CARBON TRUST

Focus for success

A new approach to commercialising low carbon technologies

Table of Contents

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Preface

The Carbon Trust is an independent company set up in 2001 with the support of the UK Government. Its mission is to accelerate the transition to a low carbon economy. The Carbon Trust carries out a wide range of activities, including working directly with businesses to reduce carbon emissions, explaining the strategic implications of climate change and investing in new technologies and businesses that will help to tackle climate change.

This study examines the UK's innovation system for low carbon technologies in the context of new climate change related targets. It looks at why the UK should innovate in Low Carbon Technologies (LCTs), how the UK innovation system currently works and how it needs to evolve to meet new challenges.

Our findings are based largely on the results of an in-depth economic, engineering and commercial analysis of a sample of six LCTs, a review of LCT innovation systems in the UK and internationally and a high-level review of industrial policy.

We chose six technologies to represent the range of LCTs that may well be used in the UK covering the main sectors (electricity generation, heat, energy efficiency, transport and enabling technologies) as well as the key stages of technology development. The six were: offshore wind power, wave power, fuel-cell micro combined heat and power (FCmCHP), solid state lighting (SSL), ligno-cellulosic ethanol based on hydrolysis and fermentation (LHF ethanol – an example of an advanced biofuel) and flow cells (a type of energy storage).

Our findings show that the time is right for the UK to accelerate the move towards an innovation policy which is 'technology focused', based upon customised, technology specific support for carefully prioritised LCTs. We believe this is the most cost effective way to deliver carbon reductions and generate economic benefit for the UK.

Tom Delay
Chief Executive

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Executive summary

- Key findings
- The case for UK support for LCT innovations
- The cost of innovation and the need for prioritasations
- The need for technology specific solutions
- Technology focused approach
- Key recommendations

Key findings

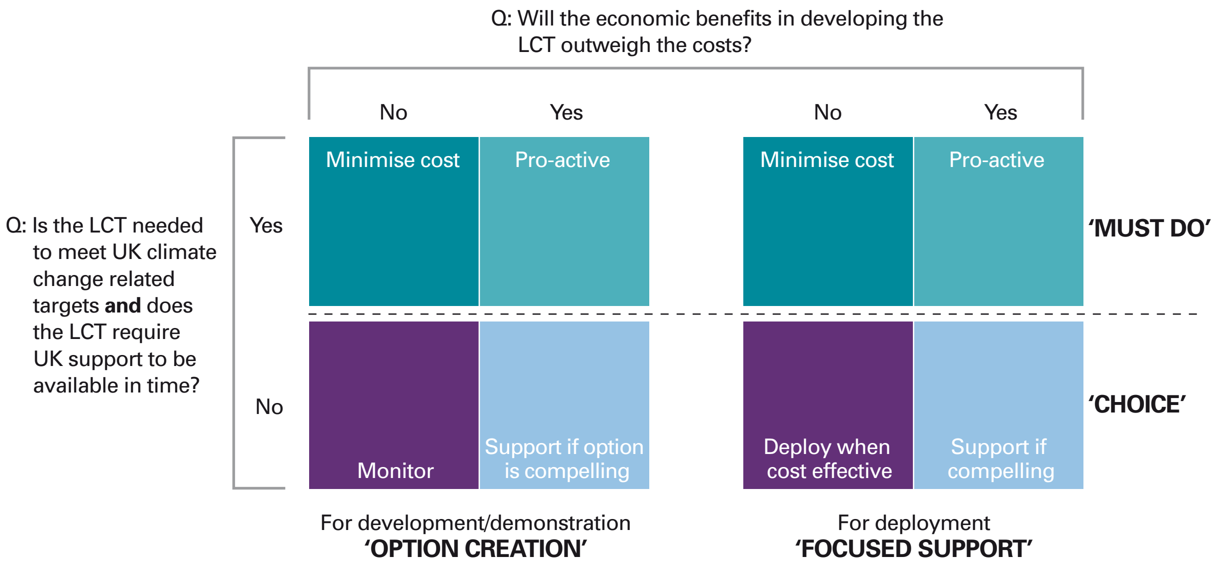
UK should support LCT innovation

There is a clear case for the UK to support the development of Low Carbon Technology (LCT). This will put the UK in a better position to address climate change and to reap economic benefits. The UK will need to deploy new and emerging LCTs to be able to meet climate change related targets. However, a variety of market failures mean that public support, from the UK or elsewhere, is required to commercialise LCTs. In many cases LCTs will commercialise through public support given by other states. So the UK has a choice: play an active and leading role in the innovation of one or more LCTs; or wait and deploy LCTs developed abroad. Detailed analysis of a sample of six LCTs has shown that the UK, by being an active player in technology development, could well generate significant net economic benefit and/or unlock technologies which will make a material contribution to UK climate change related targets.

Carefully prioritise LCTs

The UK needs to make smart investments in LCT innovation by accelerating the move towards greater technology prioritisation and away from explicit technology neutrality. LCTs present significant opportunities to create economic benefit for the UK and reduce carbon emissions. However in a resource-constrained environment, large-scale, short-term costs and longer-term and uncertain economic benefits mean that the UK can only have a global impact in a limited number of LCTs. So, the UK needs to move towards systematic and transparent prioritisation of support for LCTs. We need to distinguish between earlier stage technologies, with lower development costs and higher uncertainty, and later stage technologies, where greater focus is needed because deployment support costs are high. This prioritisation should be done at the family level (e.g. wave) rather than at the product level. We have developed and tested a possible framework based on contribution to UK climate change related targets and net economic benefit (see *Chart 1*).

***Chart 1** Prioritisation framework*



Source: LEK, Carbon Trust.

Key findings (cont.)

Customise LCT support

At the same time, there is also a need to accelerate the move towards greater technology customisation of LCT innovation support and away from generic policy mechanisms. The most cost effective way to support the commercialisation of LCTs is on a highly technology specific basis because the engineering and commercial barriers, and the solutions that need to be put in place, vary considerably by technology. Once a LCT has been prioritised, all the relevant solutions need to be put in place in order for the LCT to commercialise. These solutions include not only traditional innovation activities (e.g. R&D grants) but also both market pull and barrier removal activities (e.g. revenue support and regulatory changes) which are often not considered as part of innovation support.

A new approach

A ‘technology focused’ approach brings together these two elements – technology prioritisation and technology customisation – to improve radically the cost effectiveness of UK LCT innovation. This is very different from previous policies of supporting individual companies in sunset industries or creating national champions. A technology focused approach will support new growth markets and stimulate competition across the range of companies and products in each market. It is compatible with recent policy changes and with the overall carbon mitigation framework in the UK, as it complements technology-neutral carbon pricing mechanisms which are designed to stimulate the mass adoption of proven LCTs. This approach also integrates innovation support with manufacturing and regional activities to maximise economic benefit for the UK.

Greater adoption of a technology focused approach is a real opportunity for the UK. It increases the chances that public money is well spent, by focusing on key technologies for the UK and on the individual requirements of the technology. A technology focused approach will also increase the likelihood of the UK capturing value and jobs from the transition to a low carbon economy as well as helping to ensure the delivery of UK climate change related targets.

The case for UK support for LCT innovation

UK needs new and emerging LCTs

We need new or emerging LCTs to meet the UK's climate change related targets of 80% cuts in carbon emissions by 2050 and 15% renewable energy by 2020. This has been best illustrated by the work of the Committee on Climate Change which shows that existing technologies, including energy efficiency, onshore wind and nuclear, will only take us part of the way towards our targets. We need emerging LCTs, like offshore wind power, to become commercially viable so that they can be deployed on a larger scale. As there is considerable uncertainty around the innovation of any technology, including technical, economic and market risks, the UK will need to have access to LCT options whose total potential carbon savings are greater than that needed to meet carbon reduction targets.

LCT innovation needs public support

Innovation in LCTs needs public support. Market failures mean that private sector involvement alone will not generate enough investment to fully commercialise these technologies. For example, electricity generation technologies suffer from a number of market failures including: lack of niches and early adopters; risk averse suppliers; knowledge spillover effects and infrastructure tailored towards existing technologies.

Import or innovate?

In general, innovation of LCT is a global game. In at least four of our sample of six LCTs, the great majority of the innovation effort will be undertaken outside the UK, supported by other governments. The UK has a choice, to play an active and leading role in the innovation of one or more LCTs or to wait and deploy LCTs developed abroad. Our study shows there is no generic answer to this question but rather two specific cases in which active involvement is justified where a LCT:

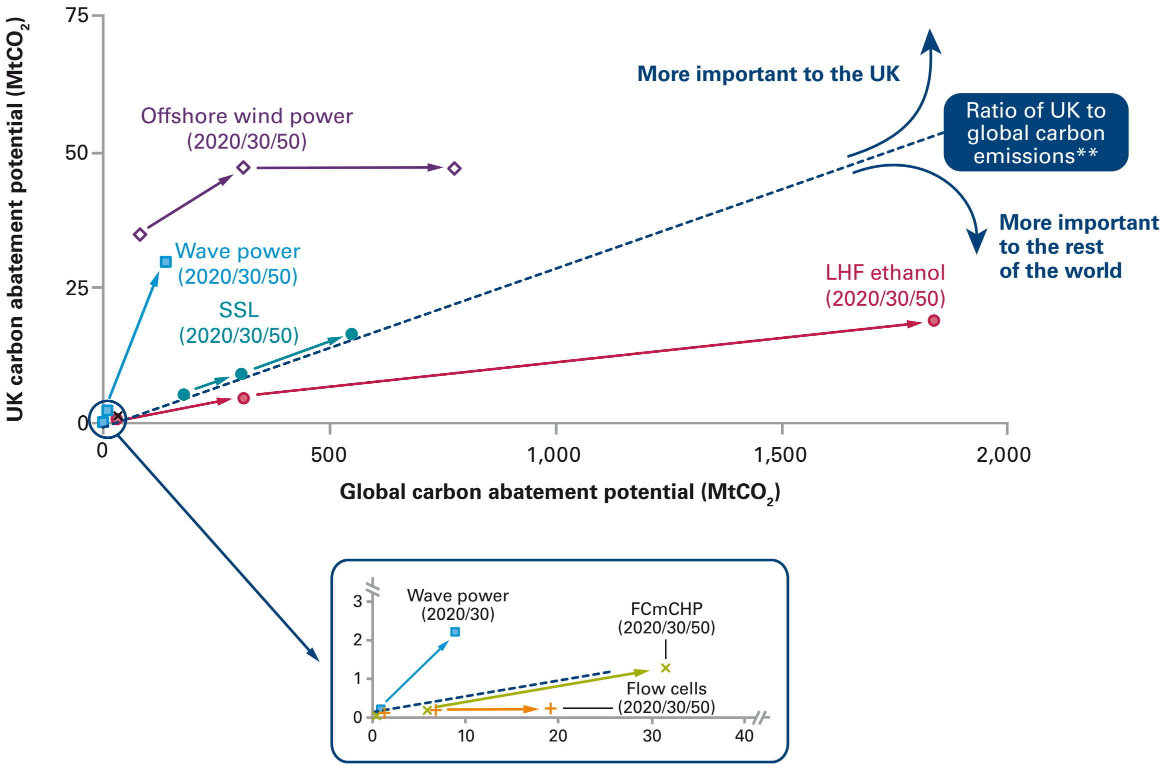
- Is vital for meeting the UK's climate change related targets and would not be available in time without the UK's support.
- Creates net economic benefit for the UK.

Needed to meet UK climate change related targets

Looking at our sample of six LCTs, which were chosen to be representative of the range of challenges faced by emerging LCTs, two of them, offshore wind power and wave power, are needed to meet UK climate change related targets and are unlikely to be available in time without the UK's support.

Chart 2 shows that, of the six LCTs considered, wave power and offshore wind power are proportionally much more important to the UK than the rest of the world. In both wave power and offshore wind power the UK is one of only a small group of countries leading the development of these technologies and, at least in the medium term, UK involvement will have an important impact on our ability to deploy the technology in a timely fashion.

Chart 2 *UK and global carbon abatement potential by technology**



*Mid deployment scenario.
**Gradient based on the ratio of global to UK carbon emissions from the use of fossil fuels in 1990.

Source: Technical consultants (Boston Consulting Group, Black & Veatch, BRE, E4tech, EA Technology, ENTEC, Gastec at CRE, Mott Macdonald and SKM); Energy Information Administration, 'International Energy Annual 2006', updated 2008; Carbon Trust analysis.

Create economic benefit

The second justification for UK support of LCT innovation is the creation of economic benefit. Our study estimates the potential to create up to 175,000 direct 'green jobs' in our representative sample of six LCTs, which could generate revenues of up to ~£25bn per year by 2050 (see *Chart 3*). The UK is also likely to have significant competitive advantage in the secondary service sector – particularly in areas such as finance and legal services. This will create jobs in addition to the direct jobs shown in *Chart 3*. Most of the technologies in our sample are too embryonic to assess the level of secondary jobs. However, it is possible to do so for offshore wind power as its development is further advanced. Including service jobs increases 2020 and 2050 offshore wind power jobs from up to 50,000 and 135,000 to up to 70,000 and 220,000 respectively[1], illustrating the potential for service jobs in other similar technologies (e.g. wave power, LHF ethanol and flow cells).

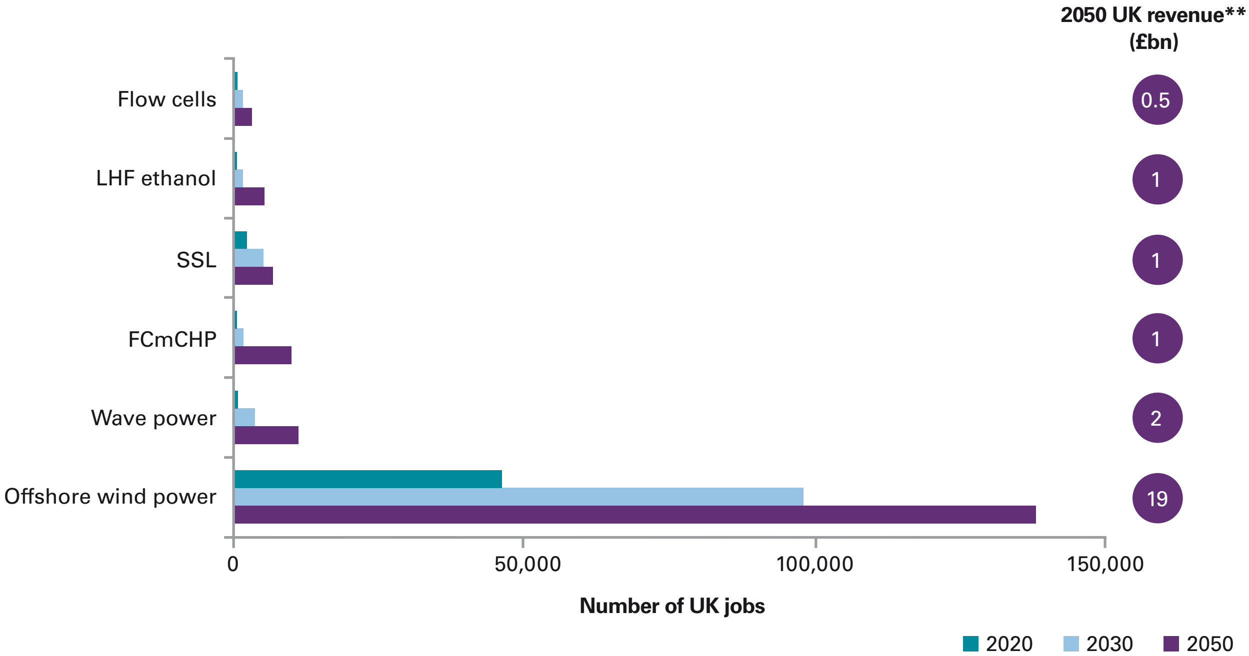
These are 'sunrise' industries with significant global markets and large growth potential. Choosing not to be an innovation leader would mean foregoing much of this economic development potential.

Offshore wind main jobs driver

Of the six sample technologies we examined, the majority of the job creation potential is in offshore wind power. Offshore wind power combines both a large global and domestic market with the potential for the UK to develop a strong base, building on existing skills and attracting key manufacturers. The UK could be a global market leader.

LHF ethanol and SSL are expected to be major markets globally, but in general, the UK is more likely to develop niche positions or focus on part of the value chain. Wave power, FCmCHP and flow cells are likely to be somewhat smaller markets – although, in the case of the first two, the UK could be the leader or among the leaders, respectively.

***Chart 3** Estimated UK direct job creation by technology**



*Includes supply chain jobs and incorporates leakage effects as we explicitly consider the market share of UK based companies in the supply chain; excludes income multiplier and displacement effects as in this case we have focused upon jobs within these industries and not included the impact on the wider economy; mid deployment, high learning, high UK market share scenario.
**Revenue to UK based companies from the sale and operation of technology equipment, excludes sales of the output (e.g. electricity), at 2008 prices.
Source: Technical consultants; Carbon Trust analysis.

[1] Source: Carbon Trust, 'Offshore Wind: Big Opportunity, Big Challenge', 2008.

Rigorous approach to economic benefit

We have estimated the net UK economic benefit generated by innovating each of our sample of six technologies compared with the alternative of importing the technology when it is cost effective[2].

It should be stressed that the evaluation of net economic benefit is not an exact science as it involves a large number of imponderables over a long period of time (our analysis goes to 2050). However, it does allow the key uncertainties to be identified (e.g. effectiveness of innovation, market uptake and economic conditions, such as energy prices and the extent that labour and capital is otherwise fully engaged). A variety of plausible scenarios have been created and then a judgement made on the likelihood of a technology generating net economic benefit for the UK.

Our assessment included all the relevant costs (public and private sector RD&D spend and the additional cost of the LCT over conventional technology) and the benefits (value-added to national income[3] and carbon benefits) and we have used a number of scenarios to examine the range of possible outcomes.

To assess the potential for value added, we considered the ability of companies operating in the UK to exploit an LCT by examining the UK's endowment of natural resources and academic and industrial capability. This was then translated into scenarios of market shares across the value chain in the domestic and export markets. We have also highlighted the potential scale of displacement effects – for example, not all jobs created will be filled by people who are unemployed.

[2] Based on comparing UK innovation of an LCT with a scenario of importing it when cost effective, both assessed against a counterfactual of 'business as usual'.

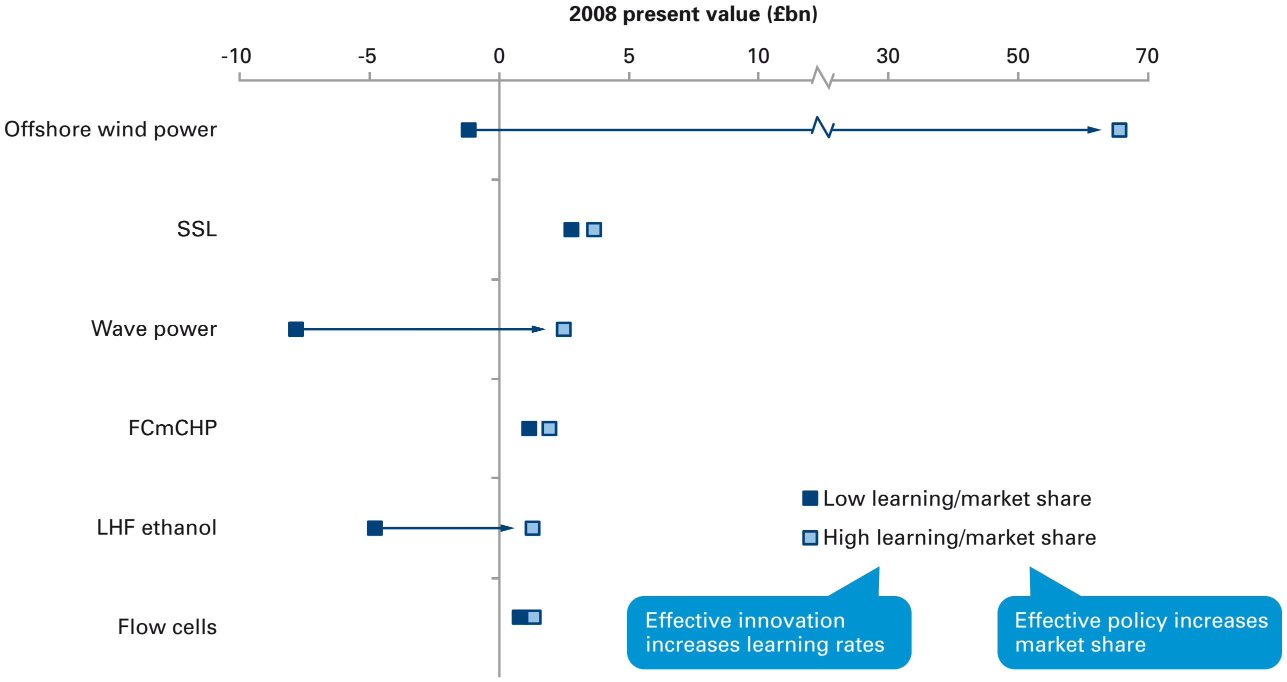
[3] Value added defined as UK salaries plus employers National Insurance contributions plus UK profits.

Effective innovation critical to generating economic benefit

Our analysis summarised in *Chart 4* shows that, excluding displacement effects, all the sample of six technologies can generate economic benefit for the UK. Although, as with jobs, the major contribution is from offshore wind power. *Chart 4* also illustrates clearly the importance of effective innovation (through both well-designed mechanisms and effective delivery). If innovation is effective it will lead to faster learning (and therefore lower costs) and greater UK market share in both export and domestic markets.

For example, at central energy prices, offshore wind power generates a loss of around £1bn[4] of value for the UK at low learning and UK market share. However, with more effective policy it could generate significant net economic benefits of ~£65bn. Effective innovation policy will help to increase learning rates from the lower end of those exhibited by onshore wind (9%) to the higher end (15%). Increased RD&D, in both new and existing components, and maximised economies of scale will fulfil this potential for cost reduction. Effective integration of innovation and economic development activity will also help to attract major existing or new turbine manufacturers to base all of their offshore wind operations in the UK, draw in the associated supply chain, maintain the UK's strong position in services (e.g. finance and legal) and capture 55-60% of installation activity. This would create a hub capable of maintaining a strong UK position in the regional European market beyond 2020.

***Chart 4** Net economic benefit to 2050 (excluding displacement effects)**



*Mid deployment and central energy prices scenario. BERR central scenario assumes crude oil prices of $65-75/bbl.

Source: Technical consultants, Carbon Trust analysis.

[4] All economic benefit figures are the present value (at 2008 prices) of annual costs and benefits to 2050 discounted at 3.5% for the first 30 years and 3.0% thereafter (in accordance with HMT's Green Book guidelines).

Three of our sample of technologies generate net economic benefit after displacement effects

Displacement effects, which allow for the fact that labour and capital used in LCT based industries may otherwise have been used productively, also have an important impact. Using fit for purpose assumptions[5] developed in consultation with DECC economists, the net economic benefit for offshore wind falls from c.£65bn to c.£25bn.

Displacement effects are more likely to be significant when the economy is working at capacity, which is clearly not the case presently. Even including displacement effects, three of our technologies show positive net economic benefit at central energy prices and assuming effective innovation – offshore wind, SSL and, to a modest degree, FCmCHP.

