and carbon abatement can be ameliorated. Effective policies can maximise benefits for UK businesses and energy efficiency can reduce bills and emissions simultaneously.

We focus on three areas:

a) Energy system flexibility: Ensuring that the energy system is flexible and efficient and able to accommodate new demands e.g. more electric cars, low-carbon heating and lower-cost renewables.

b) Supply cost: Ensuring that secure and low carbon energy is provided at least cost.

c) Innovation in efficiency: Policies to promote ongoing energy efficiency improvement in homes and businesses.

Energy system flexibility

Flexible options in the energy sector include application of more efficient and more flexible generation technologies, energy storage, demand side response, interconnection and also reduced needs for various balancing services through improved system management and forecasting techniques.

Imperial College's research shows that the system integration cost of low-carbon generation technologies will significantly depend on the level of system *flexibility*. Enhancing system flexibility reduces system integration cost of renewables *by an order of magnitude*.

For instance, work for the Committee on Climate Change (Strbac *et al.*, 2015) shows that the whole-system cost disadvantage of wind generation against nuclear reduces from circa £14/MWh in a low flexibility system to £1.3/MWh in a fully flexible system achieving 100 g/kWh emission intensity. At the same time, the whole-system cost of solar PV reduces from being £2.3/MWh higher than nuclear to being £10.7/MWh lower than nuclear as the result of improved flexibility. Work by Imperial and colleagues for the National Infrastructure Commission demonstrates that the value of flexibility in a future energy system could be as high as £8bn per year (Strbac *et al.*, 2016).

These conclusions are reinforced by a recent meta-analysis of the costs and impacts of intermittency, undertaken by Imperial for the UK Energy Research Centre (UKERC). This research finds that whilst the costs of integrating wind and solar remain modest - up to around 30% penetration of variable renewables (circa £10/MWh in UK conditions) - the range of cost estimates in the literature is wide. The reason for the diversity of estimates is due in large part to assumptions about balance of system flexibility (Heptonstall, Gross & Steiner, 2017).

It is of paramount importance that the UK continues to develop sources of system flexibility, promoting network operation, demand response and storage. One of the key opportunities that excites us at Imperial College is the potential to understand and enhance *whole system integration*. This means considering new loads such as electric vehicles, together with new sources of supply and emerging technologies to operate energy networks in an integrated fashion. This will be an important area for wider policies to promote and facilitate flexibility.

A long term energy strategy needs to take a systems level approach and consider the implications of closer interactions between the power, gas (for heat) and transport sectors and the required infrastructural changes. Whilst electrification is likely to be a key component of a lower carbon, least cost energy system, other technologies and vectors are also important. Linking electricity, hydrogen and fuel cells can help provide the least-cost solution to decarbonising the UK economy out to 2050 (Ekins et al 2017).

Supply cost: **Reducing the costs of secure and low carbon energy**
In our response to Question 28, we set out the rationale for an approach which retains the Contracts for Difference created in the 2013 Energy Act and moves to a more competitive and technologically neutral approach to their utilisation.

Limiting costs for consumers will also depend upon making best use of cost effective sources of electricity. Gas remains the lowest cost option, neglecting carbon costs. However, gas is subject to long term volatility and uncertainty associated with global fossil fuel prices. Despite recent price falls, rising wholesale gas and power prices were the principal causes of rising energy costs throughout the period from 2002 – 2014 (Department for Business, Energy and Industrial Strategy, 2016). However there is strong evidence of cost reduction trends and opportunities in leading renewable generation options (Gross et al., 2013). Internationally, recent power purchase and feed in tariff auctions have seen bid prices in the best sites for onshore wind and solar which are at or below parity for fossil fuel generation (International Energy Agency, 2016).