High energy prices dramatically increase economic benefit

Finally, energy prices can have a significant impact. For example, at central energy prices LHF ethanol (one of a number of advanced biofuels) is a cost to the UK economy of c.£3.5bn to 2050. However, at high energy prices, LHF ethanol could generate a net economic benefit of around c£2bn.

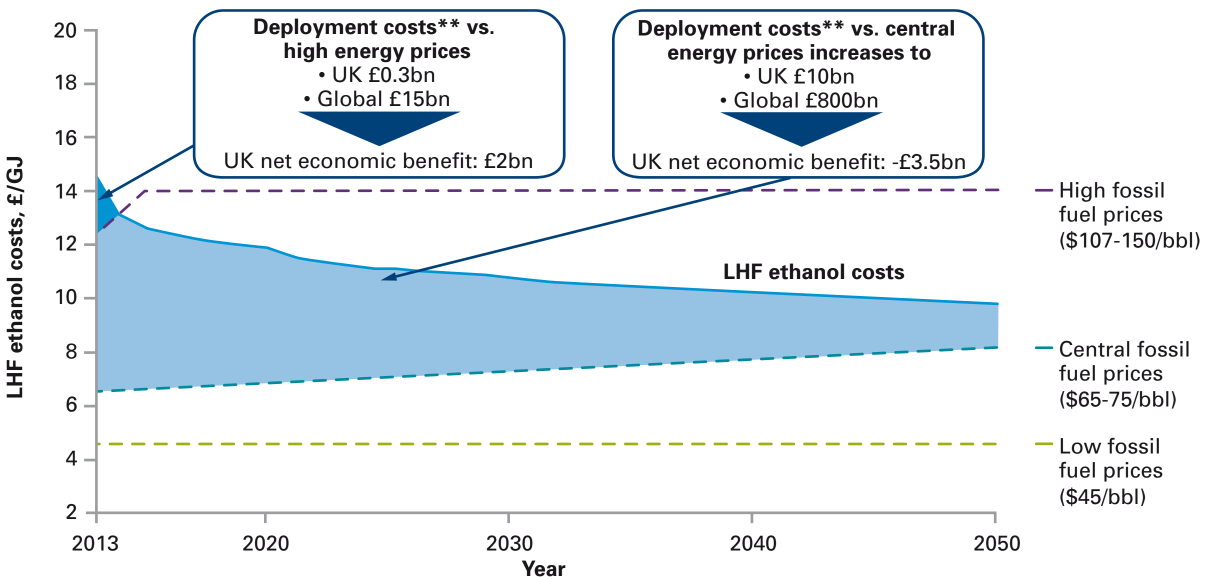
This is driven mainly by lower deployment support costs (vs. mineral based transport fuels). This is illustrated by the 'area under the curve' in *Chart 5*, which shows the costs of LHF ethanol falling with time. In the high fossil fuel price scenario, LHF ethanol reaches cost parity (and therefore no longer needs public subsidy) in the next decade, but does not reach cost parity until after 2050 in the central energy price scenario[6].

Security of energy supply and leadership may also justify UK support of LCT innovation

There are other reasons for the UK to support LCT innovation, although they have not been a focus of the quantitative analysis that underpins this report:

- Increased deployment of LCTs which contributes to security of energy supply and would not be available in time without the support of the UK.
- Establishing or reinforcing UK's leadership role on climate change as an international collective action issue.

Chart 5 *Variation of net economic benefit including displacement effects with energy prices**



*Includes displacement effects, mid deployment, central feedstock prices, mid learning and high UK market share scenario.
** 2008 present value.

Source: Technical consultants, Carbon Trust analysis.

[5] We have made a conservative assumption that the value added from domestic sales fully displaces other activities. UK value added from export sales should be far less affected and so we have assumed only 25% is subject to displacement effects.

[6] At central feedstock price scenario which shows feedstock prices dropping slightly from £2.5/GJ in 2010 to £1.5/GJ in 2050.

The cost of innovation and the need for prioritisation

LCTs offer significant opportunities to create economic benefit for the UK and meet climate change related targets. However, we live in a resource-constrained environment, and LCT innovation often involves large-scale short-term costs and longer-term and uncertain resultant economic benefits. Given the sheer range of potential LCT options, the UK (which accounts for 1-2% of RD&D spend in IEA member countries[7]) can only have a material impact in a limited number of LCTs. So there is a need to move towards systematic and transparent prioritisation of support for LCTs, distinguishing between earlier stage technologies, whose lower development costs and higher uncertainty argue for public support for multiple options, and later stage technologies, where clear focus is needed because deployment support costs are high.

Many LCT options

There is a wide range of LCT options for the UK. All of them could contribute a certain degree towards meeting climate change related targets. There are around 50 technology families and many hundreds of specific technology variants. Therefore there are a vast number of possible portfolios of technologies which could be supported.

High costs of commercialisation

The costs of LCT commercialisation can be very high. Very significant investment is needed to fully commercialise an LCT – taking it through from research and development to demonstration (collectively known as RD&D) to supported deployment (when the LCT is financially viable with public sector support in addition to the price of carbon) and then commercial deployment, at which point a technology is cost effective. For example, in order to commercialise offshore wind, the UK would need to spend up to £65bn[8] (2008, present value) in total until 2050 alongside similar investment from other leading countries such as Germany. With a current total UK budget of £1.4bn/year[9] across all emerging LCTs, the UK would not be able to support too many LCTs even with a significant increase in support funding.

Differentiated approach needed by stage of development

The cost of commercialising LCTs depends on the stage of development of the technology. The level of public support for an LCT increases as it develops until the late stages of supported deployment. At this point funding can begin to be withdrawn. This means a differentiated approach is needed:

- **Early stage** – supporting LCT innovation in the RD&D phase requires lower funding levels. However, there is also a high degree of uncertainty as to whether technologies will develop. Multiple options could therefore be supported to ensure that sufficient LCTs reach later stages of commercialisation, without needing excessive levels of public funding. For example, the earlier stage LCTs examined in this study – wave power, LHF ethanol, flow cells and FCmCHP – would require UK RD&D funding of c.£1bn in total, together with similar funding from other major countries to reach the point of large-scale supported deployment.
- **Deployment stage** – supporting LCTs which have reached the large-scale deployment phase[10] is an order of magnitude more expensive. Our study shows that on average for our sample of technologies the supported deployment phase costs around 40 times more than the RD&D phase to fully commercialise an LCT. The UK will have to choose very carefully which of the LCTs it brings into (large-scale) supported deployment as, given the costs, it may only be able to afford a small number of such technologies at the same time. Offshore wind is an example of a technology which is at the beginning of this (large-scale) supported deployment phase with, as mentioned, total required public support of up to c.£65bn over the next 40 years.

[7] Source: IEA on-line R&D statistics.

[8] This figure represents the additional cost to the UK economy as a whole at central energy prices and learning. With low energy prices and low learning this could rise to ~£105bn. Due to market failures, most of this is funded by consumers or, to a very small extent, taxpayers.

[9] Funding by UK consumers and taxpayers for RD&D and deployment costs, based on analysis for the Carbon Trust by LEK, prior to Budget '09.

[10] The point at which a LCT reaches large-scale supported deployment depends on the characteristic of the technology. For example, wave power is likely to increase in scale of deployment gradually, from current installed scale (~1MW) to 2-5MW to 15-25MW, to 50MW and onwards toward commercial sized farms. LHF ethanol, on the other hand is likely to jump directly from initial demonstration plant to full scale plant.

Chart 6 sets out our estimated support costs of the six LCTs which we examined and highlights this increase in support costs required in the large-scale deployment phase.

A prioritisation framework is needed

In order to make smart investment choices, the UK needs a framework to prioritise its support for LCT innovation. We have developed and tested a possible framework based on contribution to UK climate change related targets and net economic benefit (see *Chart 7*). The two elements of this framework are whether a LCT is needed to meet UK climate change related targets and is unlikely to be available in time without UK support; and whether the LCT will or is likely to generate net economic benefit for the UK.

The framework also distinguishes between earlier stage development/demonstration technologies where the aim is to generate technology options and later stage technologies where the aim is to focus on cost effective supported deployment. This distinction is made by plotting technologies at these different development stages on separate prioritisation matrices.

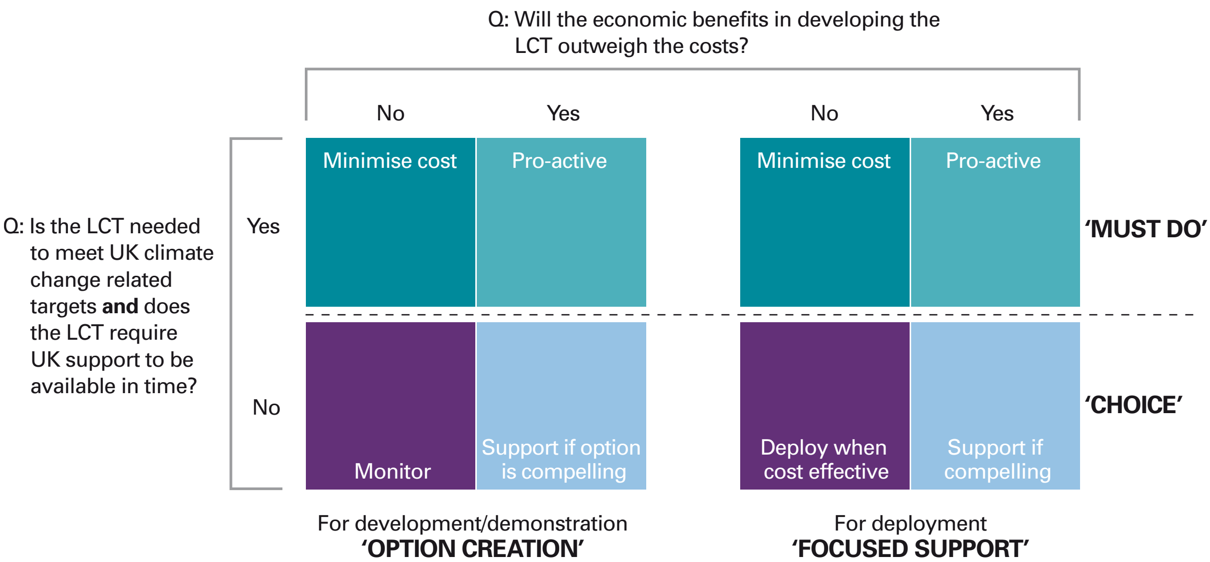
Chart 6 *UK RD&D and deployment support costs to 2050 – central scenario and range*

Technology	**UK RD&D costs to 2050*** (2008, present value, £bn)	**UK deployment support costs to 2050*** (2008, present value, £bn)
SSL**	0.1	0.1
Offshore wind	0.8	64
FCmCHP	0.06	0.1
Flow cells***	0.4	0.02
LHF ethanol	0.2	10
Wave	0.6	10
Total (Range)	**~2 (1 to 3)**	**~85 (3 to 175)**

*Figures in table represent central scenarios, ranges given for total including learning, deployment and fossil fuel price scenarios. The total central estimate of £87bn (present value) is equivalent to annual costs of c.£4bn/year to 2050.
**SSL is close to commercialisation so the remaining deployment costs are small.
***Main challenge is in RD&D – high potential learning rate means low deployment cost once large-scale deployment begins.

Source: Technical consultants, Carbon Trust analysis.

Chart 7 *Prioritisation framework*



Source: LEK, Carbon Trust

Framework is based on climate change related targets and economic benefit

The position of a LCT in the framework helps to set the general stance of the Government towards the LCT. The colouring in the chart defines three categories of response across both early stage development technologies and later stage deployment.

'Must do' – pro-active/minimise cost (Green)

If the LCT is needed to meet climate change related targets and is unlikely to be available in time from overseas, then UK action is required (top row of matrices). If net economic benefit is likely to be generated (the top right quadrant) then a more pro-active stance is appropriate – economic benefit may be achieved, in part, by facilitating the establishment of local industrial activity and by investing now in order to capture export markets. If net economic benefit is unlikely to be generated then a policy aimed at effectively minimising the costs of the LCT is most appropriate (top left quadrant).

'Choice'– support if compelling (Blue)

If a LCT is either not needed to meet climate change related targets or likely to be available from overseas, then UK public sector support is only justified if a strong case can be made that net economic benefit is generated and it represents better value for money than alternatives (bottom right quadrant).

'Choice'– monitor/deploy when cost effective (Purple)

The stance for technologies in the bottom left quadrant, (i.e. those which are either not needed to meet UK climate change related targets or likely to be available in time from overseas and which are unlikely to generate net economic benefit) depends on the stage of development. For those at the large-scale deployment stage, the stance is to deploy when the technology has been proven cost effective elsewhere. For those at the development stage a monitoring stance is appropriate. These are relatively early stage technologies so circumstances may well change leading to a re-appraisal of the right stance.

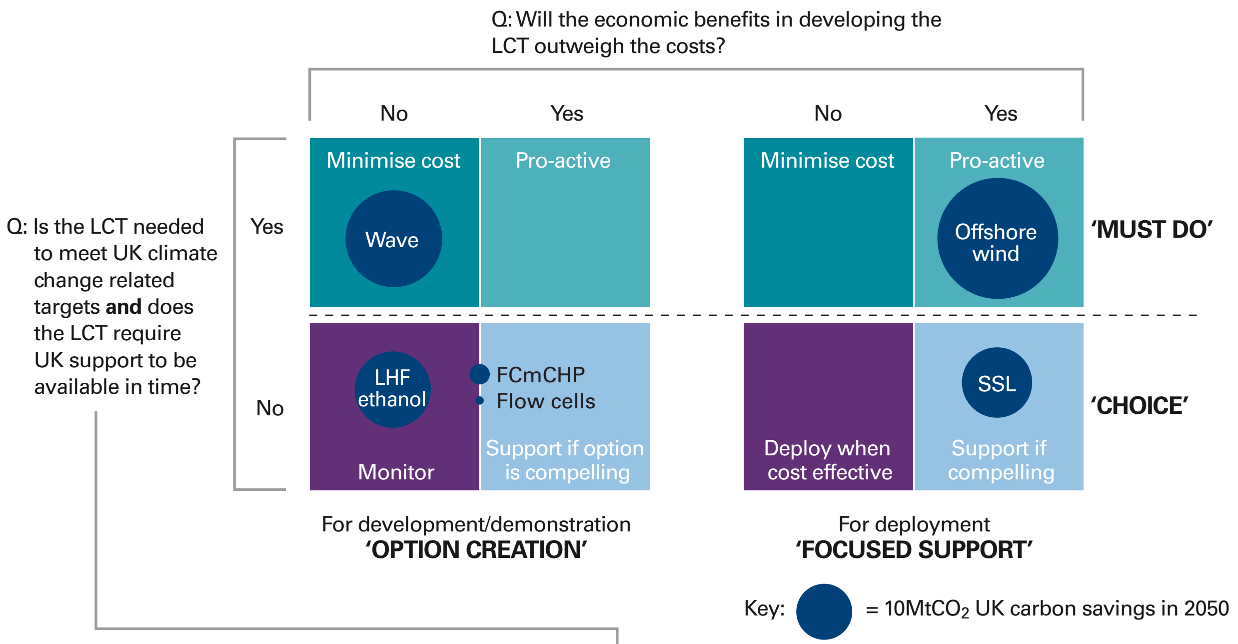
We have tested the framework on our sample of technologies

Chart 8 shows our sample of six technologies plotted on the prioritisation framework. The technologies span all three categories of response.

'Must do' – pro-active/minimise cost (Green)

- Offshore wind power is needed to achieve the UK's 2020 renewable and carbon targets and is unlikely to be ready in time without UK support as the UK is one of two leading markets. Despite potentially large deployment support costs, the UK may well generate net economic benefit by exploiting a large export market, attracting inward investment by turbine manufacturers to complement existing offshore and services skills and leveraging the potential to develop a strong position along the value chain. The UK's approach should be to actively innovate/deploy and seek to exploit economic benefit by encouraging investment and service activity.
- Wave power is likely to play an important part in the radical decarbonisation of UK electricity by 2050. The UK has a significant amount of the total global resource, and is home for many of the leading developers. Therefore it is unlikely to be available without UK support in development, demonstration and deployment. The economic case, based on export of engineering and design skills and manufacture of high value added components, is not as strong as offshore wind, but may improve significantly if the worldwide size of the market is larger than expected or an earlier/major technology breakthrough is achieved. The UK's approach should be to pursue this technology option focusing on further early demonstration and improving the cost effectiveness of the technology.

Chart 8 *Prioritisation of the six technologies covered in this study**



Technology	Is the LCT needed to meet UK climate change related targets?	Does the LCT require UK support to be available in time?	Notes
Offshore wind power	✦✦✦	✦✦✦	• **Must do**
Wave power	✦✦✦	✦✦✦	
SSL	✦✦✦	✦	• **Choice**
LHF ethanol	✦✦	✦	
FCmCHP	✦	✦	
Flow cells	✦	✦	

Key:
✦✦✦Strong likelihood
✦✦Potentially
✦Low likelihood

*Estimates of carbon abatement and economic benefit are based upon each LCT passing proofs of principle, concept, viability, scalability and durability.

Source: Technical consultants; LEK, Carbon Trust analysis.

'Choice' – support if compelling (Blue)

- SSL is likely to commercialise rapidly irrespective of UK support, as the market is global and development is driven by multinational companies with a global perspective. As deployment support costs are now likely to be quite small, the UK could generate net economic benefit in niche markets and parts of the supply chain (e.g. specialist luminaire design and manufacture). However, even in the best case this is unlikely to be substantial. Deployment of SSL represents a material and cost effective carbon opportunity in the near-to-medium term. The UK's approach should be, at minimum, to deploy at scale when the technology is proven and cost effective and in preparation remove all relevant barriers at minimum cost.
- Neither FCmCHP nor flow cells will need UK support to commercialise in a timely fashion. Markets outside the UK are attractive, some major developers are based abroad and other countries have substantial support programmes in place. Both carbon savings and potential economic benefits are relatively modest in the context of the other technologies studied. The UK's approach should be to assess these technologies against other alternatives and provide support if they prove to be a compelling option.

'Choice' – monitor /deploy when cost effective (Purple)

- LHF ethanol has a significant carbon prize, but the economic case is marginal and international activity is very substantial (the US, Germany, etc.) so the UK is unlikely to have significant impact on the development of the technology. The UK's approach should be to monitor developments – note the UK may well be better placed in other advanced biofuels.

Definitive prioritisation and resulting actions however can only be fully established when all likely LCTs have been assessed against this framework. Furthermore, prioritisation needs to take into account technology breakthroughs generating greater than expected cost reductions, larger markets for current applications and additional revenue from 'spin off' applications.

Initial steps being taken

Government has already started to move in this direction, for example the recently announced competition for CCS. However, with around 50 technology families, all at different levels of maturity, there is a need for a more thorough and transparent prioritisation process which analyses all relevant LCTs consistently.

Framework helps with 'what' not 'how'

Establishing clear priorities will ensure resources are targeted at areas where the UK has an opportunity to lead and will help attract private sector investment. The precise allocation of resources among prioritised LCTs needs to be informed by the requirements of individual technologies themselves. This is because they will each be at different points in their development cycle and many needs are technology specific.

The need for technology specific solutions

Very few general solutions

By examining in detail the six LCTs in our sample, it has become clear that each has its own innovation challenges which need addressing and that there are very few general solutions.

All technologies need at least one specific action

We have developed potential solutions to the key innovation challenges faced by each of the sample of six LCTs which are summarised in *Chart 9* (see next page).

Our analysis indicates that all of these technologies need at least one significant action or solution that is specific to the technology itself to move it towards commercialisation. For example, both solid state lighting and flow cells require standards to compare performance. However, the standards themselves are technology specific and targeted at a different audience (business/consumers vs. industrial developers).

Similarly LHF ethanol, offshore wind power and wave power all require robust market pull mechanisms. However our analysis and recent experience has shown that all three will need tailored instruments offering different levels and types of support.

Generic solutions are not enough

There are some solutions which are more generic – removing planning barriers for major LCT electricity generation is the clearest example. However, generic solutions alone are not enough to address the innovation challenges faced by any of the six LCTs we have looked at.

The diversity of solutions has led many to try to simplify the situation and group solutions into broad categories. This can be useful (e.g. for high level communications) but the tendency to group solutions, may lead to mis-targeted efforts and wasted resources.

Chart 9 *Policy solutions required for commercialisation by technology*

Technologies	Technology specific policy solutions	Generic policy solutions
Solid state lighting	• Influence EU regulatory lighting actions under the Energy using Products (EuP) Directive	• Stimulate easier uptake (e.g. public procurement to demonstrate business case, etc.)
	• Introduce industry standard that allows easy product comparison	• Improve education/awareness of energy efficiency
	• Enforce appropriate point of sale labelling portraying lifetime savings	
Fuel cell micro CHP	• Develop field testing demonstration programme of FCmCHP	• Implement Government intention to address microgeneration challenges (metering, export pricing, etc.)
	• Review Building Regulations procedures to reflect the benefits of FCmCHP	
Flow cells	• Introduce deployment mechanism (almost certainly specific to storage)	
	• Develop specific electricity storage demonstration projects	
	• Change regulatory framework (e.g. the Balancing and Settlement Code) to allow aggregation of potential value to be captured by storage participants	
	• Establish industry performance standards	
LHF ethanol	• Vigorous and rapid implementation of a robust policy relating to biofuels support and the socio-environmental framework	
	• Develop an RD&D strategy for biofuels addressing focus, longevity and coordination of R&D funding and concentration of activity (size of centres and strength of networks)	
Offshore wind power	• Invest additional public RD&D of £100m-600m to 2020	• Extend duration of the incentive mechanism (proposals in Renewable Energy Strategy)
	• Integrate 1-3 demonstration sites with development of R&D/manufacturing cluster(s)	• Robustly implement plans to simplify process for grid connection and planning process (reviews in progress)
	• Make the most economic wind farm sites available without negatively impacting economic and environmental concerns	
	• Set the scale of the incentive mechanism to motivate developers. Track costs and adjust for electricity price changes to maximise efficiency (proposals in Renewable Energy Strategy and Budget '09)	
Wave power	• Address funding gaps, with greater coordination and a focus on innovations leading to step change cost reduction	• Depending on the detailed nature of the offshore wind solutions above, these may deal with some of the grid, planning process and incentive mechanism issues
	• UK-wide Strategic Environmental Assessment allowing future planning around potential sites (building upon work in Scotland)	

Customise support

To be effective technology support needs to be customised. This means putting in place all the solutions needed to move the technology to commercialisation. A real risk is that only some of the solutions are addressed, severely reducing the effectiveness of technology support. For example, commercialising FCmCHP requires three key solutions: UK field trials, changes to Building Regulations procedures, and removal of generic microgeneration challenges (metering, export pricing, etc.). If only two of these are successfully addressed, say field trial and generic microgeneration challenges, then FCmCHP will still continue to struggle to commercialise as Building Regulations will hinder its adoption.

For prioritised technologies, the solutions required for successful commercialisation go beyond the traditional 'technology push' activities (e.g. grant funding of demonstration projects). *Chart 10* clearly shows that all of our technologies require solutions which can be classified as 'barrier removal' (e.g. amending regulations such as product standards) or 'market pull' (e.g. deployment mechanisms such as the Renewables Obligation). However, for technologies where the stance is to deploy when cost effective, barrier removal should be the focus of the UK's commercialisation activities, particularly if they are critical to meeting UK targets.

Initial steps being taken

Government has already started to move in this direction with, for example, the proposed banding of the Renewables Obligation, offering differentiated support to stimulate the deployment of specific technologies. However, this change is occurring on a case-by-case basis.