If the UK is to benefit from decreasing renewable energy costs it will be important to provide contractual terms which are attractive to investors (see response to question 28). The government has already indicated that it intends to auction contracts for offshore wind, subject to cost reduction, and there is good evidence to suggest that prices for offshore wind could be in the region of £80- £90/MWh for projects commissioning in the early 2020s (Gross, 2015). However the UK is currently not able to benefit from continued global reductions in the prices of onshore wind and solar photovoltaics, the costs of which are even lower, because both are currently excluded from the portfolio of technologies that are eligible for policy support. The government made a manifesto commitment to end subsidy for onshore wind, but it is now possible that onshore wind could be commissioned without subsidy (subject to appropriate long term contracts). If overall decarbonisation costs are to be minimised the government could reassess its approach to onshore wind and ground mounted solar which are emerging as the lowest cost low carbon sources of electricity.

Many scenarios also suggest that carbon capture and storage (CCS) is likely to be an important contributor to a least cost path to a low carbon economy. CCS offers one route to providing low carbon electricity, alongside nuclear and renewables. However, CCS also offers a route to decarbonised heating (through the use of hydrogen in the gas network) and can be applied to some large industrial sources of CCS (Oxburgh et al., 2016). Our analysis indicates that if the potential for CCS to contribute to the goals of the Climate Change Act and secure industrial benefits for UK companies are to be realised then during the 2020s, the government will need to provide policies to support technology development and facilitate the development of pipeline and storage infrastructure (Gross, 2016).

Energy Efficiency

A large body of research finds that energy efficiency is often able to reduce energy bills in a very cost effective way, with low payback periods and net financial benefits for consumers (Committee on Climate Change, 2017). Efficiency gains have reduced the typical household bill by around £500 and saved around 1 tonne of carbon per household in the period since 2004 (Committee on Climate Change, 2017).

However efficiency is often subject to a range of barriers to adoption, including access to upfront capital (energy efficiency may have higher initial costs, offset by lower running costs), lack of information on the part of consumers and 'split incentives' between building owners and building occupiers in the rental sectors. For these reasons governments internationally have a long standing set of policies to promote energy efficiency, including direct regulation of buildings and appliances, obligations on energy suppliers and a range of incentives and information schemes (Department for Business, Energy and Industrial Strategy, 2013).

In 2015, the UK government removed funding for the company providing loans under the *Green Deal*, arguing that the scheme was ineffective (DECC 2015). Support for energy efficiency is now focused on low income groups, through the ECO scheme, an obligation on energy suppliers (Ofgem 2016). The government also removed the *Zero Carbon Homes Commitment* (HM Treasury 2016). In both cases the reasons that policies were scrapped are well documented but create two important policy gaps – finance for householders wishing to invest in best available energy efficient refurbishment, and policy to promote best practice innovation in the building construction sector. In both sectors building and appliance regulation continue to promote efficiency improvement. However, whilst regulation can ensure minimum standards there are now no policies to promote *best practice* investment, whether by homebuilders or homeowners. This risks reducing incentives for *innovation* in energy efficiency. Ultimately this could undermine the development of the next generation of new technologies able to reduce energy costs through efficiency, and reduce opportunities for UK businesses to secure commercial opportunities in the energy efficiency industries.

At the time of writing, the government has not committed to a clear timeline for replacing the Green Deal (ECCC, 2016). The government has argued that the zero carbon home commitment is unnecessary given existing building regulations. However, ongoing innovation in the energy efficiency industry will be encouraged if the UK has a buoyant domestic refurbishment market and stretching targets for new builds. Providing cost effective replacements for the Green Deal and Zero Carbon target would facilitate investment by owner occupiers and challenge the building industry to push the boundaries of energy efficient home design. This could serve the twin goals of creating competitive advantage for innovative UK companies and reducing energy bills over the longer term.