Needs joined up Government

The design and delivery of customised technology support will go beyond what is traditionally considered as innovation and will cut across a number of departments and other organisations. For example, for FCmCHP, a field trial would come under the auspices of DECC or the Environmental Transformation Fund and the regulatory changes under DCLG. Creating and implementing joined-up support programmes is always a challenge for Government. However it is now more feasible to embark on this course because:

- Technology prioritisation will reduce the size of the task, increasing focus and reducing the number of measures to be put in place.
- The recent formation of DECC has eliminated one of the main areas of co-ordination and created the potential for a more powerful voice across Government.

Chart 10 *Classification of policy solutions required to stimulate innovation by technology*

Technology	Push	Barrier removal	Pull
Solid state lighting		✓	✓
Fuel cell micro CHP	✓	✓	✓
Flow cells	✓	✓	✓
LHF ethanol	✓		✓
Offshore wind power	✓	✓	✓
Wave power	✓	✓	✓

Note: A tick indicates the presence of one or more solutions in a category, based on Chart 9.

Source: Technical consultants, LEK, Carbon Trust analysis.

Technology focused approach

A technology focused approach brings together technology prioritisation and customisation to meet climate change related targets through more cost effective, targeted support of LCTs. It is fully compatible with current market mechanisms, like carbon pricing, and should lead to more effective use of public money rather than necessarily just more expenditure.

New approach is evolutionary

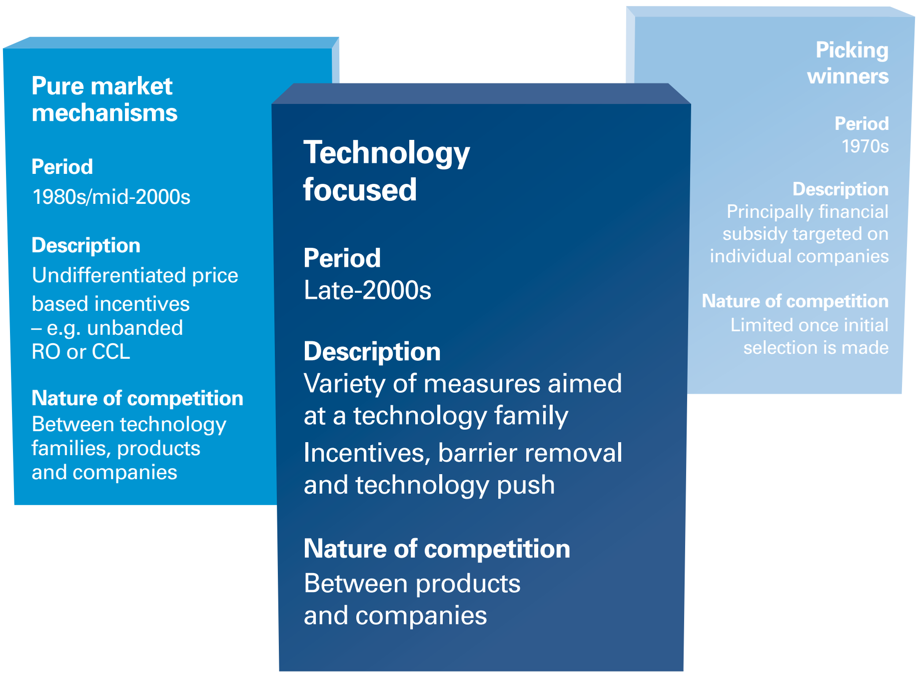
A technology focused approach is best understood in the context of the evolution of Government policy for industry in general and in this area in particular[11] (see *Chart 11*).

1960/70s – national champions and propping up ailing firms

In the 1960s and 1970s there was a strong Government view, supported by many stakeholders, that Britain needed to hold on to its manufacturing base, which was still largely UK-owned. When UK industries were less internationally competitive, the instinct was to rescue them with direct financial assistance. But the industries the Government supported were in sectors where we were losing our long-term competitive advantage. The efforts were expensive in the short term and doomed in the medium term.

As well as seeking to shore up an ailing industrial base, the UK also tried to promote specific 'national champions'. Government believed that there were several high-tech areas where Britain could lead the world. So, significant public money went into the R&D on Concorde and the AGR design of nuclear reactors, both of which proved to be 'white elephants'.

Chart 11 *Evolution of Government policy to stimulate next generation LCTs*



[11] Scrase I. and MacKerron G., 'Lock-in', 2009. In Scrase I. and MacKerron G. (eds), 'Energy for the Future. A New Agenda', Palgrave Macmillan, pp. 89-100.

1980s/90s – free markets are king

Partly as a reaction, Government policy swung to the other extreme in the 1980s and 1990s. Free markets became king and the focus was on macro-economic policy. For LCT this meant explicit technology neutrality and establishing generic market mechanisms like the unbanded Renewables Obligation. Undoubtedly a success in the wider economy, this approach alone did not bring forward emerging LCTs – or indeed sustainable energy in general – as quickly as expected or now required.

Key feature of the technology focused approach

A technology focused approach strikes a balance between these extremes and has the following key features:

- Identifying priority LCTs through systematic and transparent assessment.
- Recognising the differences between earlier and later lifecycle stages.
- Designing customised support for each of the prioritised technology families.
- Strong competition for support between companies active within a technology family.
- Careful monitoring against milestones to keep waste to a minimum.

Generating UK benefit

The technology focused approach should extend beyond technology development and deployment and integrate with manufacturing and regional activities to maximise economic benefit for the UK.

At present innovation activities in the UK are largely unconnected with economic development activity either at the national or local level. The new Low Carbon Industrial Strategy potentially provides an excellent vehicle for bringing these together.

At the heart of these efforts are likely to be the creation of integrated innovation and manufacturing clusters of activity.

Sunrise not sunset industries

A technology focused approach builds on the lessons of the 1960s and 1970s in at least two ways. Firstly, it is not seeking to shore up ailing industries where UK-owned businesses have been overtaken by foreign competitors. It seeks to grow UK activity in a sector which, for the public good, must grow in the long term. It is agnostic about the ownership of businesses and seeks to make the UK a good place in which to conduct LCT innovation and develop LCT based businesses.

Encourages competition

Secondly, it does not make specific choices about companies or 'hardware' as was done in the 1970s. On the contrary, it encourages a high level of competition between different types of 'hardware' within a technology family and between different developers.

In line with Stern

This is very much in line with the broad framework articulated in the Stern Review. The Stern Review set out three routes to drive mitigation of climate change: carbon pricing, innovation/technology policy, and regulations/overcoming inertia. The technology focused approach is an effective method of delivering the innovation/technology policy route, supplementing the impact of general carbon pricing mechanisms and helping to coordinate regulatory action for emerging LCTs. Because it is targeted on the specific requirements of a LCT, a technology focused approach should result in more cost effective policies and programmes. It is highly scalable being just as effective for one or many LCTs.

Key recommendations

Our main recommendation is that Government needs to accelerate the move away from a policy focus on technology neutrality and generic mechanisms to a policy focus on technology priorities and customising support. This will involve:

- Adopting and implementing a framework for prioritising LCTs from a national perspective. The framework developed during the course of this study could be a starting point.
- Designing customised technology support (both policies and programmes) and coordinating the key LCT innovation activities (i.e. market 'pull', technology 'push' and barrier removal), so that comprehensive, joined-up support is provided to priority LCTs.
- Integrating innovation and business support strategies and activities to ensure the economic development potential of LCT innovation is realised.

As a minimum, adopting this approach increases the chances that public money is well spent, focusing it on key technologies for the UK and on the individual requirement of the technology. As a result, a technology focused approach will increase the likelihood of the UK capturing value and jobs from the transition to a low carbon economy as well as ensuring the delivery of UK climate change related targets.

Failing to adopt this approach will mean the UK will not have the right strategic focus for its LCT innovation, limiting economic gains, wasting technology support funding and jeopardising the achievement of climate change related targets.

Part A
Introduction, methodology and technology analysis

Why and how we did this study and the main conclusions from our detailed technology assessments

1. Introduction and context

With tougher targets now in place to combat climate change, we examine whether new LCTs are needed to meet those targets and, if so, how best to commercialise them.

The climate change challenge

The global challenge of emissions reduction

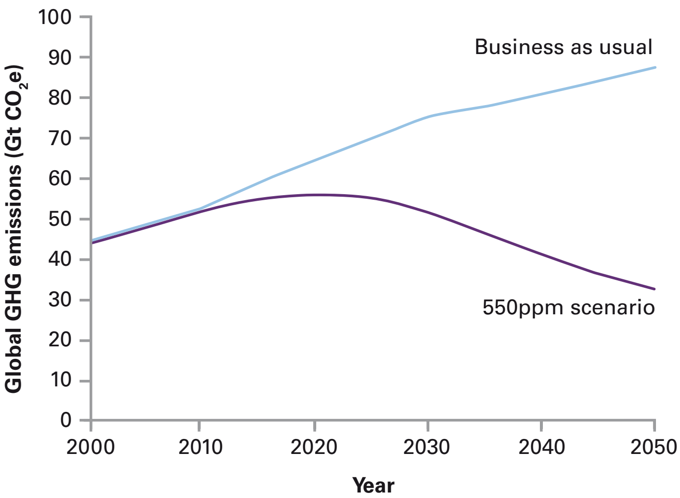
Emissions reduction is a huge global challenge. In a recent study[1] we projected a 'business as usual' scenario of global annual greenhouse gas emissions doubling between 2000 and 2050 as a result of continuing population and economic growth (see *Chart 1a*).

If this 'business as usual' scenario were to become reality, there could be an increase in atmospheric greenhouse gas concentration from 433 parts per million carbon dioxide equivalents (ppm CO_2e) in 2006 to around 1,000ppm CO_2e or more by 2100, threatening catastrophic increases in temperature of over 5°C[2].

Avoiding the worst effects of climate change (by limiting long-term temperature rises to 2°C) requires greenhouse gas concentrations to stabilise below 550ppm CO_2e and possibly below 450ppm CO_2e.

To remain below 550ppm CO_2e requires annual global emissions to peak by 2020 at the latest, followed by deep cuts in emissions so that carbon dioxide emissions are around 33Gt CO_2e in 2050, nearly 25% lower than in 2000 and over 60% below the 'business as usual' scenario (see *Chart 1a*). Stabilising at 450ppm CO_2e is even more daunting, requiring global emissions to fall to 12Gt CO_2e by 2050, 70% lower than in 2000. This presents a major challenge for the global economy.

Chart 1a *Projected global greenhouse gas emissions (2000-50)*



Source: Oxera, Carbon Trust analysis.

[1] Carbon Trust 'Climate change – a business revolution', 2008.
[2] Source: European Environment Agency, 'Atmospheric greenhouse gas concentrations (CSI 013) assessment', 2008.

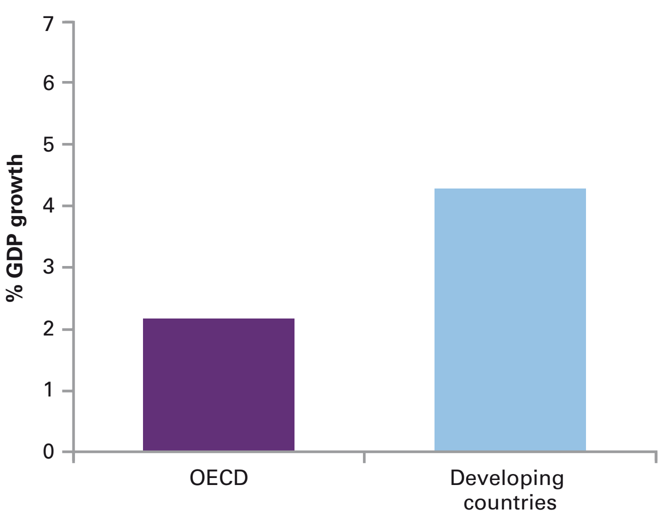
OECD[3] countries must achieve dramatic reductions in emissions levels to achieve stabilisation at a global level

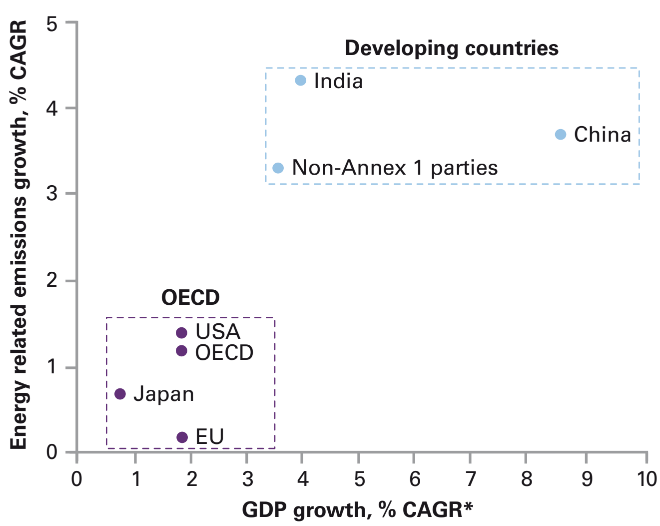
Higher economic growth rates are predicted for developing economies compared to industrialised nations and the strong historical link between GDP growth and carbon emissions growth is expected to continue (see *Chart 1b*). As a result, carbon emissions growth will be much higher in the developing world than the developed world.

It is well accepted, however, that the developing world should not be denied the development and welfare opportunities enjoyed in the developed world for so long. The link between energy usage and economic and social wellbeing was noted in the Stern Review:

'Energy helps promote access to better education, better health, enhanced competitiveness and improved economic growth'.[4]

Chart 1b *Economic growth forecasts and the correlation between economic growth and the growth in carbon emissions*





Source: IEA; WRI; Stern Review, 2006; LEK analysis.

*CAGR is Compound Annual Growth Rate.

[3] Organisation for Economic Co-operation and Development.
[4] Source: Stern Review: The Economics of Climate Change, 2006.

The combination of these factors places increased responsibility for carbon reduction on countries in the developed world. This principle was articulated in the work of the Princeton Carbon Mitigation Initiative which illustrated that, to achieve stabilisation of emissions levels worldwide, emissions in OECD countries must reduce dramatically in absolute terms from today's levels to accommodate an increase in emissions in developing countries (see *Chart 1c*).

New tougher UK targets

Like other OECD countries the UK faces a huge challenge to achieve emission reductions. The UK is taking a lead in committing itself to challenging targets. The Climate Change Act 2008 has put into statute the UK's targets to reduce greenhouse gas emissions through domestic and international action by at least 80% by 2050 and at least 34% by 2018-22 (against a 1990 baseline)[5], the first legally-binding commitment in the world.

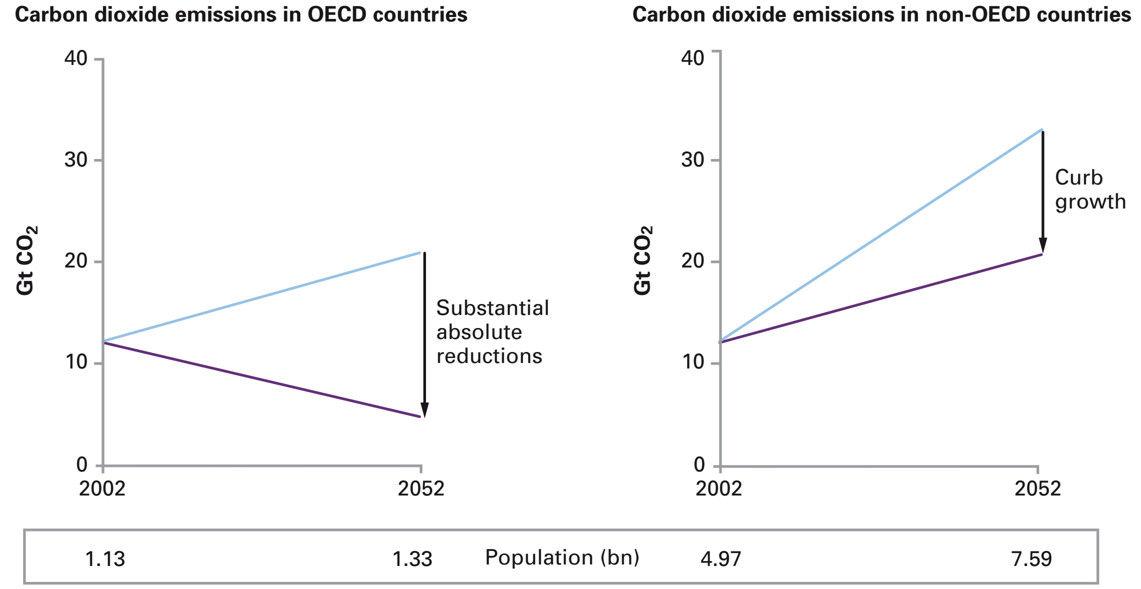
This is reinforced by a firm trajectory based on ongoing five-year carbon budgets with the first ones now set for 2008-12, 2013-17 and 2018-22.

This is a substantial tightening of the UK's previous aspiration to cut carbon emissions by 60% by 2050.

The EU has also launched an initiative that set climate change related targets. The EU Renewables Directive sets a target of 20% of EU final energy consumption to come from renewable sources by 2020, which includes a UK share of 15% of energy from renewables by 2020.

Although the UK can point to a good track record of carbon reduction in recent years driven by fuel mix changes arising from the 'dash for gas', greater use of renewables and increased levels of energy efficiency, meeting these new targets still represents a major challenge which will require significant action on many levels.

Chart 1c *Princeton Carbon Mitigation Initiative – OECD vs. non-OECD carbon dioxide emission reductions for stabilisation**



*Not consistent with Chart 1a owing to differing data sources, years and scope.
Source: Scientific American; Princeton Carbon Mitigation Initiative (Socolow & Pacala); OECD; UN; US census, LEK analysis.

[5] Source: Department for Energy and Climate Change.

The global need for low carbon technology innovation

It is becoming widely accepted that technology innovation has a key role to play in addressing climate change. For example, the Stern Review highlighted innovation support as one of the three routes to stimulate mitigation of carbon emissions, along with carbon pricing and regulation/information.

LCT innovation has two impacts: it reduces the costs of LCTs which are already partially deployed; and it creates new LCTs. The world will need both impacts in order to achieve the required reductions in carbon emissions. The recently published Global Abatement Cost Curves[6] illustrate this point. These show that in total all LCTs with estimated costs of less than €60/t CO_2e have the maximum potential, if aggressively pursued, to save a total of 38Gt CO_2e by 2030 which would be sufficient to be on track to stabilise atmospheric greenhouse gas concentration at 480ppm. This shows a clear need for innovation as:

- Many of the technologies are not yet ready to be deployed at large scale and are high cost (e.g. carbon capture and storage, solar technologies, etc.). Cost reduction between 2010 and 2030 could result in savings of c.€1,000bn/year globally.
- New technologies will be needed after 2030 as the carbon reduction potential of those currently being developed will be largely exhausted.
- In reality some LCTs will not live up to their full potential as there is considerable uncertainty around the innovation of any technology, including technical, economic and market risks. Therefore, globally there need to be LCT options available whose total potential carbon savings are greater than those required to meet carbon reduction targets.

Although this makes a strong case for LCT innovation to take place, it does not state why the UK, rather than other countries, should bear the burden and reap the benefits of innovation in LCTs.

[6] Source: McKinsey.

Major recent changes to the UK innovation system

As part of its overall response to climate change, the UK has placed an increased emphasis on LCT innovation. As a result, the UK's LCT innovation system has evolved rapidly: spending has increased sharply, new policies have been put in place and new innovation bodies created.

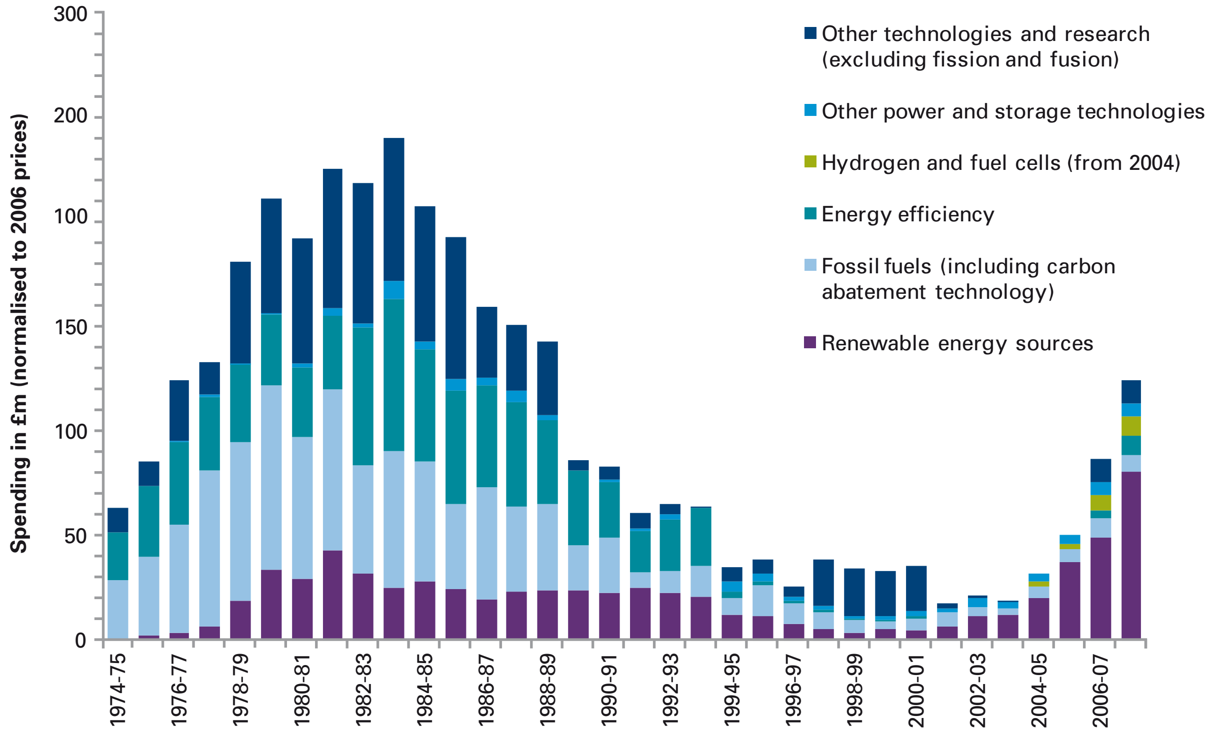
Government spending on LCT RD&D has increased ten-fold from its low point in 2001, although it is still somewhat below the peak in spending following the oil price shocks of the 1970s (see *Chart 1d*).

There has also been an increase in both policy activity and the creation of new institutional structures. Some of the key developments in the UK LCT innovation framework can be seen in *Chart 1e*, which are paralleled by development in the regions and the devolved administrations, notably the creation of ITI Scotland in 2003.

The UK LCT innovation system, therefore, has recently evolved substantially and some parts of the system are relatively new (e.g. the Energy Technologies Institute and the Technology Strategy Board). Indeed, it seems likely that the pace of change will continue to be rapid.

Despite this, questions still remain about the adequacy of the UK innovation system in supporting the commercialisation of LCTs, including the comprehensiveness of the system, the degree and level of funding, the UK's ability to support development of multiple LCTs and the role of UK economic benefit as a goal of innovation policy.