It is also important to ensure that energy efficiency regulations and standards continue to promote progress in energy efficiency. By far the most significant driver for energy efficiency improvement in buildings and appliances is direct regulation. As the UK moves to leave the European Union it will be important for the government to ensure that the UK continues to set ambitious standards for building and appliance efficiency. It is also likely to be desirable for UK manufacturers and equipment suppliers selling into both UK and other EU markets for efficiency standards to remain closely linked.

28. How can we move towards a position in which energy is supplied by competitive markets without the requirement for on-going subsidy?

Our interpretation of this question – the focus is on power market subsidies

We interpret this question to be principally focused upon the electricity market and the *contracts for difference* (CfDs) that exist for low carbon generation, since there is little ongoing government subsidy in the oil and gas markets.

The electricity market also includes a *capacity mechanism* designed to ensure that electricity supplies are reliable. The capacity mechanism was introduced in response to a phenomenon referred to in electricity market economics as *missing money* (Newbery, 2015); where for a variety of reasons peak power prices may not rise to a level sufficient to induce investment in new capacity. Investors may also believe future prices to be too uncertain to ensure adequate returns on investment in new capacity. However in a well-designed market, capacity payments reduce wholesale prices, which offsets the costs of the capacity payment, and hence capacity payments are not subsidies per se. For these reasons we do not focus this submission on the capacity mechanism.

We note that in UK energy markets in general the full social costs of carbon emissions are not included in prices since many energy users, such as domestic and most commercial gas customers, are not subject to a carbon price. In the power sector the carbon price floor is currently frozen at £18/tonne, with the expectation of the traded price in 2030 in a range of £38 - £116 per tonne (BEIS, 2017). In the long term, if the government is to remove subsidies for non-fossil fuels this needs to be accompanied by a carbon price to internalise the damage caused by oil, coal and gas. Even if this is achieved, there may be a need for long term contracts for some forms of low carbon generation in the electricity sector, due to wholesale power price volatility.

We are aware of suggestions that the CfDs and capacity market could be combined into a single auction that combines a commitment to provide firm power across peak periods and a carbon target (House of Lords, 2017). However these proposals lack detail and it is not clear how they could be made to work in practice, given that the CfDs and capacity mechanism serve distinct and separate objectives. The former exist to allow investors in low carbon *energy* to benefit from a low risk private law long term contract for electricity generated at all times of the day and throughout the year. The objective here is to increase the share of low carbon energy at minimum cost to consumers. The latter exists to help ensure the UK has adequate *capacity* across peak demand periods. The objective here is to ensure that there is an incentive to make capacity (new and existing power stations and demand side response) available when demand is high. Conflating these objectives is unlikely to improve the design of policies and it is difficult to envisage how a single auction could be made to work in practice. Doing so may require new legislation, introducing uncertainty and delay to the detriment of ongoing investment in the electricity system.

The role and importance of long run contracts for low carbon power

We understand that the government has an aspiration to reduce the amount of direct subsidy for non-fossil fuels, and also wishes to move the energy market to a more ‘technology neutral’ environment (DECC, 2015). An Imperial College Working Paper sets out how government could reduce costs and create a more technology neutral environment through an evolutionary approach that makes best use of existing policies (Gross, 2015). An evolutionary approach that moves existing policies onto a more technology neutral and competitive basis has the important effect of minimising delay and avoiding further damage to investor confidence, which was badly undermined when a series of unexpected policy changes were made during 2015 (ECCC, 2016). The principal points of the Working Paper are reproduced here.

The strengths and weaknesses of CfDs have been widely discussed, but they have already proven effective in attracting investment (Blyth 2014). For reasons discussed in more detail below CfDs offer investors a secure and stable long term environment. Properly managed, they have the potential to attract finance at relatively low risk premiums, which should benefit consumers by reducing financing costs (Blyth 2014). Concerns about cost effectiveness arise in part from high prices provided to some technologies before prices were determined by auction. These failings therefore relate to the early administration of the scheme rather than the CfDs per se. In addition, the broad principles of fixed price support schemes are well proven; over 100 countries have feed in tariffs of some form (REN 2015). They are familiar to investors, effective, and remain the principal policy used to promote the deployment of low carbon generation globally (IEA, 2008, Gross 2013). Many countries are also moving to use tenders to set the prices paid to low carbon technologies.

Therefore, there are good reasons for the UK to maintain auctioned Contracts for Difference as the primary policy to promote low carbon generation. The government should determine its approach to auctions going forward. Two broad possibilities appear possible: The first would be to retain the current system of 'pots' distinguished by technology maturity, the second to move to a single series of technology neutral auctions. If the former approach is followed, payments to the most mature technologies could be capped at a 'subsidy free' level, defined so as to represent the price of the least cost new entrant (likely to be gas fired Combined Cycle Gas Turbines [CCGT]). The government may also wish to set overall price caps on auctions for all technologies, declining over time, to further encourage innovation and control costs. Whatever the precise approach it will be important to signal to developers that CfD payments are expected to reduce substantially over time; that continued support is contingent on cost reduction; and that this is non-negotiable.

The need for longer term clarity

If the CfDs are to deliver in terms of risk reduction and provide lowest cost to consumers, then developers and investors also need clarity about policy goals over a timeline consistent with project development and construction (Blyth, 2014). These typically run from around five years to around a decade, depending on the size and complexity of the project. For this reason, CfD auction plans and timetable should be set out to 2025. A successful and clear sighted CfD regime would boost low carbon infrastructure investment and cost reductions over the coming years. The timing of auction rounds need to be set clearly in advance, and ambition for each auction specified as far in advance as possible, subject to clear criteria for adjustment to the volume of capacity to be auctioned as costs become clearer and deployment levels for different technologies emerge from auctions. The research evidence suggests that important sources of low carbon power – CCS, nuclear and offshore wind – will require some degree of subsidy in the period to 2025 (Gross, 2013). Whilst auctions and cost caps can drive costs down it is unlikely to be possible for these substantial sources of power to be entirely subsidy free for a number of years yet, particularly in the absence of a strong carbon price and if gas prices are low. For this reason the government also needs to provide an indication of the finance available for low carbon energy beyond 2020.

The levy control framework

In the 2017 Budget the government proposed to define how it will replace the current Levy Control Framework (LCF) in the Autumn Budget (HM Treasury, 2017). Whatever mechanism replaces the LCF needs to provide investors with clarity about the funding available for low carbon energy. This needs to be consistent with the timelines for project development. In the absence of this it is unlikely that development of important and potentially lower cost sources of power such as offshore wind will continue. This has important industrial policy implications, since there has been considerable development of the offshore wind supply chain in the UK. A 'stop-start' approach which leads to existing suppliers exiting the market because it is not possible to continue projects in the absence of policy goals for the 2020s is likely to be detrimental to both ongoing cost reductions and the ability of UK companies to benefit from opportunities to develop offshore wind in the 2020s (Gross, 2015).

The role of carbon pricing

The government also committed to replace the carbon price support mechanism with a single carbon price and to release details of this in the Autumn Budget (HM Treasury, 2017). Imperial College research indicates that the Carbon Price Floor is currently proving effective in ensuring that gas fired generation is more economic than coal. This, combined with the substantial increase in renewable energy capacity that policies have delivered in recent years has significantly reduced CO_2 emissions from the power sector (Drax, 2017, Gross, 2017).

A stable and long term carbon price alongside CfDs would also help provide investors with clarity and encourage investment in lower carbon energy. However carbon taxes may be viewed by investors as politically uncertain and a carbon price cannot offer investors the same degree of security as a long term, legally binding contract. The reasons have also been set out in earlier Imperial College research (Gross, 2012, Heptonstall, 2007, Gross, 2017) and are summarised below.