Chart 1d *UK Energy RD&D spending by IEA category (excluding nuclear)*



Note: Consistency of the available data and the match between UK and IEA definitions has varied over the years, meaning that direct year-to-year comparison can be misleading. Hydrogen and fuel cells were only recently added to the dataset as a separate category, and would previously be covered under 'other technologies and research'. It should be noted that these figures cover only RD&D funded directly by the UK national Government (e.g. the research councils and the Technology Strategy Board), and do not include support from an increasingly wide range of RD&D players in the devolved administrations (Scotland, Wales and Northern Ireland) and the English regions. The 'fossil fuels' category has evolved over the years, and currently consists of spending on cleaner fossil fuels and carbon abatement technology.

Source: IEA (based on UK submissions since 1974); notes from Environmental Transformation Fund Strategy.

Introduction to this study

With tough new climate change related targets and a renewed focus on LCT innovation, it seems timely to stand back and examine the system as a whole and identify the direction for the future.

This study therefore examines the key questions facing the UK's innovation system:

- Why the UK should choose to innovate low carbon technologies.
- How the innovation system needs to adapt in order to meet the new challenges.

The remainder of Part A of this report sets out the approach and methodology which we used to analyse these questions and summarises the detailed analysis of each representative technology. The key findings of the study are in Part B and the implications for policy are discussed in Part C.

Chart 1e *Timeline of key developments in UK LCT innovation framework*

Year	Key policy and strategy review and publications	Creation of key energy innovation institutions
2001		• Carbon Trust
2002	• Performance and Innovation Unit Energy Review	• DTI New and Renewable Energy Programme
2003	• Renewables Innovation Review • Energy White Paper 2003	
2004	• Science and Innovation Investment Framework 2004-2014	• DTI Sustainable Energy Capital Grants programme • DTI Technology Programme • Research Councils Energy Programme, UK Energy Research Centre
2005	• Stern Review: The Economics of Climate Change	
2006	• Climate Change Programme Review	• Energy Research Partnership
2007	• Energy White Paper 2007 • Sainsbury Review of Science and Innovation	• Technology Strategy Board becomes an NDPB* (formerly Technology Programme) • Energy Technologies Institute
2008	• Environmental Transformation Fund Strategy • Innovation Nation White Paper	• Environmental Transformation Fund
2009	• Renewable Energy Strategy	

*Non-departmental Public Body.
Source: Environmental Transformation Fund, Carbon Trust.

2. Approach and methodology

To inform this study we undertook detailed assessments of six illustrative LCTs. This section sets out the scenario-based methodology we used to choose and assess the technologies.

Introduction to our approach

Our approach to answering the key questions of the study, as outlined in Chapter 1, is intentionally analytical and quantitative rather than theoretical and qualitative. We have therefore developed a scenario-based approach which creates a unique evidence base of information on actual low carbon technologies which is, wherever possible, grounded in engineering, financial and commercial reality.

The study is largely informed by detailed assessments of an illustrative sample of six LCTs: offshore wind power; wave power; flow cell electricity storage; ligno-cellulosic ethanol based on hydrolysis and fermentation ('LHF ethanol', one of a number of advanced biofuels); fuel cell micro combined heat and power ('FCmCHP'); and solid state lighting ('SSL'). The main conclusions of each assessment are provided in Chapter 3; the text boxes in this section describe the key characteristics of each technology.

Each technology assessment was carried out by an engineering consultancy with in-depth specialist understanding of the LCT and, where necessary, they were supplemented by a business-oriented consultancy to provide support on commercial and financial issues.

These detailed engineering and commercial assessments provide a strong evidence base detailing the challenges facing commercialisation of LCTs, allowing implications to be drawn for the UK LCT innovation system as a whole.

In addition, a number of complementary but more wide-ranging analyses were also completed:

- An analysis of current UK LCT innovation spend.
- An initial overview assessment of the requirement for earlier stage technologies in order for the UK to achieve its climate change and renewable energy targets for 2020 and 2050.
- A comparison of the attractiveness of UK innovation policy compared with other leading countries.
- A brief review of international industrial policy and the link to LCT innovation.

Wave power

Waves are caused by wind blowing over the sea. The longer the water distance (fetch) over which the wind blows, the greater the transfer of energy and the larger the waves. Waves are contained in the water nearest the surface; when they approach shore some energy is lost as the waves meet the seafloor. Wave energy generators convert wave energy into electricity. The deployment location is the primary defining characteristic of wave devices, which spans onshore (shoreline), nearshore or offshore locations. The deployment location gives an indication of how much energy there will be available to the device, with more energy available in offshore environments.

There are several basic different types of wave energy converters including: oscillating wave surge converters, attenuators, overtopping devices, oscillating water columns, point absorbers and submerged pressure differential devices[1]. Some devices combine several of these types into one.

[1] Source: EMEC.

Technology sample selection

We chose an illustrative sample of the LCTs that the UK is likely to need to meet carbon and renewable energy targets and that are representative of the range of challenges faced by emerging LCTs.

In selecting the technologies to be used in this study, a long list of technologies was prepared using the Carbon Trust's Low Carbon Technology Assessment framework of around 50 technology families as a starting point (see *Chart 2a*) and, where relevant, drilling down further into sub-categories.

Chart 2a *Technologies reviewed in the Carbon Trust 2007 Low Carbon Technology Assessment*

Category	Technology families
Buildings	Building control Building cooling Building heating Building materials Lighting
Industry	Industrial equipment (general) Industrial process/system (general) Industry-specific equipment Industry-specific processes
Transport	Biofuels Hydrogen for road transport Improved road vehicles
Enabling technologies	Alternative hydrocarbons Building design Electrical energy storage Electricity transmission and distribution Grid connection and balance of system Hydrogen production Hydrogen storage Information systems for energy users Thermal energy storage

Category	Technology families
Renewables	Advanced photovoltaics (PV) Biomass for heat Biomass for electricity Conventional PV Geothermal Large hydro Offshore wind Onshore wind Small-scale wind Small hydro Solar thermal electric Solar water heating Tidal: lagoons and barrages Tidal stream Wave: nearshore Wave: offshore Wave: shoreline
Fossil fuels and nuclear	Carbon capture and storage Cleaner coal Coal mine methane Fuel cells: large static Fuel cells: portable Fuel cells: small static High efficiency Combined Cycle Gas Turbine (CCGT) Large-scale Combined Heat and Power (CHP) Nuclear fission Nuclear fusion Small-scale CHP

These technology families were then screened for significant abatement potential, relevance to the UK and innovation requirement.

The technologies were then assessed on a number of secondary criteria and a group selected to ensure that together they were representative of the technologies that the UK is likely to deploy in order to meet its climate change and renewable energy targets, including:

- **Stage of development** – technologies still in the development and early demonstration stages as well as those which have reached deployment.
- **Sector** – technologies covered the electricity, transport, heat and energy efficiency sectors.
- **Delivery type** – decentralised technologies, those delivered centrally and enabling technologies.
- **Timescale** – technologies relevant to both near-term (~2020) as well as long-term (~2050) targets.
- **User** – technologies which are business to business, consumer products and relevant to the public sector.

A summary of the chosen technologies is set out in *Chart 2b*.

Technology assessment methodology

Introduction to our methodology

We examine two possible reasons for UK LCT innovation support: the technology is needed in order to meet carbon and renewable energy targets and the technology can generate net economic benefit for the UK.

Any methodology to address the need for a specific LCT and its economic impact must be able to deal with the uncertainties inherent in technology development and the nature of efforts to tackle climate change. For this reason, we have developed a largely scenario based methodology. This does not aim to develop a precise evaluation of economic impact, but rather give a quantitative indication of the range of economic impacts that could occur.

We also examine the ways in which the UK LCT innovation system can be improved by investigating the improvement opportunities apparent in our sample of LCTs.

Our four-step approach to identifying technology importance, impact and the nature of support

Our methodology has four steps, outlined in *Chart 2c*. We address each of these in turn in this section.

Chart 2b *Technology selection and representation criteria*

Technologies	Innovation stage		Sector				Type			Time		User		
	Development and demonstration	Deployment	Electricity	Transport	Heat	Efficiency	Centralised	De-centralised	Enabler	Near term	Long term	B2C	B2B	Public sector
Offshore wind power		✓	✓				✓			✓			✓	
Wave power	✓		✓				✓				✓		✓	
Flow cells (electricity storage)	✓		✓						✓	✓			✓	
LHF ethanol (an advanced biofuel)	✓			✓			✓				✓	✓		
Fuel cell micro CHP	✓				✓			✓			✓	✓		
Solid state lighting		✓				✓		✓		✓		✓	✓	✓

Source: LEK.

Ligno-cellulosic ethanol based on hydrolysis and fermentation (LHF ethanol)

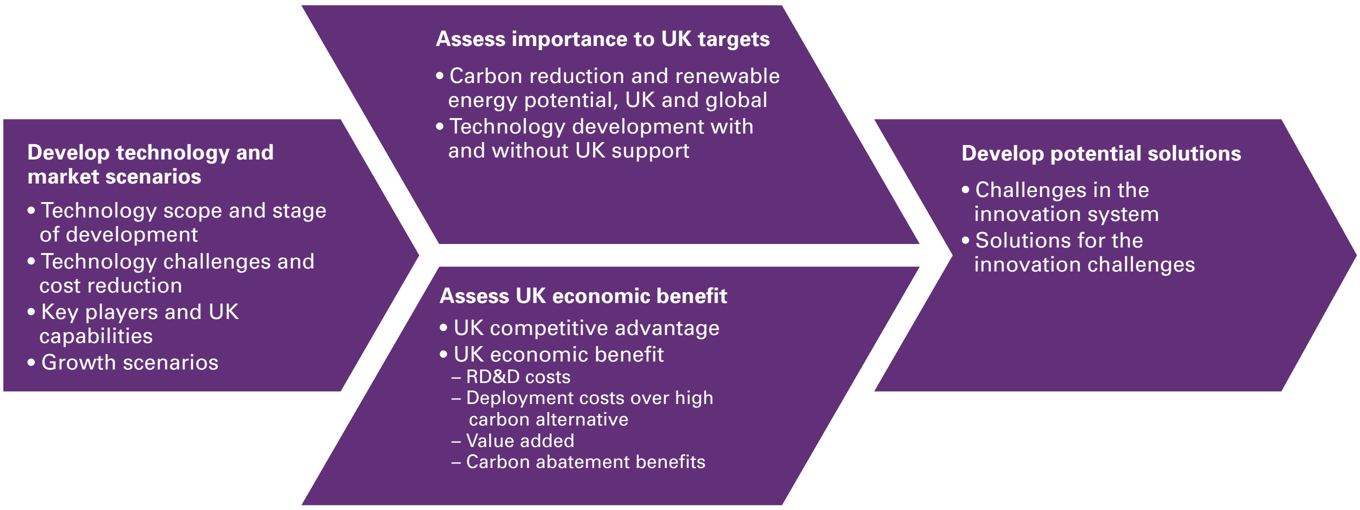
Ethanol is an alternative transport fuel to petrol (and, to a certain extent, diesel). However, there are concerns about some of the current sources of ethanol both because of their sustainability and because they may increase food prices through their use of food crops such as corn.

To avoid these problems, newer biofuel technologies use waste, such as corn stover or rice husks, or specially grown non-food crops which can be cultivated on marginal land. These feedstocks are often high in lignin (which confers the strength to wood) and cellulose (which is the structural component of plant cell walls), both of which are difficult to process. A number of ways are being developed to turn ligno-cellulosic feedstocks into biofuels.

In this study we have focused on one of the most advanced processes which breaks down the ligno-cellulosic feedstock into sugars (by hydrolysis) and converts the sugars to ethanol (by fermentation). To be economic, LHF ethanol must operate at the scale of a modern chemical plant.

There are many other advanced biofuel technologies, which use different feedstocks (including algae, etc.), processes (e.g. gasification and synthesis, pyrolysis, etc.) and products (butanol, different forms of diesel, etc.).

Chart 2c *A four-step approach to establish a justification for supporting LCTs in the UK and the potential nature of UK intervention*



Develop technology and market scenarios

To attempt any assessment of a technology, it is essential to have a good understanding of its characteristics, scope and status and the possible ways in which it could develop both technically and commercially.

Technology scope and stage of development

The starting point is to define the scope of the technology and identify its stage of development. We define technologies at the family level where the inputs, technical transformation and outputs are common, rather than at the level of an individual process or product.

We use five stages of development to indicate the progress of technology from initial idea to full commercialisation:

- During the first stage, the focus is on R&D, with the aim of developing a feasible technology concept.
- The technology then moves into development and demonstration once the various components of the technology are combined to form a recognisable technology. At this point, multiple variants within this technology are demonstrated and tested for proof of concept.
- Next the technology moves from demonstration to early deployment as it becomes marketable to a customer. A sign that the technology has moved to this is the emergence of a dominant design for a given application. An example is the coalescing of onshore wind turbine manufacturers around the horizontal turbine with a three-bladed rotor. The overall focus is on the learning curve as significant cost reduction is required to move towards commercialisation.
- As it nears commercialisation the technology enters the fourth stage. Several scale projects are operational. However, returns are not yet attractive at this stage without subsidy (over and above a carbon price). Further cost reduction is achieved through experience, rather than more active innovation.
- The final stage represents full commercialisation, as returns are attractive without specific subsidy.

Offshore wind power

Onshore wind power is one of the most established forms of renewable energy generation. However, there are only a limited number of places where it is socially acceptable to site wind turbines due to noise, a desire to preserve the appearance of the countryside and radar interference.

One solution is to site wind turbines offshore, far enough away from the shore so that the visual impact is limited. At present the costs of offshore wind power are greater than those of onshore wind power as the higher wind speeds and greater electricity production is currently outweighed by higher capital and operating costs.

Credit: Offshore Wind Power Marines Services

Offshore wind power is far less mature a technology than onshore wind power and has considerable scope for cost reduction. For example, global deployment of offshore wind power, c.1GW in 2007, is 100 times smaller than onshore wind.

We focus on technologies which are in the second, third and fourth stages (development and demonstration, and deployment) as these are sufficiently well defined to assess and require considerable resource to commercialise. These correspond, broadly, to Technology Readiness Levels[2] 3 to 9.

Technology challenges and cost reduction

Based on the characteristics and current performance of the technology, we identify the key technical challenges that the technology faces in reaching mass deployment and commercialisation, along with the key enabling technologies. We then estimate the range of resources and time required to meet those challenges, using previous experience and models of development (such as that proposed by Gibbins and Chalmers[3]). This allows us to estimate the costs needed to reach the point at which learning by doing predominates.

We then use learning curve analysis as the principal approach for forecasting cost reduction to 2050 due to technology developments and economies of scale. Learning rates – percentage cost reduction every time installed capacity doubles – are calculated and then used to make indicative forecasts. Different technologies demonstrate a wide range of learning rates, from 5% to 50%[4]. Learning rates for each key component of a technology are estimated based either on actual data or on those achieved in analogous industries. Given the uncertainty in forecasting future costs, we develop a range of scenarios.

Fuel cell micro combined heat and power (FCmCHP)

Producing electricity from fossil fuels results in waste heat exemplified by the need for cooling towers around conventional power stations. Combined heat and power (CHP) harnesses this waste heat and so reduces carbon emissions.

When CHP is deployed on a small scale, such as in individual houses, small blocks of flats or small office premises, it is described as micro CHP. A micro CHP system can be driven by internal combustion engines or other technologies, such as Stirling engines or fuel cells.

We have focused on fuel cell micro CHP systems which draw in natural gas and reform it to produce hydrogen which is then fed into a fuel cell which electrochemically produces both heat and electricity.

The heat is used for hot water and heating and the electricity is either used locally or exported to the grid. Because of the spikiness of demand for heat, a FCmCHP system usually includes a boost burner (to produce extra heat on demand) and a heat store (e.g. a hot water tank).

[2] As developed and used by NASA.

[3] Source: Gibbins, J. and Chalmers, H. 'Preparing for global rollout: A 'developed country first' demonstration programme for rapid CCS deployment' Energy Policy, 36(2), 501-507, 2008.

[4] Source: BCG.

To generate the learning curve we draw on a variety of sources and the knowledge of our technical consultants to estimate capital and operating costs either currently (if the technology is in deployment) or at the start point of the learning curve (i.e. after demonstration) if the technology is at an earlier stage. UK deployment is based on our consultants' estimates of what would happen if the UK actively supported the technology. The capital costs are annualised and include our consultants' estimate of the required private sector return when the technology is in deployment.

Key players and UK capabilities

We assess the strengths the UK brings to bear to the innovation of a technology. In particular we examine:

- UK academic and R&D capabilities.
- UK industrial strengths throughout the value chain including engineering and design, manufacturing and fabrication, installation, and operation and maintenance.
- The UK's natural resource and infrastructure.

We compared UK capabilities to those of other key countries who are seeking or may seek to develop the technology.

Growth scenarios

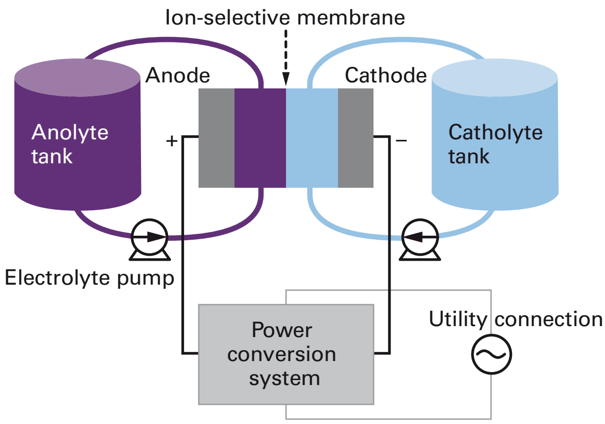
Building on a good understanding of the technical aspects of the technology, we examine its potential to replace other technologies and formulate deployment scenarios. This involves:

- Identifying market segments which are suitable for the technology. Defining the market potential both in the UK and the rest of the world.
- Assessing the potential for market penetration based on technology cost and performance and other relevant factors.
- Identifying the key uncertainties and formulating scenarios for the growth of the market in volume terms in the UK and the rest of the world.

Flow cells

Electrochemical flow cell systems are a type of battery. Uniquely, the energy is stored in two liquid electrolyte solutions. This has the advantage over other batteries in that the power and the storage capacity are independent: the storage capacity is determined by the quantity of the electrolyte used and the power rating is determined by the active area of the cell stack used to react the electrolytes.

Schematic diagram of a flow cell



Flow cells are an enabling technology for storing intermittent renewable power (e.g. wind power), to match supply and demand. Other uses include remote power and uninterruptible power supply applications.

Assess importance to UK targets

Our next step is to assess the importance of the LCT to the UK. This means examining whether the technology is needed to meet carbon and renewable energy targets and whether it requires UK innovation support to be available in time.

Carbon reduction and renewable energy potential

Based on our deployment scenarios, we assess the potential for low carbon energy generation and reduced energy consumption. Using relevant emissions factors, we assess the carbon saving potential both for the UK and globally (see 'Our key assumptions' box at the end of this chapter). We then put these into the context of UK carbon reduction and renewable energy targets using both Carbon Trust and other scenarios focusing on 2020 and 2050. For 2020, the UK's carbon reduction and renewable energy targets mean quite specific analysis is possible to assess whether a technology is necessary to meet those targets. For 2050, the degree of uncertainty is much greater. We therefore examine a range of scenarios under which the UK meets its 80% carbon reduction target to identify whether a technology appears in a number of instances. If so, it seems probable that the LCT will be needed to meet targets.

Technology development with and without UK support

We review a number of factors to judge whether a LCT is likely to develop abroad in time for UK requirements. These include:

- The location of any relevant resource and whether the UK is a significant proportion of global resource.
- The location of the key technology development players and the robustness of the technology development plans of those players (be it countries or companies).
- The significance of UK funding in the global context.
- Whether the UK is expected to be a lead or major market for the LCT globally.

Assess UK net economic benefit

Assess UK competitive advantage

Based on the review of key players and of UK capability, we assess the competitive advantage of companies operating in the UK and differentiate:

- Between value chain stages i.e. research and development, engineering and design, manufacturing and fabrication, installation, and operation and maintenance.
- Between the market for the technology device (e.g. an installed offshore wind turbine) and the market for the operation and maintenance of the device.

Estimate UK net economic benefit

Our next step is to estimate the net economic benefit of developing a LCT in the UK. To do this, we estimate the economic burdens and benefits for the UK economy as a whole, rather than the financial impact on individual players. We therefore ignore transfers between different parts of the economy. We discount annual costs and benefits to 2008 values using the societal rate of 3.5% for the first 30 years and 3.0% for the remaining years to 2050[5]. We compare scenarios where the UK supports the innovation of a technology with scenarios where the technology is imported when cost effective, both against a counterfactual of business as usual, to understand the economic benefit of innovating a LCT in the UK rather than 'free riding' on global technology development efforts.

The commercialisation of LCTs has complex effects on the economy in addition to job creation and output growth. Resources – manpower, capital, land, etc. – are diverted from other uses[6]. The new industries created may employ more or less people with different skill profiles and at higher or lower wages and profitability than would have been the case if the resources had been used in existing industries. Collectively these are known as **'displacement effects'**.

We therefore examine some of these possible displacement effects to construct net economic benefit estimates. These estimates are based on fit-for-purpose assumptions regarding the possible displacement effects developed in consultation with economists from the Department of Energy and Climate Change. The key cost and benefits for the UK economy and our displacement assumptions are described below.

Solid state lighting

Solid state lighting refers to energy efficient lamps which are made out of light emitting diodes (LEDs) or organic light emitting diodes (OLEDs) that can be made to emit light in a range of colours by passing a current through them in one direction.

LEDs are made from a variety of semiconductor materials that combine the elements gallium, aluminium and indium with arsenic, phosphorus and nitrogen. White light solid state lamps can be made either by combining red, green and blue LEDs or by coating blue or ultra-violet LEDs with a phosphor. LEDs can be efficient, robust and have a long life but the light output of individual LEDs is low compared with conventional light sources.

Organic LEDs are made from carbon-based semiconductors, either as short chain molecules or polymers. They are in the form of flexible polymer films or are coated on glass substrates with a surface area of between 50mm^2 and 2.4m^2 and provide diffuse light.

Solid state lighting can be used for a wide variety of lighting applications and is significantly more energy efficient than other existing forms of lighting.

[5] Source: HMT Green Book. The required private sector returns are taken into account in the learning curve.

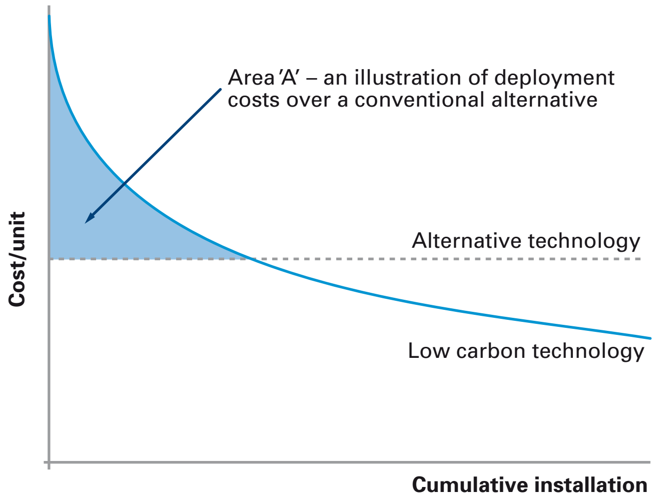
[6] Which could be productive (e.g. jobs in existing industries or land in other uses) or not (e.g. employing people who are currently unemployed or exploiting land which is currently 'fallow').