In the electricity generation arena, the principal limitations of carbon pricing can be found at the interface between politics and the needs of investors in low carbon generation (Gross, 2012). Carbon pricing has distributional and (if pursued unilaterally) industrial competitiveness impacts. In the absence of other policies to promote investment in zero carbon power, carbon pricing requires that the combination of carbon price and fuel price rises to the cost of the marginal least-cost low carbon option. This is likely to be more expensive for consumers than targeted payments to low carbon generators and investors are aware that carbon taxes can be lowered as well as rise. Because of these concerns, carbon pricing is perceived by investors in low carbon generation to be politically risky (Blyth 2014). Carbon price support cannot offer the same degree of investor security as a legal contract through a CfD. Carbon prices also do not offer the same degree of insulation from wholesale power price volatility provided by CfDs, and it is difficult for certain categories of investor to adequately hedge against wholesale power price volatility. This is the principal argument for 'subsidy free' CfDs for mature low carbon technologies.

29. How can the Government, business and researchers work together to develop the competitive opportunities from innovation in energy and our existing industrial strengths?

Imperial College researchers welcome the strong support for research in clean energy announced in the Industrial Strategy. It is also important, however, for the wider policy environment to continue to provide emerging technologies with a route to market and support UK companies in demonstration and commercialisation efforts. In addition, it is increasingly being recognized that the innovation process is not unidirectional and that challenges and R&D needs which are recognised at later-stages need to be fed back into the basic research process, as Figure 1 illustrates. (RCUK Energy Strategy Fellowship, 2013) The UK government, in bringing together the Research Councils and InnovateUK under UKRI, has provided a potential structure to improve this feedback process, but this should be actively monitored to ensure that feedback is occurring.

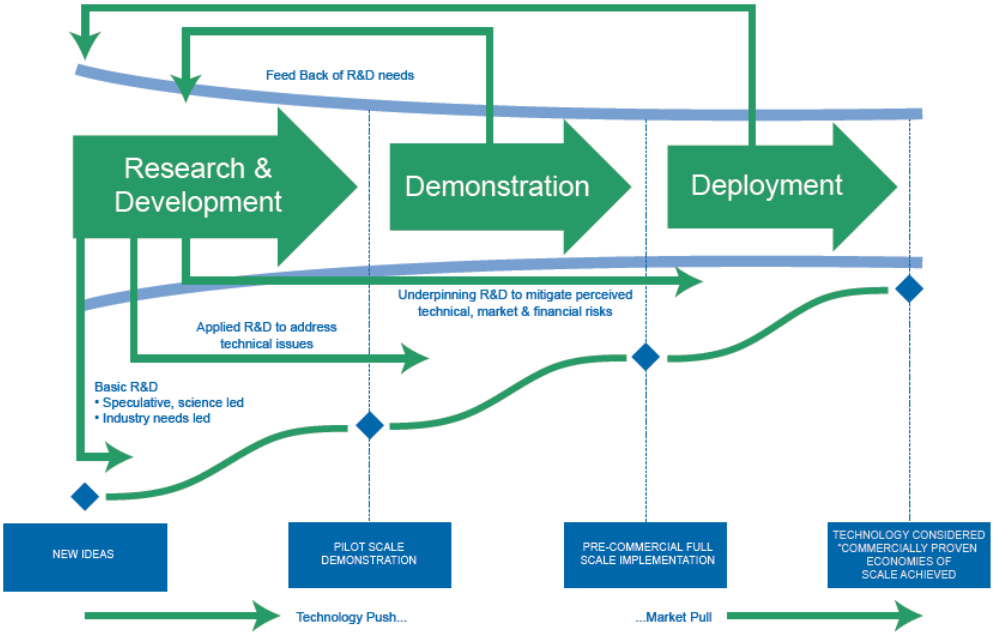

Figure 1: The Energy Innovation Process (ERP 2007)

The research evidence also points to the risk that emerging innovation falls into the so called 'valley of death', since in the early stages of development it may be too expensive for commercial deployment. (Energy Research Partnership, 2007) This is often particularly the case for clean energy innovations, where there is little or no product differentiation (for example electricity is just electricity regardless of how clean the supply may be).