RD&D costs

If the UK develops a technology it will bear RD&D costs that it would not do if the technology was imported. We have estimated the level of both private and public sector RD&D costs necessary for the UK to develop a new technology. These in turn are based on the technology challenges identified earlier and quantification of the overall RD&D needs to bring a LCT to the stage of deployment. The demonstration spend is estimated based on an assessment of the number of demonstration plant required globally, the cost of a demonstration plant and the UK contribution to the global effort necessary to generate a material domestic industry.

RD&D costs are not subject to displacement effects.

Chart 2d *Technology development cost curve*



Deployment costs over high carbon alternative

These are the resource costs imposed on the economy by the deployment of an LCT when its unit costs are above those of the alternative. Our assumptions regarding alternative technologies are presented at the end of this chapter in the 'Our key assumptions' box.

To estimate these costs, we used an approach based on the learning curves as described earlier. This is illustrated diagrammatically by the 'area under the curve' above the marker price for the alternative technology, as depicted by the area 'A' in *Chart 2d*.

This area represents the total cost (i.e. unit cost multiplied by installed output) over and above what the market will bear. This is the 'subsidy' level needed for the LCT to reach the point of commercialisation. In other markets this might be borne by the private sector on the basis that the returns later on will pay back this investment. However, due to the market failures inherent with LCTs these additional costs will be largely borne by either the public sector or transferred to consumers.

This area under the curve estimates the minimum additional support cost. In reality costs are likely to be higher due to policy deadweight (where support is given even if it is not strictly necessary) and other factors. We only consider the minimum costs as any excess is a transfer within the economy rather than an additional economic cost.

In order to take account of uncertainties, we estimated deployment costs using alternative energy prices, learning rates and (where appropriate) start points and input costs.

Deployment costs are not subject to displacement effects.

UK value added

Valued added to national income is the main source of industrial benefit to the UK and comprises the salaries paid to UK employees and the profits made by UK based companies in both domestic and export markets[7]. To quantify UK value added[8] we estimate:

- The total market by value for a technology covering both capital (e.g. purchase of equipment) and operations and maintenance, broken down by value chain step (e.g. R&D, engineering and design, manufacturing and fabrication, installation, operation and maintenance).
- The share of UK-based companies in both domestic and export markets by value chain step. This is based upon:
  - The competitive advantage of companies operating in the UK;
  - The evolution of industry structure and dynamics, (e.g. the relationship between economies of scale in manufacturing and freight costs and hence the location of manufacturing); and
  - The extent of international knowledge spillover, which strongly influences the degree of competition.
- UK revenues from domestic and export markets.
- UK jobs and salaries based on typical industry ratios for job/£revenue and drawing on either industry data or the 2007 ASHE survey for salary data.
- UK profits based on typical pre-tax margins for similar technologies.

Value added is highly susceptible to displacement effects. In consultation with DECC economists, we use the following assumptions to illustrate the potential impact of displacement effects:

- Value added generated by sales to the domestic market – this is subject to high displacement effects i.e. it is very likely that the resources displaced would have earned similar value added elsewhere. Therefore, when allowing for displacement effects we do not credit any value added from domestic sales to economic benefit.
- Value added generated by sales to the export market – this is subject to low displacement effects and so we credit 75% to economic benefit i.e. the creation of exports creates additional value for the UK which the displaced resources are unlikely to have earned.

Carbon abatement benefits

Abating carbon reduces damage to the environment. We value this either using forecasts of market prices or 'shadow' prices derived by Government. Carbon abatement is based on market deployment prior to a technology becoming cost effective; thereafter carbon abatement could be realised by importing the technology. Emission factor and carbon pricing assumptions are described at the end of this chapter (see 'Our key assumptions' box).

With 'business-as-usual' as our counterfactual, the benefits of carbon abatement are not subject to displacement effects.

[7] Plus employer's national insurance contributions. UK value added includes exports from UK operations but not from UK-owned operations overseas. UK-based companies means the relevant economic activity is in the UK (i.e. excludes the overseas operations of UK parented companies but includes the UK operations of foreign parented companies).

[8] Includes supply chain value added and incorporates leakage effects as we explicitly consider the market share of UK-based companies in the supply chain, but excludes income multipliers (which measures the further economic activity resulting from the creation of local economic activity through income expenditure).

Develop potential solutions

Challenges in the innovation system

We use a systematic framework to assess the innovation challenges for a technology. In particular, the innovation system surrounding a technology is tested for the presence or absence of four key factors:

- Credible end market.
- Adequate public technology development support.
- Adequate private finance.
- Appropriate human capital.

This framework helps to ensure consistency and to determine whether generic issues can be identified in the UK innovation system.

Solutions for the innovation challenges

Where relevant we formulate potential solutions to the key innovation challenges on the basis that the UK wishes to develop rather than import the technology. These are only potential solutions as, generally, they have been developed qualitatively, to address all the key challenges, and have not been evaluated quantitatively.

We use the solutions framework outlined in *Chart 2e* in order to maintain consistency of approach:

- Pull factors are regulatory and market mechanisms which create a credible end market (e.g. revenue support such as EU Emissions Trading Scheme).
- Barrier removal generally involves addressing institutional or regulatory issues which are slowing progress (e.g. streamlining planning).
- Push factors involve some sort of subsidy or public support intervention (e.g. R&D grants).

Chart 2e *Solutions development framework*

Mechanism	Push	Barrier removal	Pull
Description	Provision of Government financial support for development in terms of: • Level • Appropriateness • Fairness • Efficiency	Action not words in the removal of deficiencies or barriers that only the Government can address	Creation of a credible market
Examples	• RD&D grants • Capital grants • Field trial support	• Major infrastructure changes such as extensions to electricity grid • Making regulations appropriate for new LCTs	• Provision of effective subsidy mechanisms linked to output targets (e.g. cap and trade schemes) • Supplier obligations

Source: LEK.

Our key assumptions

Alternative technologies

We compare the environmental and economic performance of a technology with the conventional technology used in a business-as-usual scenario. These conventional technologies are:

- Combined-cycle gas turbines (CCGT) for offshore wind power and wave power.
- Mineral-based fuels for LHF ethanol.
- CCGT and a gas-fired condensing boiler for FCmCHP.
- Compact fluorescent lighting for solid state lighting.
- Pumped storage and open-cycle gas turbines for flow cells.

Energy prices

Fossil fuel prices were taken from the 'low', 'central' and 'high high' cases used in the updated BERR modelling underlying the 2007 Energy White Paper. These assume crude oil prices of $45/bbl, $65-75/bbl and $107-150/bbl respectively. Wholesale gasoline prices were derived from crude oil price plus a refinery margin as reported by the US DOE[9].

Costs of CCGT-based electricity generation were estimated using BERR natural gas prices and levelised costs of generation estimated using a model made available by BERR[10]. Retail electricity and gas prices were developed using actual ratios of wholesale to retail prices. We assume that the full costs of CCGT-based generation are a proxy for wholesale electricity prices.

Carbon prices

For the non-traded sector, we used shadow carbon prices as published by Defra[11]. For the traded sector, we use projections prepared in consultation with DECC[12].

Emission factors

Unless otherwise stated, electricity emissions factors assume that CCGT is the marginal new plant on the system. This implies an emission factor of 0.38kg CO_2/kWh for supply side technologies and 0.43kg CO_2/kWh for demand side technologies. As sensitivities, we tested carbon savings using emission factors consistent with those in the 2007 Energy White Paper scenarios, the core trajectories published by the Committee on Climate Change and current grid mix.

Emission factors for gasoline and natural gas are 84.6kgCO_2/GJ and 0.19kgCO_2/kWh respectively[13].

[9] Source: Energy Information Administration.

[10] Source: DTI, 'New build assessment of various technologies'.

[11] Source: Defra, 'How to use the Shadow Price of Carbon in policy appraisal', 2009.

[12] Source: DECC, 'Greenhouse Gas Policy Evaluation and Appraisal in Government Departments', 2008 prices to 2020. Thereafter we use provisional DECC projections used in the absence of an officially-agreed post-2020 set of projections.

[13] Source: E4tech.

Technology prioritisation framework

We have developed and tested a framework to summarise the results of the technology assessments in terms of the justification for UK support (see *Chart 2f*).

The two elements of this framework are first, whether a LCT is needed to meet UK carbon reduction targets and is unlikely to be available in time without UK support; and second, whether the LCT will or is likely to generate net economic benefit for the UK. The framework also distinguishes between earlier stage development/demonstration technologies, where the aim is to generate technology options, and later stage technologies, where the aim is to focus on cost effective supported deployment. This distinction is made by plotting technologies at these different development stages on separate prioritisation matrices.

Using this framework as a starting point, we then used the position of a LCT in the framework in order to help set the general stance of the Government towards the LCT i.e. by categorising the general policy approach. The colouring in the chart defines three categories of response across both early stage development technologies and later stage demonstration:

'Must do' – pro-active/minimise cost (Green)

If the LCT is needed to meet climate change related targets and is unlikely to be available in time from overseas, then UK action is required (top row of matrices). If net economic benefit is likely to be generated (the top right quadrant) then a more pro-active stance is appropriate – economic benefit may be achieved, in part, by facilitating the establishment of local industrial activity and by investing now in order to capture export markets.

If net economic benefit is unlikely to be generated then a policy aimed at effectively minimising the costs of the LCT is most appropriate (top left quadrant).

'Choice'– support if compelling (Blue)

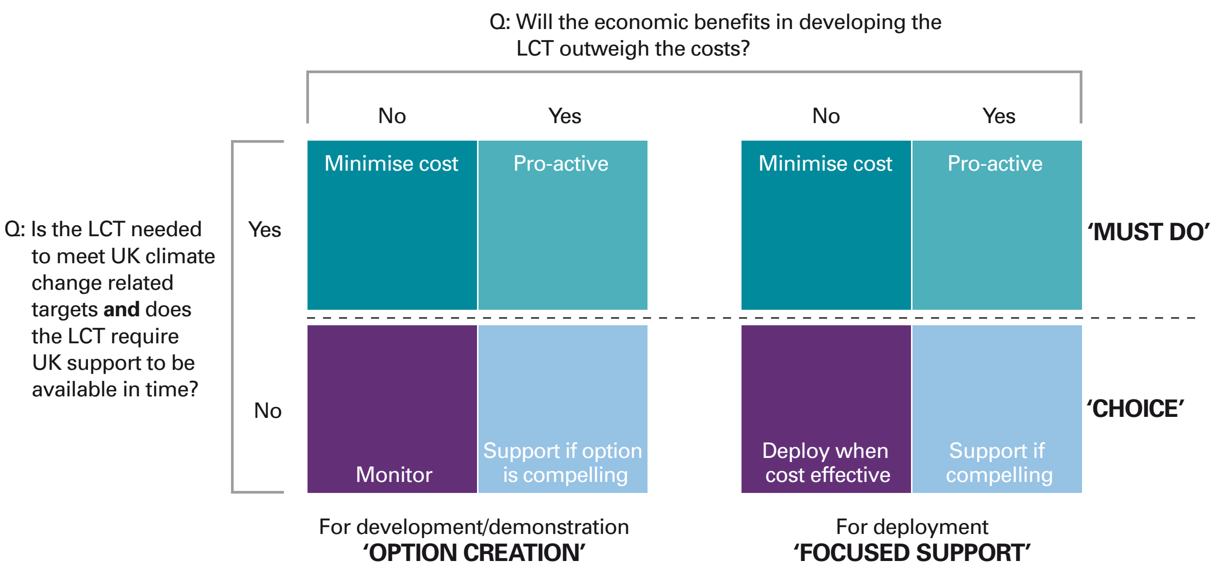
If a LCT is either not needed to meet climate change related targets or likely to be available from overseas, then UK public sector support is only justified if a strong case can be made that net economic benefit is generated and it represents better value for money than alternatives (bottom right quadrant).

'Choice'– monitor/deploy when cost effective (Purple)

The stance for technologies in the bottom left quadrant, (i.e. those which are either not needed to meet UK climate change related targets or likely to be available in time from overseas and which are unlikely to generate net economic benefit) depends on the stage of development. For those at the deployment stage, the stance is to deploy when the technology has been proven cost effective elsewhere. For those at the development/demonstration stage a monitoring stance is appropriate. These are relatively early stage technologies so circumstances may well change leading to a re-appraisal of the right stance.

We use this framework in our assessment of each of the six representative technologies studied in the next section.

Chart 2f *Prioritisation framework*



Source: LEK, Carbon Trust.

3. Technology assessment summaries

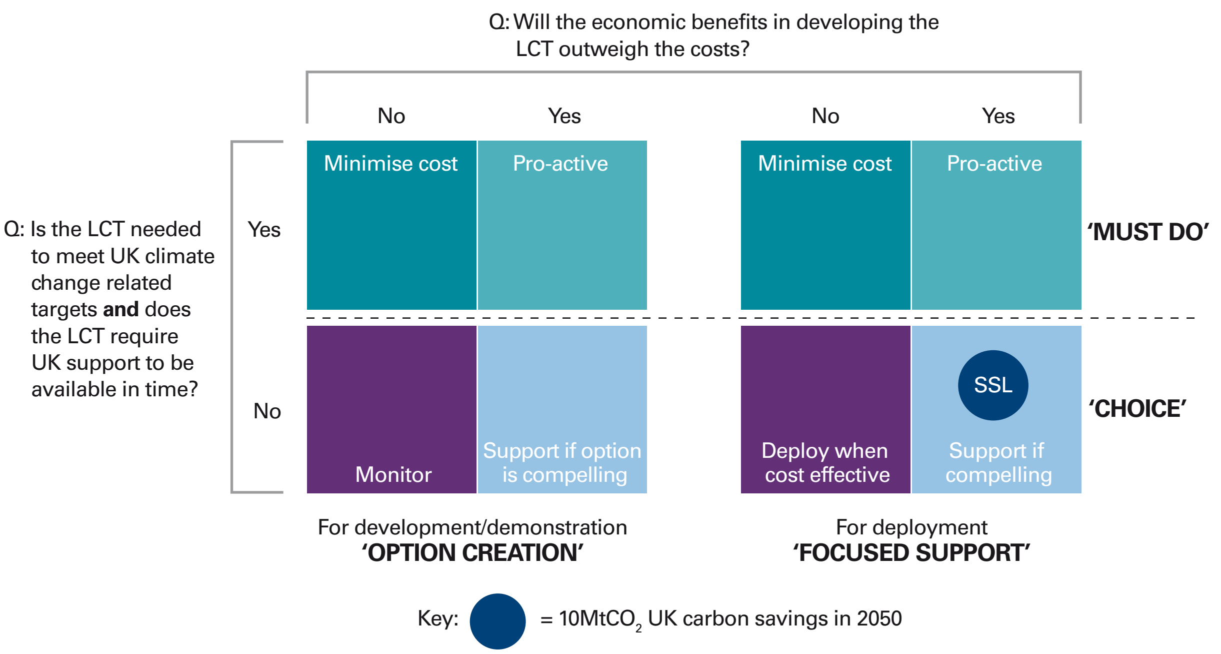
The detailed technology assessments summarised here provide much of the evidence for the remainder of this report.

3.1 Solid state lighting (SSL)

Conclusion: UK should prepare the market for mass deployment

- While overall market penetration is still low SSL has reached the deployment stage and is likely to fully commercialise by 2014.
- Carbon savings are likely to be material and therefore important for the UK in meeting carbon targets. However, UK public support will not influence the speed of technology development.
- The UK should generate net economic benefit as the UK has capabilities in some niche areas and SSL will be a mass global market.
- In order to create the right environment for SSL to be deployed as soon as possible, the UK needs to address a number of key market challenges including performance comparability, the difficulty in comparing lifetime costs and regulation not rewarding higher performance.
- The key action for the UK therefore is to address these market challenges in order to prepare for mass deployment from 2014 onwards.

***Chart 3.1a** SSL in the context of our framework*

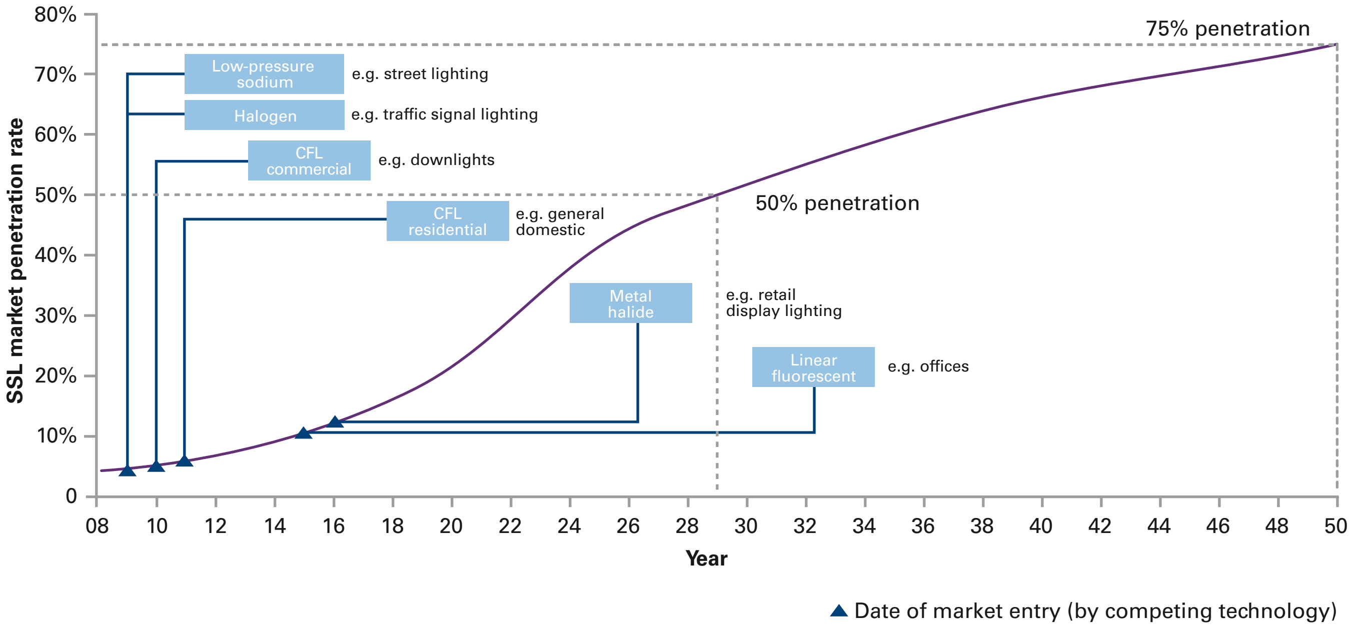


Note: Economic benefit assessment includes displacement effects.
Source: Building Research Establishment, LEK, Carbon Trust.

While overall market penetration is still low, SSL has reached the deployment stage and is likely to fully commercialise by 2014

- The fundamental science for SSL is relatively well established and, while mass market penetration is still minimal in some areas, SSL is close to commercialisation. However, SSL still faces two key technical challenges which may affect its ability to penetrate specific markets: effective heat dumping through the luminaires and colour rendering.
  - While SSL units don't create much heat compared to existing light sources, their performance and lifetime are poorer at high temperatures and therefore specially designed luminaires are needed. This is a more significant issue for the replacement market rather than in newbuild applications where this problem can be more easily 'designed out'.
  - The issue with colour rendering (i.e. the way that the light reveals colours to the human eye) is that high quality white light is very expensive. It can be achieved by either getting the right combination of red, blue and green LEDs in one unit in order to achieve a balanced white light (a difficult process which is also less energy efficient) or by using a single blue or ultraviolet LED with a corresponding phosphor which emits light at a longer, redder wavelength (a process which is being actively researched). However, when set up correctly, the light quality is very high. SSL also allows much more flexibility in the colour of light, which is extremely difficult to achieve with other competing technologies.
- SSL is already commercialising for some niche applications:
  - Coloured lighting (e.g. coloured display LEDs, coloured decorative lighting, traffic lights, etc.) where it can compete without the added expense of exact colour rendering.
  - Where the long lifetime of the unit is of importance (e.g. emergency lighting, automotive and aviation lighting, low power display lighting, LCD display backlighting, addressable picture walls, etc.).
- In some of these areas SSL has reached early deployment. However, overall market penetration into the mass lighting market is still low.

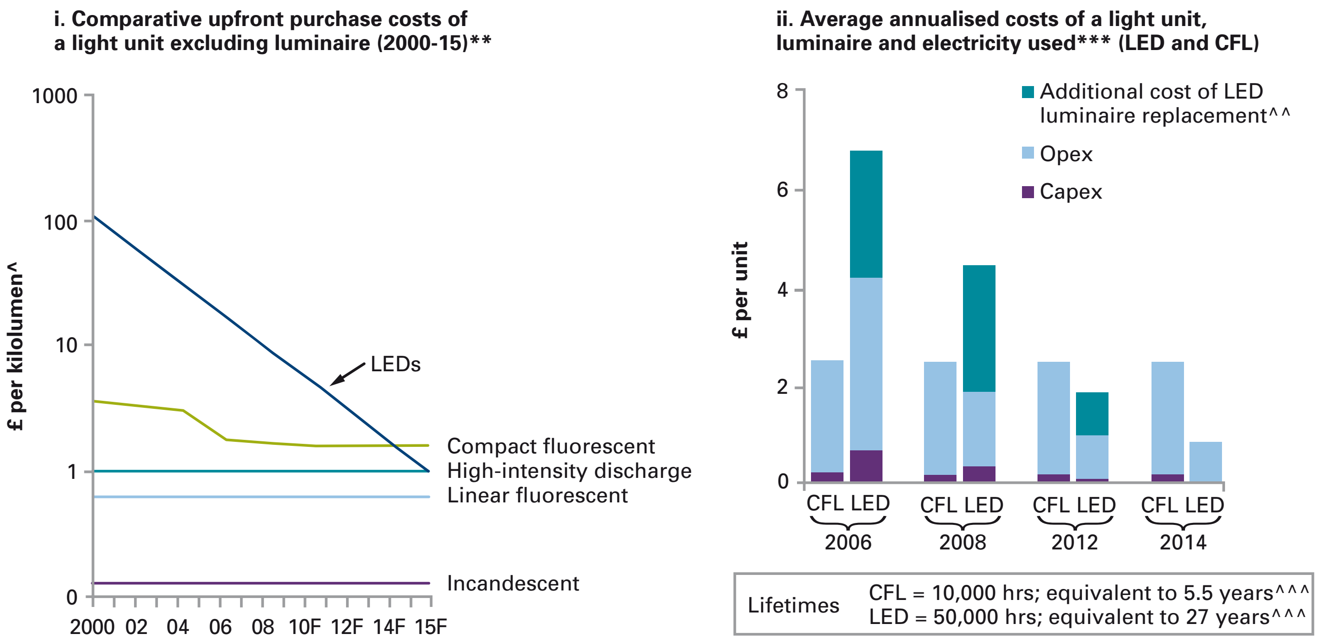
***Chart 3.1b** Penetration of SSL in the overall UK lighting market* (2008-50)*



*Includes lamps and luminaires.
Source: Building Research Establishment.