For this reason there is a long standing economic argument for policy to provide early markets. Indeed this was the principal justification for the subsidies provided to wind and solar energy in many countries around the world. Public procurement is also a policy option that could contribute to supporting early markets. Leading renewable energy costs are falling and the government is moving to reduce subsidies in the power generation sector. (Rhodes A *et al,* 2014)

However it is important not to lose sight of the important role that government can play in assisting the next generation of clean energy innovations throughout the innovation chain from basic R&D through to pre-commercial deployment. New technologies may not gain a foothold and be driven down the cost curve if market arrangements and regulations prevent their value from being realised. Success will require active and sustained engagement between researchers and industry, which the government should aim to mediate and proactively promote. This engagement will aid government's understanding of how the full value of innovative energy technologies can be maximised, and design market structures and incentives accordingly. Doing so is likely to be essential if the UK is to benefit from new commercial opportunities that emerge from the UK's strong and successful energy research base.

References

BEIS (2017) *Carbon valuation* Available from: https://www.gov.uk/government/collections/carbon-valuation--2 [Accessed 20th March 2017].

Blyth, W, McCarthy, R, Gross, (2014) *Energy Strategies Under Uncertainty - Financing the Power Sector: Is the Money Available?*, Available from: http://www.ukerc.ac.uk/publications/ukerc-energy-strategy-under-uncertainties-financing-the-power-sector-is-the-money-available-.html, [Accessed 20th March 2017].

Committee on Climate Change. (2015) *Advice on the fifth carbon budget.* Available from: https://www.theccc.org.uk/publication/the-fifth-carbon-budget-the-next-step-towards-a-low-carbon-economy/ [Accessed 20th March 2017].

Committee on Climate Change. (2017) *Energy Prices and Bills Report 2017.* Available from: https://www.theccc.org.uk/publication/energy-prices-and-bills-report-2017/ [Accessed 20th March 2017].

DECC (2015) *A new direction for UK energy policy* Available from: https://www.gov.uk/government/speeches/amber-rudds-speech-on-a-new-direction-for-uk-energy-policy [Accessed 20th March 2017].

Department for Business, Energy and Industrial Strategy. (2013) *Energy Efficiency Strategy: 2013 update*. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/266187/2901415_EnergyEfficiencyStrategy_acc.pdf [Accessed 20th March 2017].

Department for Business, Energy and Industrial Strategy. (2016) *UK Energy in Brief 2016*. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/540135/UK_Energy_in_Brief_2016_FINAL.pdf [Accessed 20th March 2017].

Department for Business, Energy and Industrial Strategy. (2017) *Building our Industrial Strategy Green Paper.* Available from: https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf [Accessed 20th March 2017].

Department of Energy and Climate Change, (2013), *Green Deal Finance Company funding to end',* Available from: https://www.gov.uk/government/news/green-deal-finance-company-funding-to-end [Accessed 20th March 2017].

Drax Electric Insights, http://electricinsights.co.uk, [Accessed 20th March 2017].

ECCC (2016) *Investor confidence in the UK energy sector* Available from: https://www.publications.parliament.uk/pa/cm201516/cmselect/cmenergy/542/542.pdf [Accessed 20th March 2017].

Energy and Climate Change Select Committee, (2015) *Leaving the EU: implications for UK energy and climate change policy*.

Energy and Climate Change Select Committee, (2016), *Lord Bourne gives evidence on fifth carbon budget,* Available from: https://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/news-parliament-2015/fifth-carbon-budget-decc-evidence-15-16/. [Accessed 20th March 2017].