- SSL is predicted to reach 50% overall penetration by around 2030 and 75% by 2050 (see *Chart 3.1b*). This will involve the progressive substitution of existing technologies – with low-pressure sodium and halogen likely to be replaced first and then Compact Fluorescent Lamps (CFLs), linear fluorescents and finally metal halide. Penetration is likely to take longer in some of the mass markets (e.g. home interior lighting) where both colour rendering and low cost are important.
- Due to learning effects, the point of sale unit costs for LEDs are expected to be comparable with CFLs by 2014 and high-intensity discharge lamps by 2015 (excluding luminaire and electricity costs). The left hand side of *Chart 3.1c* shows the likely cost reduction in light units comparing LEDs with other existing technologies. It also illustrates just how quickly LED costs are falling. LEDs are reliant on technologies from the microelectronics and semiconductor industry sectors which have traditionally seen very fast learning effects in new products.
- LEDs are cost competitive with CFLs already if the full costs of electricity over the lifetime of the unit are included, but the replacement luminaire costs are not. This is in part due to the significantly longer lifetimes of the units, which are five times longer for LEDs than CFLs. However, even including the luminaire, the lifetime cost difference is expected to disappear by 2012 (as illustrated in the right hand side of *Chart 3.1c*).

Chart 3.1c** Lighting cost comparisons



*Lighting unit costs were taken from the US DOE multi-year plan report and the report describes it as 'the average purchase cost of a 3 watt white-light LED device driven at 350mA (excluding driver or fixture costs)'. This is assumed to be the cost of a 'module' that includes the chip(s), board, heat sink and some optics but not any extra aesthetic fitting or the drivers. For CFL the unit cost is an equivalent lamp.
**Based on forecast prices from 2009 onwards.
***The effect of differential product lifetimes are included in the cost calculation; assumes a 600 lumen average lamp operated five hours per day; average cost of electricity is 11 pence per kWh.
^A unit of measurement of the amount of brightness that comes from a light source (e.g. a wax candle generates 13 lumens).
^^Marginal cost difference between LED and CFL luminaires forecast to reach zero in 2014.
^^^Average daily usage is five hours.

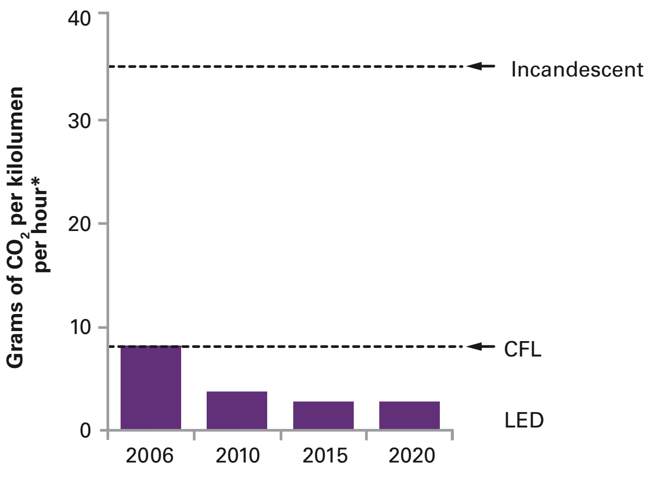
Source: Building Research Establishment; LEK analysis.

Carbon savings are likely to be material and therefore important for the UK in meeting carbon targets

- Carbon emissions per kilolumen for LEDs are currently just 20% of incandescent lighting and are already comparable with CFLs. However, as *Chart 3.1d* demonstrates, this is predicted to fall significantly over the next 10 to 15 years giving rise to greater potential carbon savings. CFLs are unlikely to experience further improvements (or reduced costs) as it is now a relatively mature technology.
- LEDs are likely to have a significant impact on carbon emissions as lighting generally accounts for 15% of domestic electricity consumption and 22% of non-domestic electricity consumption. The carbon emission reduction potential in the UK could be as high as 15MtCO_2 in 2030 and 20MtCO_2 by 2050 based upon replacing all lighting with SSL. A more likely deployment scenario leads to savings of 9MtCO_2 and 16MtCO_2 respectively – this is still potentially highly significant (equivalent to ~2.5% of 2050 projected UK emissions of 600MtCO_2).
- This 'expected' scenario is based on 85% penetration of very high colour rendering applications; 42% penetration of high colour rendering applications; and 70% penetration of medium and low colour rendering applications[1].
- Carbon savings for lighting are very sensitive to the carbon intensity of displaced electricity. Projections from the Committee on Climate Change (CCC) indicate that the level of grid carbon intensity will reduce drastically if the UK is on track to reduce overall emissions by 80% by 2050 and this will in turn drastically reduce the potential carbon savings from SSL. However, energy efficiency technologies such as SSL will still play a large part in significantly reducing overall demand which will make achieving low carbon electricity supply more cost effective.

***Chart 3.1d** Projected carbon emissions savings from SSL*

i. Comparative carbon emissions of lighting based on lighting output (2006-20)



ii. Annual carbon abatement from SSL (2030 and 2050)**

MtCO_2		2030	2050
UK	Expected	9	16
	Potential	15	20
Global	Expected	306	549
	Potential	501	677

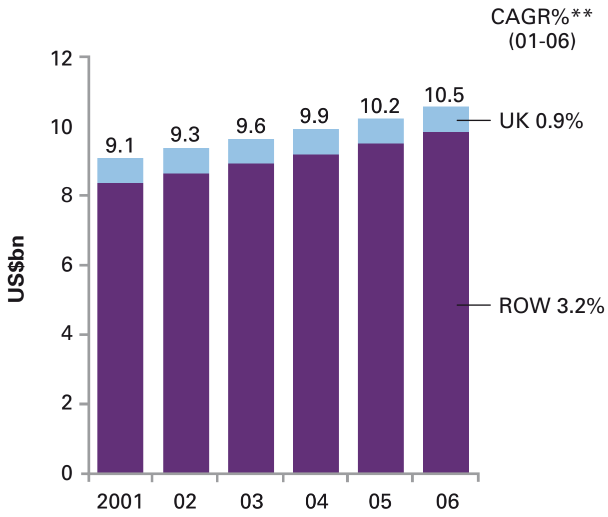
*Assumes constant grid mix carbon coefficient of 0.43 grams of CO_2 per kWh.
**Incremental savings of SSL versus CFL.
Source: Building Research Establishment.

[1] Source: Navigant Consulting Inc. Energy Savings Potential of solid state lighting in General Illumination Applications, US Department of Energy, 2006.

UK public support will not influence the speed of technology development

- As shown in *Chart 3.1e*, due to the small size and low growth of the UK's domestic market and the lack of a relevant mass manufacturing industrial base, the UK will have very little influence over the rate of technology development.
- The large lighting manufacturers appear to be well positioned in the market. *Chart 3.1f* shows the general lighting market on the left which is made up of large players including Philips, Osram and GE with a 50% share of total global lighting sales. In the LED market, which is shown on the right, Philips, Osram and Cree (in association with GE) between them already hold significant market share (including non-lighting applications) of over 40%. The largest LED manufacturer, Nichia, is mainly a manufacturer of LED screen technology and hasn't yet made a significant play in the lighting markets.
- The large lighting manufacturers also appear to be making significant investments into acquisitions, R&D and manufacturing plant (e.g. over the last five years Philips has spent €2bn on LED-related acquisitions and Philips Lumileds is spending $100m annually on capacity and $80m on R&D) and making intellectual property available through cross-licensing[2].
- The main LED and semiconductor factories are in the Far East, US or Germany. For example, Osram has invested significantly in LED chip manufacturing plants, including large investments in Germany and Malaysia.

***Chart 3.1e** Global illumination lamp sales (2001-06)**

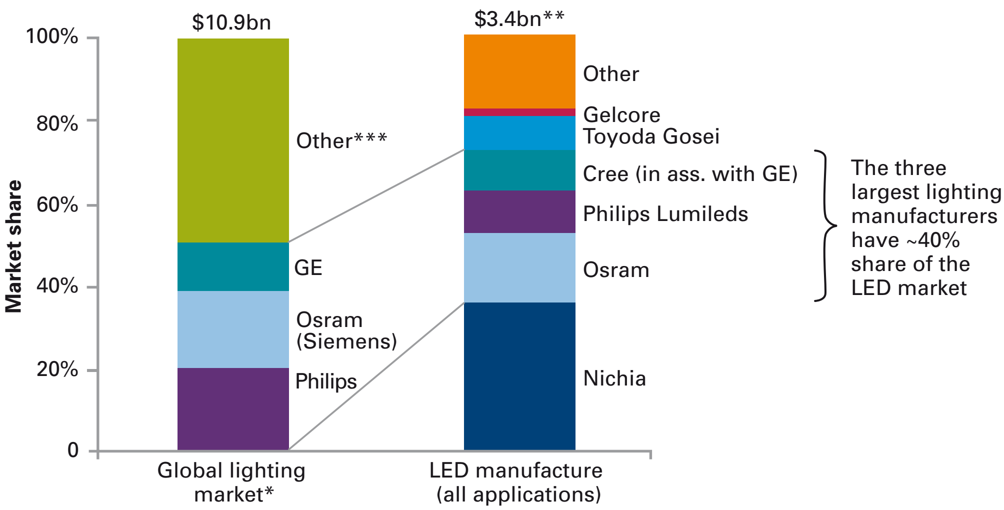


*Includes metal halide and other electronic discharge lamps.
**CAGR is Compound Annual Growth Rate.

Source: Global Industry Analysts, US Department of Energy; LEK interviews & analysis.

The incentive for the major lighting manufacturers to move forward would appear to be the risk of losing market share to non-lighting specialists such as Nichia. Therefore the incumbent lighting manufacturers are developing LEDs even though there may be a significant impact on their existing products e.g. CFLs and sunk costs in existing plants.

***Chart 3.1f** Market share of lighting market sales & LED manufacture (2007)**



*Excluding luminaires.
**Total LED market including display, signs, illumination and mobile applications.
***Sylvania-Havelis is the fourth major player with a UK market share of 15%.

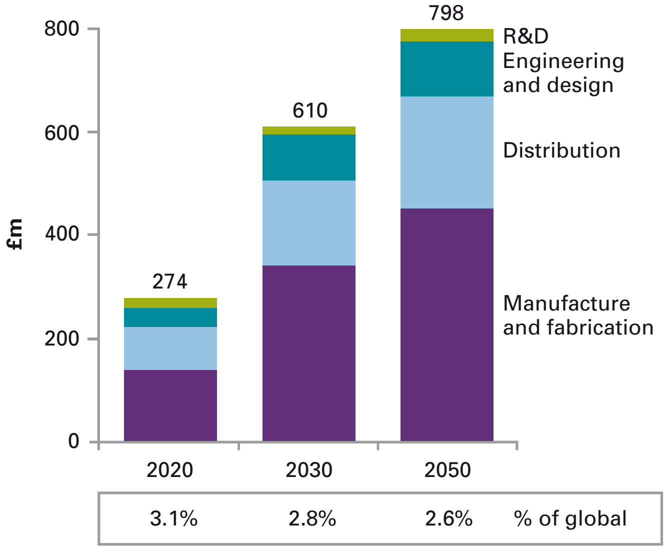
Source: Societe General, Building Research Establishment; LEK analysis.

[2] Source: Frost and Sullivan, 2008.

The UK should generate net economic benefit as the UK has capabilities in some niche areas and SSL will be a mass global market

- Overall net economic benefit for the UK is expected to be small but positive (NPV of £300m) based upon a small percentage of a very large global export market.
- The vast majority of SSL chip manufacture is highly likely to take place outside the UK by existing large semiconductor manufacturers and so therefore the UK is likely to be a net importer of the core units.
- As the majority of SSL units will be in replacement applications rather than new uses, most of the UK's revenue in terms of installation/operations, etc. is likely to replace current activities for other technology types and so won't lead to significant additional benefit.
- However, the UK has key strengths in terms of fundamental materials design research, lighting design and in the specialist luminaire market.
- The UK has leading research groups at a number of universities, however effort tends to be much stronger in fundamental semiconductor physics and materials properties of the basic LED devices themselves rather than potentially more commercial applied research.
- The UK has a presence in the luminaire market, however this tends to be fairly fragmented with no particular dominant force – luminaire manufacturers in the UK range from large firms like Thorn Lighting to much smaller companies with only a handful of staff.
- Our analysis shows that the UK SSL industry could have 7,000 jobs by 2050 and gross revenues of £800m (see *Chart 3.1g*).

Chart 3.1g *Estimated UK plc annual revenue from SSL industry (2020-2050)**



*Lamp and luminaires.

Source: BRE assumptions; Carbon Trust analysis and scenarios.

In order to create the right environment for SSL to be deployed as soon as possible, the UK needs to address a number of key market challenges

Performance comparability

- Challenge: It can be difficult for consumers to compare performance and suitability of different low carbon lighting products, leading to negative perception and reduction in demand. For example, LEDs which claim to be equivalent to a halogen lamp may appear significantly dimmer, leading to consumer dissatisfaction. This appears to have been one of the causes of the slow uptake of CFLs in the UK (albeit quicker than some other major nations). Early CFLs had a number of problems (e.g. perceived poor colour, flicker and run-up time). While these problems have now been resolved, the poor performance of earlier CFLs means that consumers still have a perception of poor quality. There is a danger that cheap, early market LEDs may taint the technology in a similar way.
- Potential solution: Coordination between Government and industry to set in place industry standards that allow easy comparison of product performance and root out poor products.

Difficulty in comparing lifetime costs

- Challenge: Most consumers are not aware of the potential cost savings from new forms of lighting. The higher 'capital' cost of installing or retrofitting LED lighting deters consumers. LEDs have significant potential for lifetime cost and energy savings (both because of their longer life and higher energy efficiency), but this is not portrayed at point of sale in a way that is easy to understand. Most consumers apply high discount rates to distant future savings or do not think they will see a return in their current property (particularly when the lifetime of the unit will perhaps outlive the time that a consumer spends at a property).
- Potential solutions:
  - Improved public awareness of the rewards available from investing in all energy efficient housing upgrades, including lighting.
  - Demonstration of technological improvements at either the EU or UK level.
  - Enforce appropriate point of sale/labelling materials that portray the lifetime costs in an easy to understand way.

Higher performance not rewarded by regulation

- Challenge: Some areas of current regulation support low carbon lighting in general (e.g. CFLs) but are not designed to help drive through the next (potentially more efficient) technology. This is because: regulation is generally based on thresholds which do not reward better performance than CFLs; and standards which may be too low to encourage new more efficient technology solutions. Examples in the UK include building regulations (both domestic and non-domestic) and incentive arrangements such as Enhanced Capital Allowances and Carbon Emissions Reduction Target. The EU Energy using Products (EuP) Directive may also fall into the same trap.
- Potential solution: Tighten the highly influential EuP directive. Other UK-specific actions that could be used to further stimulate deployment include public procurement initiatives and tighter standards for policies relating to lighting.

The key action for the UK therefore is to address these market challenges in order to prepare for mass deployment from 2014 onwards

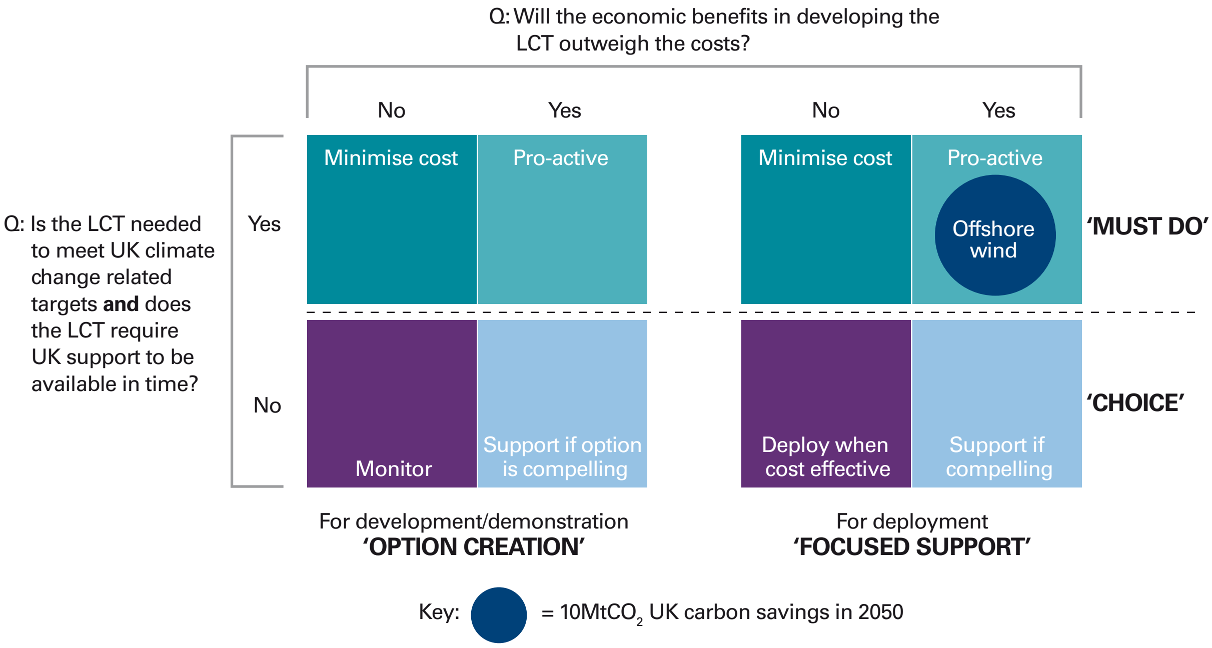
- We conclude that SSL has reached the deployment stage and, while it is needed for UK carbon targets, it will commercialise by 2014 led by existing large market players without the need for UK support. The UK will gain some net economic benefit from niche areas of the value chain. Our framework (in *Chart 3.1a*) therefore suggests that the key areas of focus for the UK are:
  - Prepare to deploy SSL for carbon targets if and when cost effective.
  - Ensure all issues relating to deployment of the technology are addressed.

3.2 Offshore wind power

Conclusion: UK should pro-actively develop offshore wind power

- The UK is likely to need at least 29GW of offshore wind power by 2020 to meet its EU renewable energy and long-term carbon emission targets.
- The UK is a lead market for offshore wind power, together with Germany, and has offshore and services skills and the potential to develop a strong position along the value chain.
- The UK could generate net economic benefit if policy is effective in reducing costs and increasing UK value added.
- To commercialise and deploy offshore wind power the UK needs to implement robustly its plans to increase public support and address regulatory issues.
- The UK's stance should be to actively innovate and deploy, seeking to exploit economic benefit by encouraging investment and service activity.

***Chart 3.2a** Offshore wind power in the context of our framework*

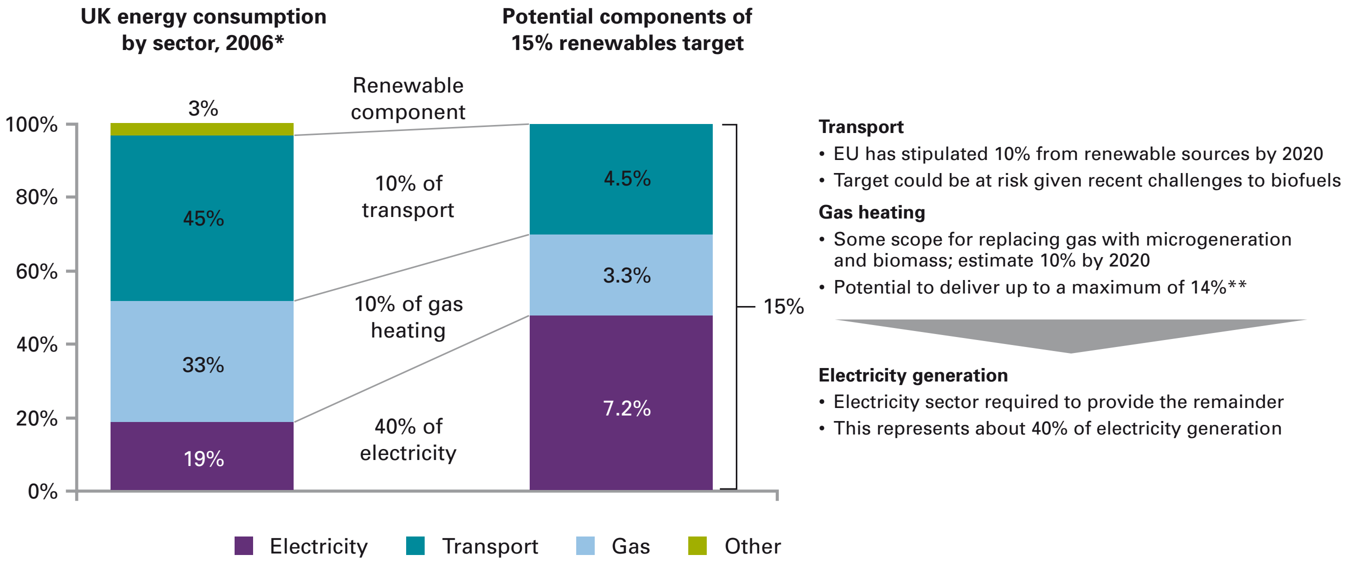


Note: Economic benefit assessment includes displacement effects.
Source: BCG, LEK, Carbon Trust.

The UK is likely to need at least 29GW of offshore wind power by 2020 to meet its EU renewable energy and long-term carbon emission targets

- Offshore wind power, based on adapted onshore wind technology, is at the deployment stage, having been demonstrated in both the UK and Denmark at the beginning of this decade.
- EU 2020 renewable energy targets require 15% of energy consumed in the UK to come from renewable sources. Although the UK target is lower than most other member states, it represents a dramatic scale-up from the UK's current position of producing 1% of energy from renewable sources.
- *Chart 3.2b* shows UK energy consumption and how each sector could contribute to the 15% renewable target. Transport represents 45% of current energy consumption and the EU has stipulated that 10% should come from renewable sources by 2020. This would contribute 4.5% out of the 15% target, although concerns about the sustainability of biofuels may put this at risk. The remainder can then be split across heat and electricity. This study assumes a base case of 10% renewable heat. This could conceivably be higher, but the Carbon Trust's experience of the barriers to deploying heat renewables from our Biomass Technology Accelerator suggests that this would be a significant challenge. Therefore, if the UK is to hit the EU renewable energy target, 40% of electricity would need to come from renewable sources by 2020.

***Chart 3.2b** Breakdown of UK energy consumption by sector and potential contribution to meeting the renewable energy target*

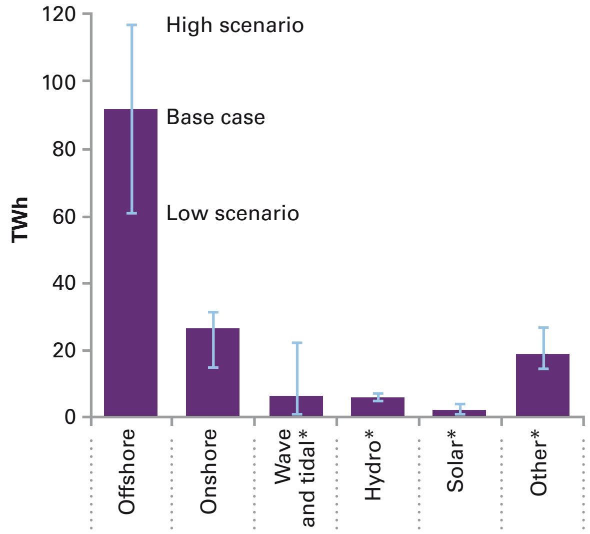


*Based on data for final energy consumption by fuel from BERR Energy Consumption Tables. Petroleum consumption is assumed to correspond to the transport sector.
**Central scenario from BERR, 'UK Renewable Energy Strategy Consultation', 2008.

Source: BERR, BCG analysis.

- Our analysis has shown that offshore wind power is crucial to delivering 40% renewable electricity by 2020 (see *Chart 3.2c*)[3] as the alternatives all have limitations:
  - Onshore wind power is likely to be limited by the availability of sites where planning permission is likely to be granted.
  - Both tidal and wave power are still immature, emerging technologies and would be expected to make more significant contributions post 2020[4].
  - Cost and environment issues with the Seven Barrage may well limit the size of the scheme to, say, 1GW.
  - The future contribution from solar will be limited by the availability of cost-competitive and scalable technology solutions.

Chart 3.2c *Forecast UK electricity supply by technology in our central 40% renewable electricity scenario in 2020*



Scenario	Offshore	Onshore	Wave and tidal*	Hydro*	Solar*	Other*
Minimum offshore wind power	19	13	7	2	1	n/a
Base case	29	11	2	2	1	n/a
Maximum offshore wind power	36	6	0	2	1	n/a

Implied capacity (GW)

*Landfill, cofiring, hydro, wave, solar and other projections from BERR, 'Renewables Obligation Consultation: Updated Modelling for Government Response', 2008.

Source: BCG analysis

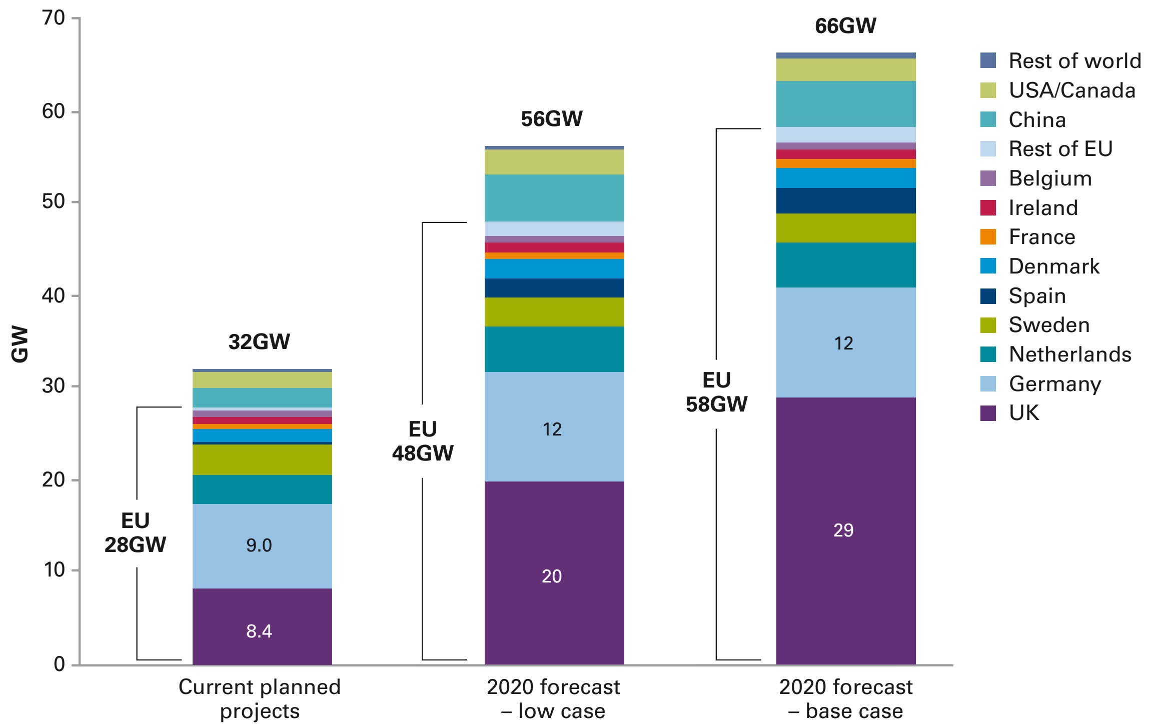
- Delivering 29GW of offshore wind power generation in just over a decade is an immense challenge. It is equivalent in scale to the 1990s 'dash for gas' and requires investment from industry on a similar scale to that invested in North Sea oil and gas in the peak decade of its development. Although extremely challenging, it is technically feasible:
  - 29GW of offshore wind farms only need 0.5% of total UK sea floor, a combined space the size of the county of Somerset. There is sufficient room in UK waters, even with all the current constraints on where offshore wind farms can be located.
  - The UK's electricity system can incorporate 40GW of offshore and onshore wind power without compromising security of supply; both the long-term need to meet peaks in demand, and the short-term requirement to balance supply and demand at all times.
  - Offshore wind technology has been operating commercially since 2002. The engineering challenge to operate in the marine environment should not be underestimated, but most developments will be able to leverage existing tried and tested technologies from the onshore wind, electrical power and oil & gas sectors.
- After 2020, there is scope for at least a further 10GW of offshore wind power capacity based on resource availability. Curtailment, balancing and load factor costs would need to be mitigated (e.g. by increased interconnection and demand management). Modelling by, among others, the Committee on Climate Change has shown that offshore wind power is a crucial component of the UK energy system in 2050.

[3] For further details see Carbon Trust, 'Offshore wind power: big challenge, big opportunity', 2008.
[4] See Carbon Trust, 'Future Marine Energy', 2006.

The UK is a lead market for offshore wind power, together with Germany, and has offshore and service skills and the potential to develop a strong position along the value chain

- The UK and Germany are expected to be the two key markets for offshore wind power up to 2020. *Chart 3.2d* shows that between them, the UK and Germany will account for up to 60% of the global offshore wind power market, with the UK alone responsible for c.45%. The UK therefore has the advantage of being the major lead market for offshore wind power in the next decade.
- The UK also has a number of other advantages in offshore wind power, including offshore and service skills and the potential to develop a strong position along the value chain:
  - Skills developed in the North Sea oil and gas industry are highly relevant to the installation and maintenance of offshore wind power as well as to parts of the design and fabrication process for key components. As North Sea oil and gas production declines, offshore wind power could provide a market for more than half the current employees with the right skill set.
  - The UK is likely to have the greatest competitive advantage in the secondary service sector – particularly in areas such as finance and legal services – built on London's position as a leading international financial centre.
  - Finally, although the UK currently has limited offshore wind power manufacturing, the UK has a number of assets through the value chain including: R&D capabilities, such as at Nottingham University, and initiatives such as the New and Renewable Energy Centre (NaREC); generic manufacturers of large, difficult to transport components (e.g. castings and forgings, etc); and niche players (e.g. BiFab in foundations).

Chart 3.2d *Forecast global offshore wind power capacity, 2020*



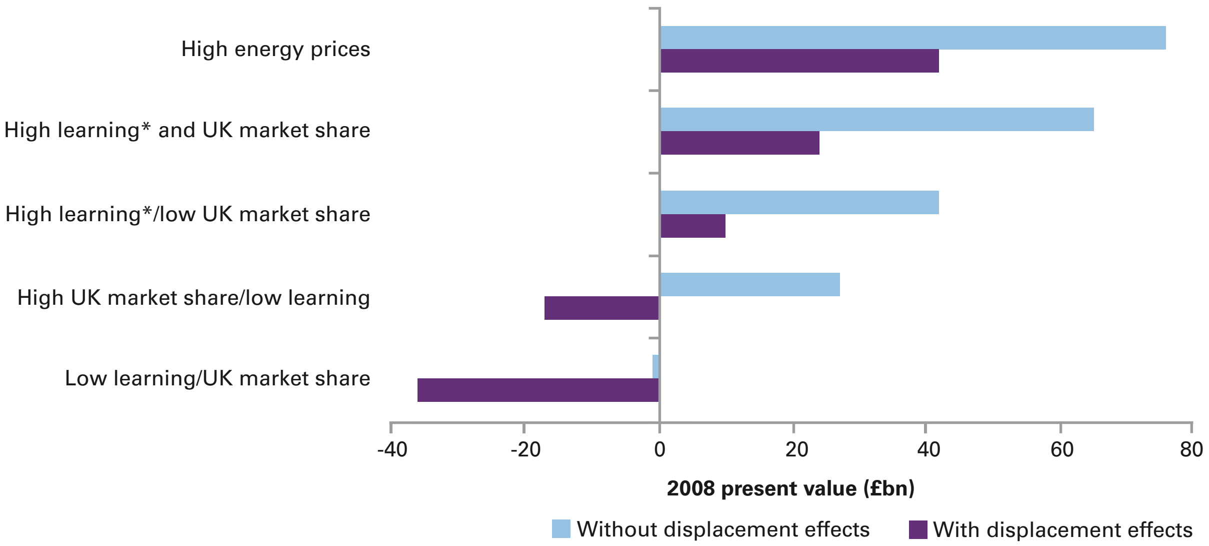
Note: Assumes 35% offshore capacity factor for all countries. 'Current planned projects' includes all projects that are operational, in the planning process or proposed with a completion date before 2020.

Source: MAKE, 2007; EU and Government reports/White papers; GWEC, 'Wind Force 12', 2005; IEA, 2007; Citigroup, 'Wind Power Industry's Prospects to 2020', 2008; Web searches; EurObserv, 'Wind Energy Barometer', 2008; BCG analysis.

The UK could generate net economic benefit if policy is effective in reducing costs and increasing UK value added

- Using low learning, low UK market share and central energy prices, then offshore wind power does not create net economic benefit for the UK (see *Chart 3.2e*). This is because the deployment cost to 2050 of c.£90bn outweighs the value added and carbon benefits. This analysis includes an estimate for the system costs of offshore wind power (including the extra costs of balancing electricity supply and demand, standby plant cost and the cost of connecting offshore wind farms to the grid transmission system).
- However, there are a number of circumstances in which the UK can expect to generate net economic benefit (see *Charts 3.2e* and *3.2f*). In particular, if learning rates are high alone or in combination with high UK share of domestic and export markets, or if energy prices are high.
- Effective policy (including incentive mechanisms, regulatory barrier removal and RD&D support, together with effective delivery) will help bring about both high learning and high UK market share and thereby deliver net economic benefit for the UK.

***Chart 3.2e** Net economic benefit to 2050: key sensitivities*

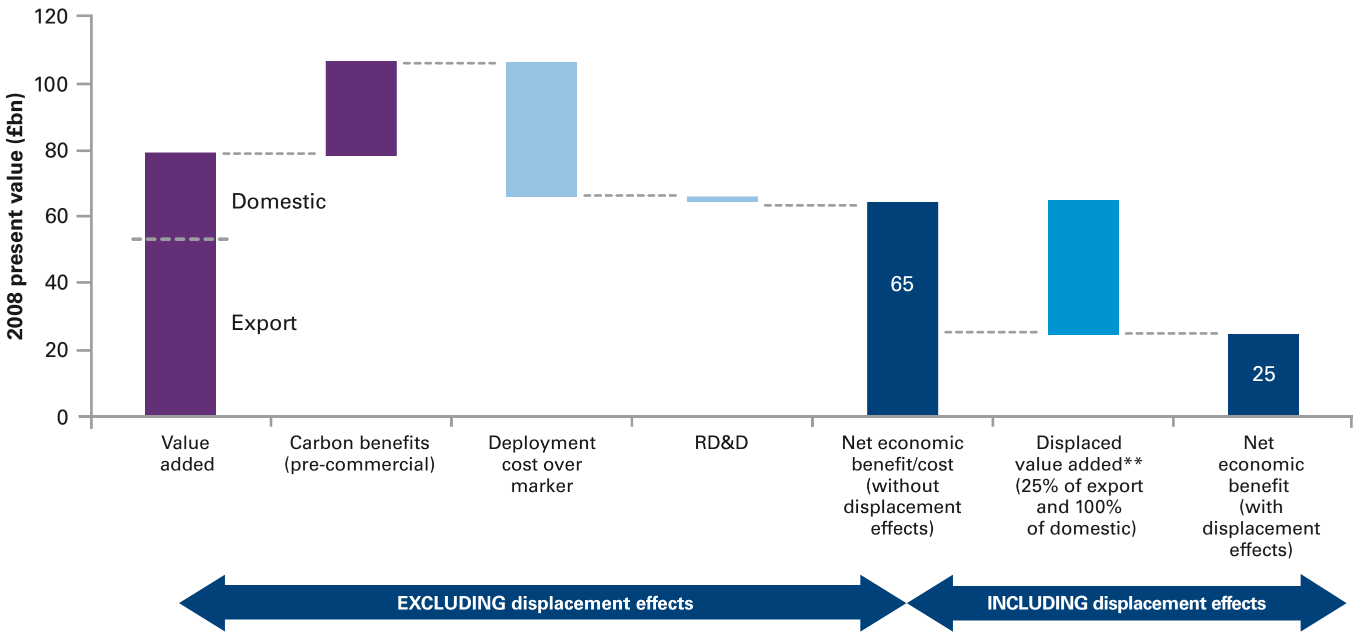


*Includes impact of better sites as well as higher learning. Removing the impact of better sites is likely to reduce net economic benefit by about £5-10bn.

Source: BCG, Carbon Trust.

- Effective innovation policy will help to increase learning rates from the lower end of those exhibited by onshore wind power (9%) to the higher end[5] (15%). Increased RD&D, in both new and existing components, and maximised economies of scale will fulfil this potential for cost reduction. This substantially reduces deployment costs by about £40-50bn, an order of magnitude greater than the increase of RD&D spend required.
- Effective integration of innovation and economic development activity will also help to attract major existing or new turbine manufacturers to base all of their offshore wind power operations in the UK, draw in the associated supply chain, maintain the UK's strong position in services (e.g. finance and legal) and capture 55-60% of installation activity. This would create a cluster capable of maintaining a strong UK position in the regional European market beyond 2020.
- The combination of high learning and high UK market share, which is enabled by effective policy, generates £65bn of net economic value excluding displacement effects and £25bn including displacement effects (see *Chart 3.2f*). This leads to c.70,000 jobs[6] in the UK in 2020, rising to over 200,000 by 2050 driven by exports as well as the domestic market. Jobs will be spread through the supply chain; 40% in installation and operations and maintenance, c.35% services, c.20% manufacturing and c.5% in R&D and engineering. By leveraging skills and the UK's position as a lead market, the UK could capture two thirds of domestic value chain revenues and 10% of the value chain in the rest of the world.

***Chart 3.2f** Net economic benefit to 2050 with and without displacement effects (high learning effects and market share, central energy prices)**



*Includes balancing, load factors and grid costs, assumes zero transmission reinforcement cost.
**Allows for the fact that labour and capital used in this LCT might otherwise have been productive in another part of the economy (see chapter 2 for further details).

Source: BCG, Carbon Trust analysis.

[5] Source: Jungingner and Faaij, 2004; Neuhoff and Coulomb, 2006; Lako, 2002; BCG analysis.
[6] Excluding displacement effects and including secondary service sector jobs (e.g. finance and legal).

To commercialise and deploy offshore wind power the UK needs to implement robustly its plans to increase public support and address regulatory issues

- We have identified the key actions required to successfully commercialise and deploy offshore wind, a number of which are in hand[7]:
  - Extend duration and scale of the incentive mechanism (Proposals in Renewable Energy Strategy and Budget '09).
  - Robustly implement plans to simplify process for grid connection and planning process (reviews in progress).
  - Invest additional public RD&D of £100m-600m to 2020.
  - Integrate 1-3 demonstration sites with development of RD&D/manufacturing cluster(s).
  - Make the most economic wind farm sites available without negatively impacting economic and environmental concerns.

Extend duration and scale of the incentive mechanism.

- Challenge: Under the current Renewable Obligation (RO), there is insufficient support to motivate developers to exploit the full potential of offshore wind power. Our analysis of the current support available indicates that only 10GW of offshore wind power would currently receive sufficient RO support (i.e. a further 2GW in round 3).
- Potential solution: Government has issued proposals in the Renewable Energy Strategy Consultation and in Budget 2009 to extend the lifetime of the RO and increase its level of support. These need to be rapidly implemented. To maximise efficiency, Government should adjust the level of support to allow for cost reduction and for electricity price changes.

Robustly implement plans to simplify the grid connection and planning processes.

- Challenge: The grid investment/connection and planning processes is not optimised for offshore wind power (and renewables in general). The current 'invest then connect' system for the grid leads to delays and associated risk for developers, restricting their willingness to invest. In addition there is a long and complex process to gain planning consent, currently taking up to 10 years from application to start of construction.
- Potential solution: With a new mechanism to share grid capacity, the core grid transmission network need not be reinforced, beyond existing plans, even with an additional 40GW of wind power. Avoiding grid upgrades in this way could save up to £2bn. The Government's Transmission Access Review proposes an appropriate sharing mechanism. Whilst additional reinforcement to the core grid transmission network to accommodate offshore wind can be avoided, around 150km of onshore grid connections will be required. The Infrastructure Planning Commission (IPC) and National Policy Statements (NPS) are essential to ensure that offshore wind farms and associated grid connections can be constructed by 2020. The Government will need to demonstrate strong leadership and stakeholder management for these to work effectively.

[7] Further details on the challenges facing offshore wind and the solutions outlined above can be found in Carbon Trust 'Offshore wind power: big challenge, big opportunity', 2008.

Invest additional public RD&D of £100m-600m to 2020.

- Challenge: Over the last three years wind turbine manufacturers, the key element of supply chain, have only invested in RD&D at the rate of 2-3% of sales, insufficient to drive learning rate improvement and cost reduction. While the majority of RD&D needs to be funded by private companies, significant publicly funded RD&D will be necessary where paybacks are too long for the market (e.g. early stage RD&D), where there is a risk of intellectual property rights leakage, or where the supply chain is served by small companies that might struggle with the investment risk. All these factors are present in offshore wind power.
- Potential solution: In light of the technology challenges facing offshore wind power, RD&D by the private sector needs to increase to 3-4% of sales with public sector support typically around 15-35%. As one of the lead markets, the UK should expect to be 20-30% of global RD&D, suggesting that UK public RD&D funding will need to increase to at least £0.1-0.6bn by 2020. This funding could be delivered through R&D grants and directed technology initiatives such as the Carbon Trust's Offshore Wind Accelerator.

Integrate 1-3 demonstration sites with development of RD&D/manufacturing cluster(s).

- Challenge: Unlike in Germany, there is no support mechanism or coordination in the UK that bridges the gap between small-scale demonstration and large-scale deployment and economic development.
- Potential solution: Integrate large-scale demonstration with efforts to develop a UK offshore wind power cluster. For example, in Germany, the Alpha Ventus test site is closely connected to an emerging offshore wind power cluster at Bremerhaven which includes port facilities, turbine and component manufacturers and R&D institutes.

Make the most economic wind farm sites available without negatively impacting economic and environmental concerns.

- Challenge: Offshore wind power costs vary considerably depending on the location; the best sites are windy, in shallow water and close to shore. However, a variety of constraints (e.g. shipping, fishing, etc.) limit the availability of the best sites, pushing developers to costlier locations such as the Dogger Bank.
- Potential solution: The Government urgently needs to provide leadership in negotiations across multiple Government departments and stakeholders.

The UK's stance should be to actively innovate/deploy and seek to exploit economic benefit by encouraging investment and service activity

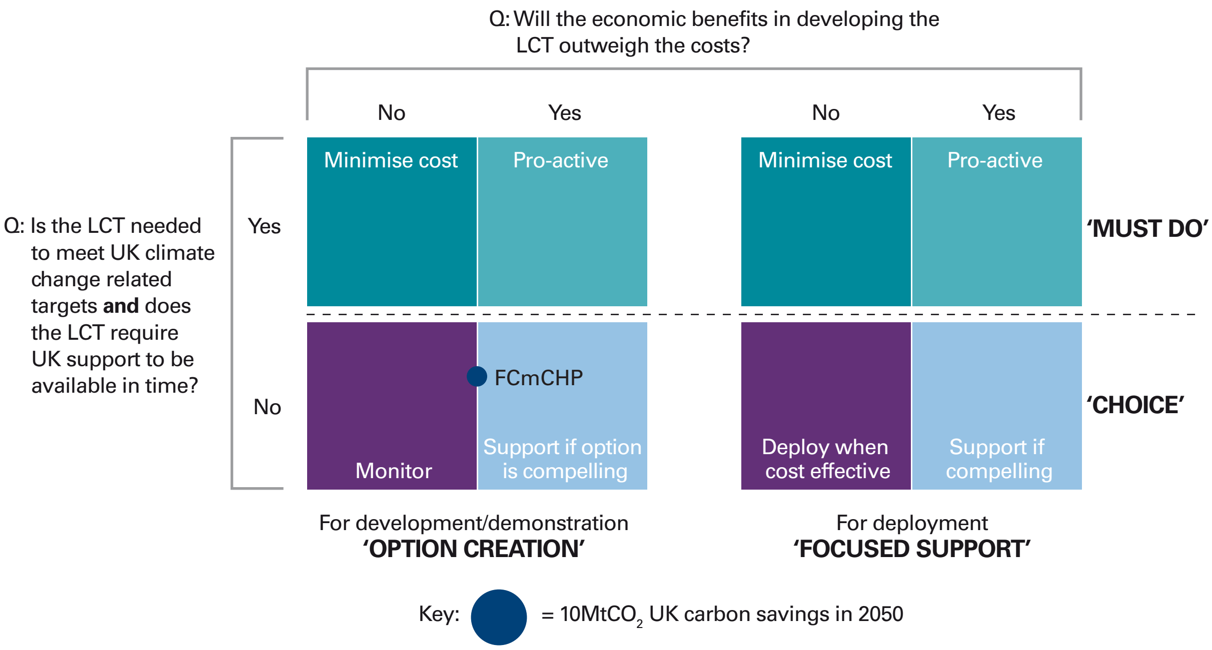
- In summary, offshore wind power is needed to achieve the UK's 2020 renewable and carbon targets and is unlikely to be ready in time without UK support as the UK is one of two leading markets. Despite potentially large deployment support costs, the UK may well generate net economic benefit by exploiting a large export market and attracting inward investment from turbine manufacturers to complement existing offshore skills, value chain position and services skills.
- The UK's stance should, therefore, be to actively innovate/deploy and seek to exploit economic benefit by encouraging investment and service activity.

3.3 Fuel cell micro combined heat and power (FCmCHP)

Conclusion: UK should support FCmCHP if it appears compelling when compared with other development/demonstration LCTs

- FCmCHP is at the demonstration stage, with at least four technology variants and a large number of devices.
- For climatic and building/heat system design reasons, UK deployment of FCmCHP may be lower than in other lead countries.
- UK carbon savings could be up to 3MtCO_2 if grid decarbonisation is slower than expected.
- The UK has significant capability, but is likely to be up against stiff international competition.
- FCmCHP is likely to become cost effective in the next decade in the commercial sector. In the domestic sector it is likely to be cost effective in the 2030s if electricity export prices are close to but not above the level which creates a perverse incentive to 'dump heat'.
- FCmCHP could generate net economic benefit of c.£2bn, however this is highly susceptible to displacement effects.
- In order to successfully commercialise FCmCHP, the UK needs to address regulatory and other barriers and put in place a plan/process for UK-specific field trials.
- UK stance should be to assess FCmCHP against other alternatives and provide support if it proves to be a compelling option from an economic perspective.

***Chart 3.3a** FCmCHP in the context of our framework*



Note: Economic benefit assessment includes displacement effects.
Source: Gastec at CRE, Carbon Trust.