Energy Research Partnership, (2007), *UK Energy Innovation*, Available at http://www.energyresearchpartnership.org.uk/tiki-download_file.php?fileId=16, [Accessed 20th March 2017]

European Commission (2012), *Electricity interconnection* 2012. [Online]. Available: http://ec.europa.eu/energy/eepr/projects/files/electricity-interconnectors/uk-ie_en.pdf. [Accessed 28 03 2017].

Gambhir, A. Gross, R, Green, R. (2014) *The impact of policy on technology innovation and cost reduction: a case study on crystalline silicon solar PV modules*. Available from: https://www.imperial.ac.uk/grantham/publications/working-papers/the-impact-of-policy-on-technology-innovation-and-cost-reduction-a-case-study-on-crystalline-silicon-solar-pv-modules.php

Gross (2010) *Continuity in UK Energy Policy* Available from: https://workspace.imperial.ac.uk/icept/Public/innovation%20and%20continuity%20in%20UK%20policy.pdf [Accessed 20th March 2017].

Gross R. (2017), *Driving innovation through continuity in UK energy policy*, Available at:

Gross, R, Stern, J, Charles, C, Nicholls, J, Candelise, C, Heptonstall, P, Greenacre, P, (2012) *On picking winners: the need for targeted support for renewable energy,* Available from: http://www3.imperial.ac.uk/icept/publications/workingpapers, [Accessed 20th March 2017].

Gross, R, Stern, J, Charles, C, Nicholls, J, Candelise, C, Heptonstall, P, Greenacre, P, (2012), *On picking winners: the need for targeted support for renewable energy,* Available from: http://www3.imperial.ac.uk/icept/publications/workingpapers, [Accessed 20th March 2017]

Gross, R. (2015) *Approaches to cost reduction in carbon capture and storage and offshore wind.* Committee on Climate Change. Available from: https://www.theccc.org.uk/wp-content/uploads/2015/06/Gross-2015-Approaches-to-cost-reduction-in-carbon-capture-and-storage-and-offshore-wind.pdf [Accessed 20th March 2017].

Gross, R. (2016) *CCS in the UK: A new strategy.* Committee on Climate Change. Available from: https://www.theccc.org.uk/wp-content/uploads/2016/07/CCS_Advisory_Group_-_CCS_in_the_UK.pdf [Accessed 20th March 2017].

Gross, R., Heptonstall, P., Greenacre, P., Candelise, C., Jones, F. and Castillo Castillo, A. (2013) *Presenting the Future.* UK Energy Research Centre. Available from: file:///K:/Management%20Folder/Operations/EFL%20Boards/Energy%20Storage%20Research%20Network/Presenting%20the%20Future-%20Electricity%20Generation%20Cost%20Estimation%20Methodologies.pdf [Accessed 20th March 2017].

Gross, R., P. Heptonstall, P. Greenacre, C. Candelise, F. Jones and A. C. Castillo, (2013), *Presenting the Future: An assessment of future costs estimation methodologies in the electricity generation sector.* Available from: http://www.ukerc.ac.uk/programmes/technology-and-policy-assessment/electricity-cost-methodologies.html. [Accessed 20th March 2017].

Heptonstall, P, Gross, R, Blyth, W, (2007), Investment in Electricity Generation: The Role of Costs, Incentives and Risks, Available from: http://www.ukerc.ac.uk/programmes/technology-and-policy-assessment/investment-in-electricity-generation-report.html, [Accessed 20th March 2017]

Heptonstall, P., Gross, R. and Steiner, F. (2017) *The costs and impacts of intermittency – 2016 update.* UK Energy Research Centre. Available from: file:///K:/Management%20Folder/Operations/EFL%20Boards/Energy%20Storage%20Research%20Network/ukerc%20intermittency%20report%20(2).pdf.pdf [Accessed 20th March 2017].

HM Treasury, (2016), *Fixing the foundations: Creating a more prosperous nation,* Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/443897/Productivity_Plan_print.pdf [Accessed 20th March 2017].

HM Treasury, (2017), *Spring Budget 2017*, Available from: https://www.gov.uk/government/topical-events/spring-budget-2017, [Accessed 20th March 2017].

House of Lords Economic Affairs (2017) Available from: http://www.parliament.uk/business/committees/committees-a-z/lords-select/economic-affairs-committee/publications/ [Accessed 20th March 2017].

Ibid

IEA. (2008). *Deploying renewables principles for effective policies: in support of the G8 plan of action.* Available from; http://www.myilibrary.com?id=192197. [Accessed 20th March 2017].

International Energy Agency. (2016) *Tracking Clean Energy Progress 2016.* Available from: https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf [Accessed 20th March 2017].

Newbery, D, (2015), *Missing Money and Missing Markets: Reliability, Capacity Auctions and Interconnectors.* Available from: http://www.eprg.group.cam.ac.uk/wp-content/uploads/2015/03/1508_updated-July-20151.pdf [Accessed 20th March 2017].

Ofgem, (2014) *Near-term interconnector cost-benefit analysis: Independent report.*

Ofgem, (2016) *Energy Company Obligation,* Available from https://www.ofgem.gov.uk/environmental-programmes/eco [Accessed 20th March 2017].
Oxburgh, R., Aldous, P., Boswell, P., Davies, C., Hare, P., Haszeldine, S., Smith, J., Temperton, I., White, A. and Worthington, B. (2016) *Lowest cost decarbonisation for the UK: the critical role of CCS.* Parliamentary Advisory Group on Carbon Capture and Storage (CCS). Available from: http://www.sccs.org.uk/images/expertise/reports/oxford/oxburgh_report_the_critical_role_of_CCS.pdf [Accessed 20th March 2017].
P. Ekins and N. Shah (2017) Extended Summary. In: I. Staffell and P.E. Dodds. (Eds.) (2017) The role of hydrogen and fuel cells in future energy systems. H2FC SUPERGEN, London, UK
R Gross, (2017), *Don't sacrifice Britain's surprising progress in power sector decarbonisation* Available from: https://energyfutureslab.wordpress.com/2016/11/23/dont-sacrifice-britains-surprising-progress-in-power-sector-decarbonisation/ [Accessed 20th March 2017].
RCUK Energy Strategy Fellowship, (2013), *The Research Councils and the Energy Innovation Landscape,* Available at: http://www.imperial.ac.uk/a-z-research/rcuk-energy-strategy-fellowship/energy-research-prospectus/documents/workshopreports/, [Accessed 20th March 2017]
Renewable Energy Association (2015) *Written evidence submitted by the Renewable Energy Association*, Energy and Climate Change Commons Select Committee.
REN 21, (2015), *Global Status Report*, Available from: http://www.ren21.net/wp-content/uploads/2015/07/GSR2015_KeyFindings_lowres.pdf [Accessed 20th March 2017].
Rhodes, A.; Skea, J.; Hannon, M., 2014, *The Global Surge in Energy Innovation*, Energies 7, 5601-5623, Available at http://www.mdpi.com/1996-1073/7/9/5601, [Accessed 20th March 2017]
Strbac G M Aunedi D Pudjianto FTeng P Djapic R Druce A Carmel Borkowski, K (2015) *Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies.* Committee on Climate Change. Available from: https://www.theccc.org.uk/wp-content/uploads/2015/10/CCC_Externalities_report_Imperial_Final_21Oct20151.pdf [Accessed 20th March 2017].
Strbac, G., Aunedi, M., Pudjianto, D., Teng, F., Djapic, P., Druce, R., Carmel, A. and
Strbac, G., Konstantelos, I., Aunedi, M., Pollitt, M. and Green, R. (2016) *Delivering future-proof energy infrastructure.* National Infrastructure Commission. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/507256/Future-proof_energy_infrastructure_Imp_Cam_Feb_2016.pdf [Accessed 20th March 2017].