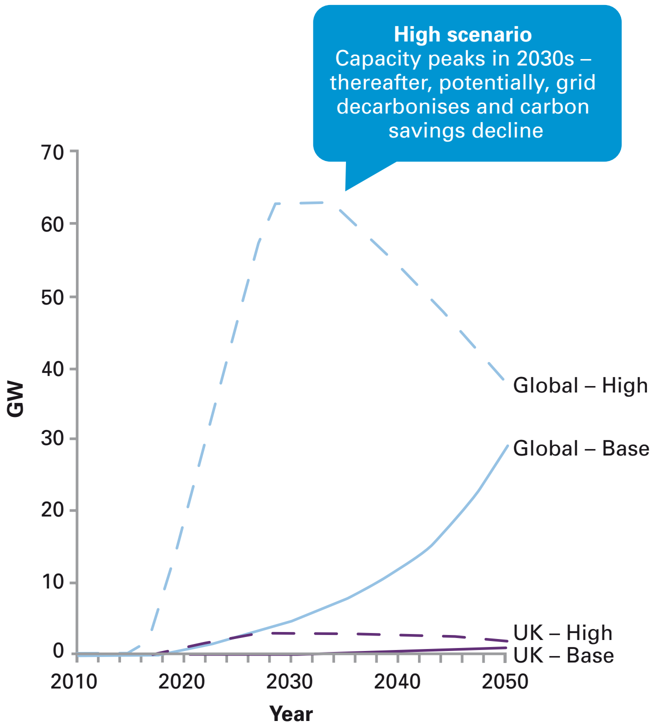
FCmCHP is at the demonstration stage, with at least four technology variants and a large number of devices

- Fuel cells are one of a number of technologies competing to power micro CHP devices. For example, micro CHP devices based on internal combustion have recently been made available commercially and other technologies, such as Stirling engines, are being commercialised.
- FCmCHP has at least four technology variants based on different fuel cell technologies including: low temperature Proton Exchange Membrane (PEM); high temperature PEM; medium temperature Solid Oxide Fuel Cell (SOFC); and high temperature SOFC.
- None of these is yet fully commercially proven, with initial sales occurring in Japan on a heavily subsidised basis.
- Each technology variant has a number of developers and devices. For example, there are at least ten SOFC-based FCmCHP developers worldwide, most operating with different devices.

For climatic and building/heating system design reasons, UK deployment of FCmCHP may be lower than in other lead countries

- Deployment in other lead countries such as Germany is expected to be significantly higher than in the UK, due to:
  - Colder climate than the UK which means that there are a greater number of degree days of heating and hence a higher level of FCmCHP utilisation leading to greater cost and carbon savings.
  - Fewer space limitations (e.g. multi-dwelling houses in Germany, often with cellars; use of outside space for installation in Japan).
  - More suitable heating patterns (e.g. more consistent, ‘unimodal’ heating patterns in German households as opposed to the ‘bimodal’ heating pattern in the UK).
  - Potentially, lower and falling penetration of hot water tanks in the UK (often used as heat storage in FCmCHP systems).
- FCmCHP is likely to face significant competition from heat pumps, internal combustion engine-based mCHP (for commercial applications), solar thermal water heating and, potentially, electric heating.
- Assuming strong incentives and support for FCmCHP, driven by a desire for rapid carbon savings prior to grid decarbonisation (see next section), deployment in the UK could peak at up to 3GW by 2030, while a more conservative base scenario shows steady growth to c.1GW by 2050 (see *Chart 3.3b*).
- Global deployment is expected to be up to c.60GW and so the UK is likely to be up to 3-5% of the global total.

***Chart 3.3b** Estimated global and UK installed FCmCHP capacity to 2050 – high and base scenarios*



Source: Gastec at CRE.

UK carbon savings could be up to 3MtCO_2 if grid decarbonisation is slower than expected

- FCmCHP systems are expected to save a considerable amount of carbon per premise in which they are installed[8] when using the current Defra figure for the carbon intensity of the electricity they displace (for long-term projects this is 0.43kgCO_2/kWh). For example, in a typical household, a FCmCHP system will save about 1tCO_2/year (or a 20% saving) and a typical commercial installation of 5kWe will save just under 6tCO_2/year (or a 24% saving) (see *Chart 3.3c*).
- Using the Defra emission factor of 0.43kgCO_2/kWh, FCmCHP could save up to c.3MtCO_2 by 2030 in our high deployment scenario and up to 1MtCO_2 by 2050 in our base scenario. This rises to c.5MtCO_2 and 2MtCO_2 respectively using a grid factor of 0.568kgCO_2/kWh, as used in building regulations procedures (SAP 2005).
- However, carbon savings are very sensitive to the carbon intensity of displaced electricity (see *Chart 3.3d*). As the carbon intensity of displaced electricity nears 0.2kgCO_2/kWh, FCmCHP carbon savings approach zero and below this level turn negative (i.e. FCmCHP increases carbon emissions). The exact breakeven point depends on the application and the efficiency of the fuel cell system.
- Projections from the Committee on Climate Change (CCC) indicate that this level of grid carbon intensity could be reached as early as 2025 if the UK is on track to reduce overall emissions by 80% by 2050 – too early for FCmCHP to make meaningful carbon savings.
- However, the CCC projections imply considerable decarbonisation and are not without risk. FCmCHP, therefore, provides a way of generating carbon savings in case the grid does not decarbonise.

The UK has significant capability, but is likely to be up against stiff international competition

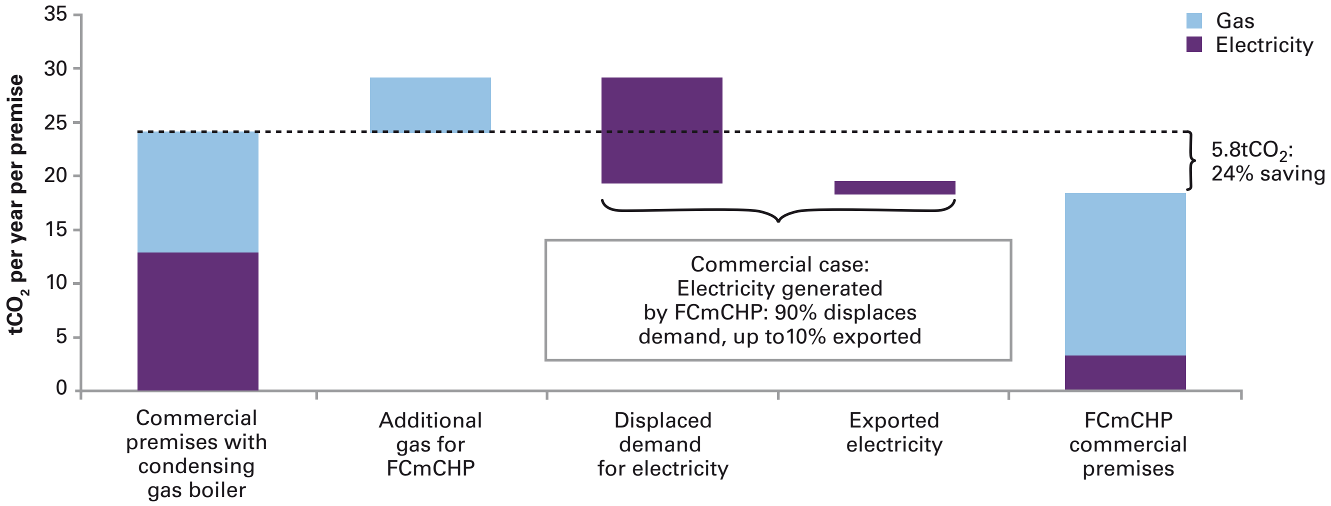
- The UK has two key FCmCHP developers, both of whom are well funded independent fuel cells companies with strong development links to UK utilities. Both SOFC and PEM technology variants are being developed in the UK.
- The UK has other strengths, both in the science base, where the UK is among the world leaders for fuel cell research, and in the supply chain where, for example, the UK is a leader in a key component for PEM fuel cells (membrane electrode assemblies).
- However, UK-based companies are up against stiff competition from abroad, where there are a greater number of developers who are often part of international engineering groups from which they can draw expertise and capital and, in some cases, whose home markets are better suited to mCHP.
  - In Japan, there are at least seven developers of FCmCHP, all of which are parts of major international groups (e.g. Toshiba, Sanyo and Kyocera).
  - In the rest of Europe, there are at least 10 other developers, of which seven are parts of major boiler or other manufacturing groups (e.g. Vaillant).
  - Developers in other countries are reportedly considering entering the market (e.g. China, Korea, India).
- Market entry barriers exist on a national basis as FCmCHP systems need to be adapted to local conditions (e.g. heating systems, power conditioning, etc.).

FCmCHP is likely to become cost effective in the next decade in the commercial sector. In the domestic sector it is likely to be cost effective in the 2030s if electricity export prices are close to, but not above, the maximum to avoid heat dumping

- Using our central assumptions of learning rates, energy prices and deployment, and valuing electricity exports at wholesale prices, FCmCHP is likely to be attractive for commercial application late in the next decade (assuming no financial subsidies) or early the following decade (see *Chart 3.3e*).
- Domestic systems could become cost effective with no subsidies around mid to late 2030s if the price received for electricity exported to the grid is close to the highest that can be paid without giving the owner of the system an incentive to generate power without using the heat (known as 'heat dumping'). 'Heat dumping' involves, for example, overheating a house with open windows, and of course means that FCmCHP would increase carbon emissions.
- Commercial application is more cost effective as there are scale economies in producing, installing and maintaining a 5kWe system (a 1kWe system is used in domestic application). In addition, 90% of electricity generated is used on the premises, displacing more expensive retail priced power (25% of electricity generated is typically used in-house in domestic applications).
- Depending on the level of public support, FCmCHP will become financially viable earlier than the point at which it becomes cost effective from a national perspective.

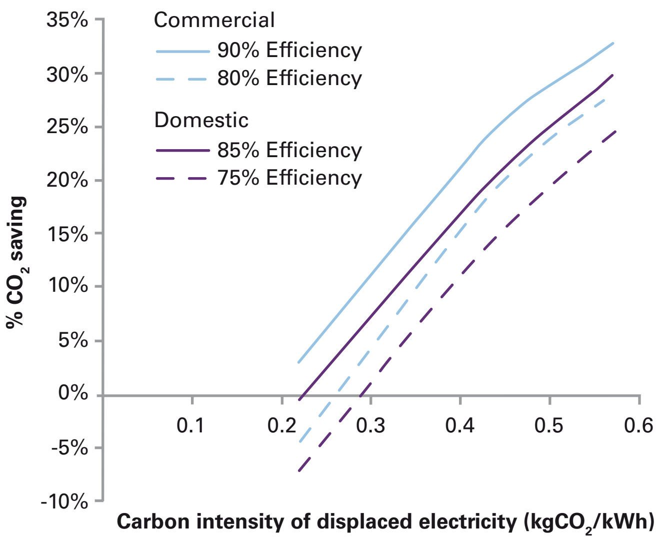
[8] Compared with using electricity from the grid and a condensing boiler for heating and domestic hot water.

Chart 3.3c *Maximum FCmCHP net carbon emissions for small commercial premises**
(5kW capacity)



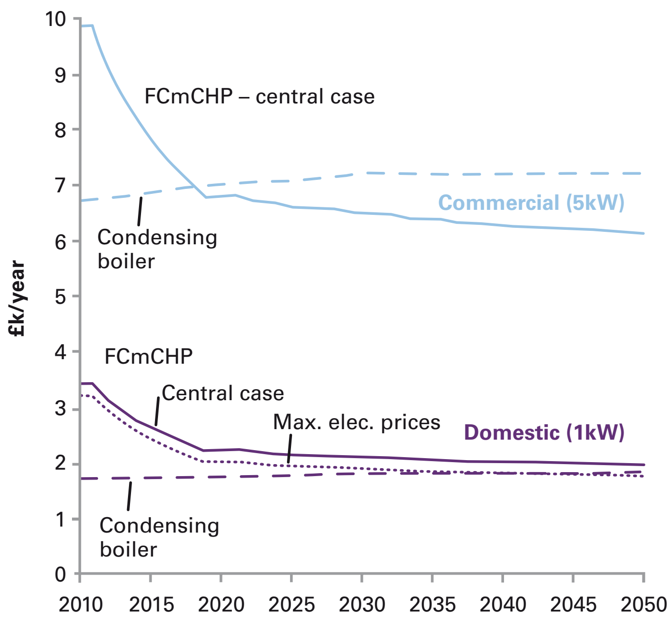
*Assumes 5,000 hr/yr of operation and a 1:1 heat:power ratio and overall efficiency of 90%.
Source: Gastec at CRE.

Chart 3.3d *CO_2 saving from FCmCHP with varying efficiency and grid electricity carbon intensity**



*Assumes 5,000 hr/year of operation and 1:1 heat to power ratio.
Source: Gastec at CRE.

Chart 3.3e *FCmCHP and condensing boiler: annualised capital and operating costs**

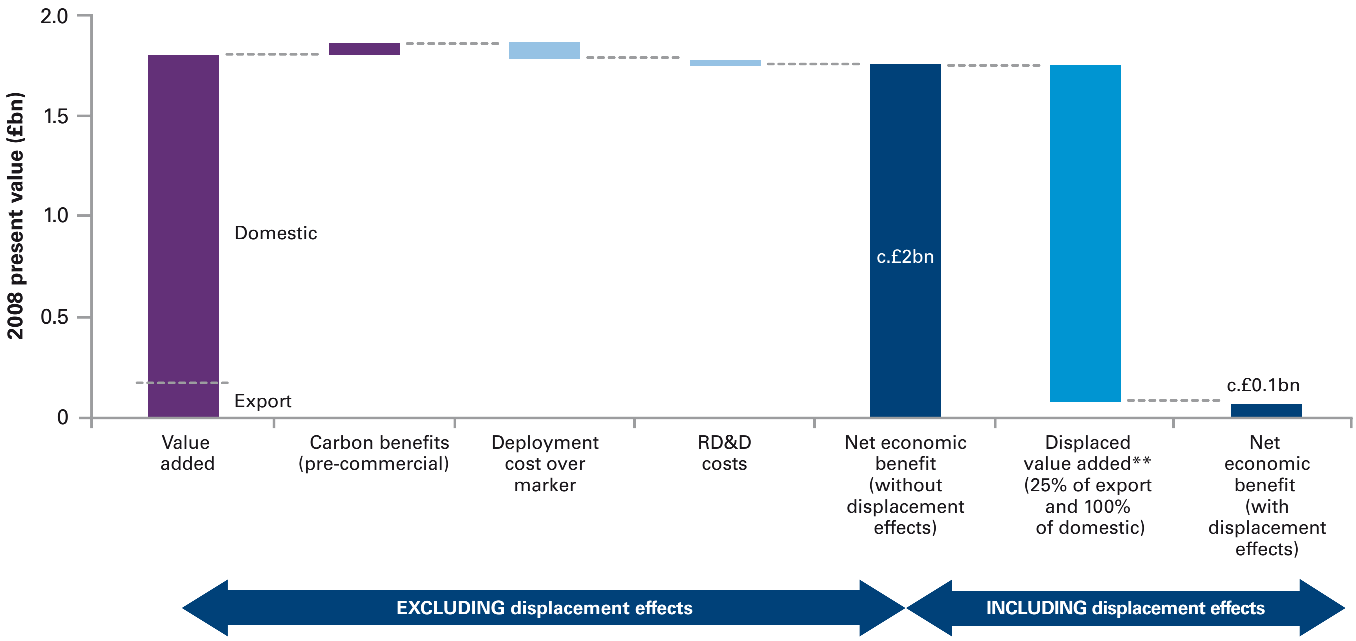


*Assumes 5,000 hr/year of operation and 1:1 heat to power ratio, mid learning and base deployment scenario.
Source: Gastec at CRE.

FCmCHP could generate net economic benefit of c.£2bn, however this is highly susceptible to displacement effects

- *Chart 3.3f* shows that, under base case conditions, FCmCHP generates about £2bn of economic benefit before displacements effect. As much of this benefit is generated by value added from domestic sales, then the net economic benefit falls to c.£0.1bn after displacement effects. It is noticeable that the costs for the UK in RD&D and deployment are relatively modest.
- If the UK achieves higher market shares then the net economic benefit, including displacement effects, could rise to c.£0.2bn. If deployment is high in the UK and globally then the net economic benefit, including displacement effects, drops to a net cost of £0.2bn, as the increase in deployment is mainly in the domestic sector which is less cost effective.
- In FCmCHP, we expect UK-based companies to be able to achieve a significant market share of product sales in the UK (15% to 30%). However, we expect the share of markets in the rest of the world to be much lower (2% to 5%). This is because:
  - The heating product market is quite local as the requirements in, say, Germany, are quite different from those in the UK.
  - The key early markets, Japan and Germany, have a large number of developers, some of whom are parts of heating products or major engineering groups who have both market reach and development capability.
  - There is expected to be a flow of manufacturing work to lower cost countries within a region, once the FCmCHP market is established.
- On the other hand, UK-based companies are expected to retain 100% share of installation and maintenance as these are locally delivered services, but will not gain any export share.

Chart 3.3f *Economic benefit to 2050 with and without displacement effects at mid learning, base deployment and value added, central energy prices**



*Combines both commercial and domestic segments and assumes low R&D spend.
**Allows for the fact that labour and capital used in this LCT might otherwise have been productive in another part of the economy (see *chapter 2* for further details).

Sources: Gastec at CRE, Carbon Trust.

In order to successfully commercialise FCmCHP, the UK needs to address regulatory and other barriers and put in place a plan/process for UK specific field trials

Address regulatory barriers mainly related to building regulations

- Challenge: Building Regulations were set when mCHP was not commercially available and so they either do not take mCHP into account, or do so via new, complex and largely untested procedures. For non-domestic buildings, Part L of the current Building Regulations does not appear to reward buildings for the use of FCmCHP. Therefore, at present, the only way to install FCmCHP is either to obtain expert advice to interpret regulations for FCmCHP or to consult a Building Control Officer on a local authority by local authority basis. Where procedures do exist (i.e. for domestic dwellings) they are complex, with limited sources of support for developers.
- Potential solution: Revise Building Regulation procedures to take account of mCHP systems. For non-domestic buildings this is likely to involve revisions to the SBEM model. For domestic building, sponsorship from an authoritative body to establish a template for new procedures is necessary.

Address challenges to microgeneration

- Challenge: Currently, there are a number of challenges which are common to a number of microgeneration technologies such as FCmCHP. These include metering and the lack of clarity on electricity export pricing and obligations such as CERT (e.g. its status after 2011).
- Potential solution: Government has recognised the need to address these issues for mCHP and other forms of microgeneration. Government has put forward proposals (e.g. specifically on metering and more broadly on feed-in tariffs) which need robust implementation.

Lack of plan/process for 'UK-specific' trials ahead of deployment

- Challenge: In order to achieve successful deployment of FCmCHP, UK pre-deployment trials will be required. At present, a 'roadmap' for this has not been specified. The specific characteristics of the UK heating market require UK-specific trials to be conducted before deployment in addition to those completed in other countries. Despite the lack of public sector funding for a field trial, this has not been highlighted as a barrier by developers.
- Potential solution: Develop and deliver a process for field testing of FCmCHP; funding is expected to come largely from developers.

UK stance should be to assess FCmCHP against other alternatives and only provide support if it proves to be a compelling option

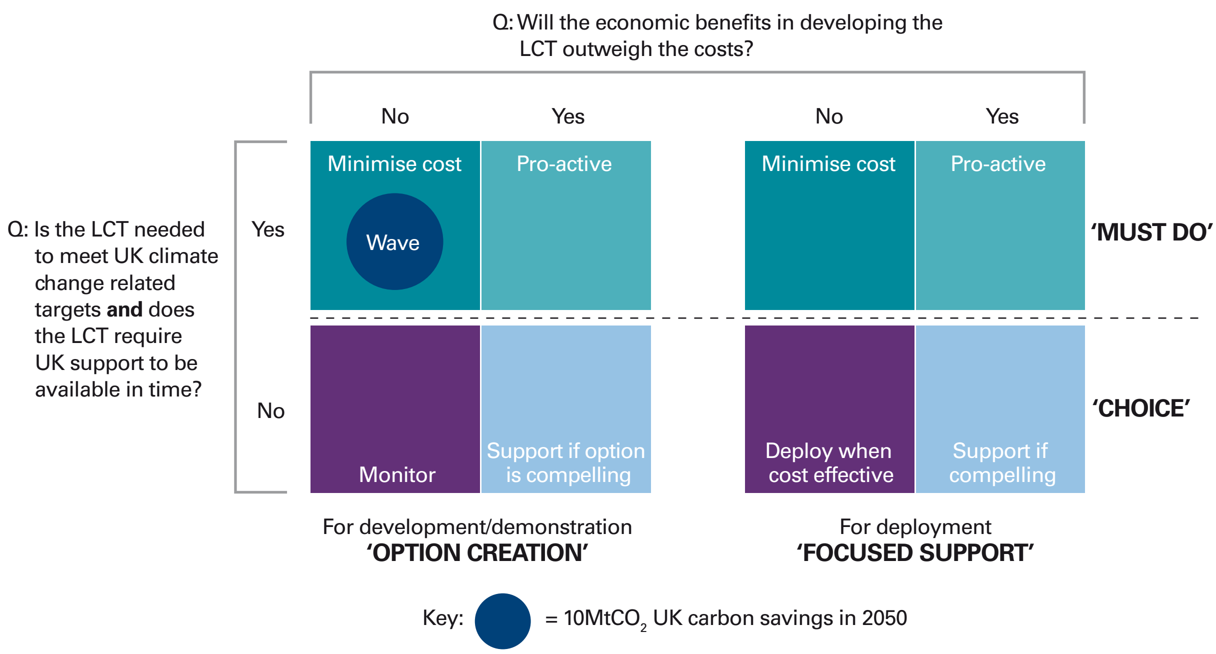
- From our analysis we conclude that FCmCHP:
  - Is in the demonstration stage.
  - Generates net economic benefit (including displacement effects) of c.£0.1bn in our central case.
  - Has the potential to save up to c.3MtCO_2, although this potential would only be realised if grid decarbonisation is substantially delayed.
  - Is unlikely to need UK support to be commercialised, although some UK-specific development work (e.g. field trials) will be required.
- Our framework therefore suggests that the UK's approach should be to assess this technology against other alternatives and provide support if it proves to be a compelling option from an economic perspective.

3.4 Wave power

Conclusion: The UK should pursue this technology option focusing on early demonstration and improving cost effectiveness

- There are a large number of device types currently in development which makes determining and supporting the most effective emerging devices difficult.
- The UK has a large wave resource and is expected to have a significant portion of global deployed wave capacity – wave power is likely to be an important source of carbon reduction for the UK in the longer term and is likely to be vital for meeting 2050 targets.
- The UK has significant capabilities in the wave industry compared to the rest of the world and along with its significant wave resources could therefore become the 'natural owner' and lead the commercialisation process for the rest of the world.
- While the UK has a significant competitive advantage, the costs of innovating wave power may still outweigh the benefits due to the long timescales and high costs involved – a technology breakthrough could significantly reduce these costs and create net economic benefit.
- In order to commercialise wave power, the UK needs to focus on addressing funding gaps and improving the system for gaining planning permission and permits, particularly with regard to environmental permits.
- As wave power is required to meet targets, the key action for the UK therefore is to minimise costs through cost effective innovation support – and particularly to drive a technology breakthrough which could reduce the deployment costs significantly.

***Chart 3.4a** Wave power in the context of our framework*



Note: Economic benefit assessment includes displacement effects.

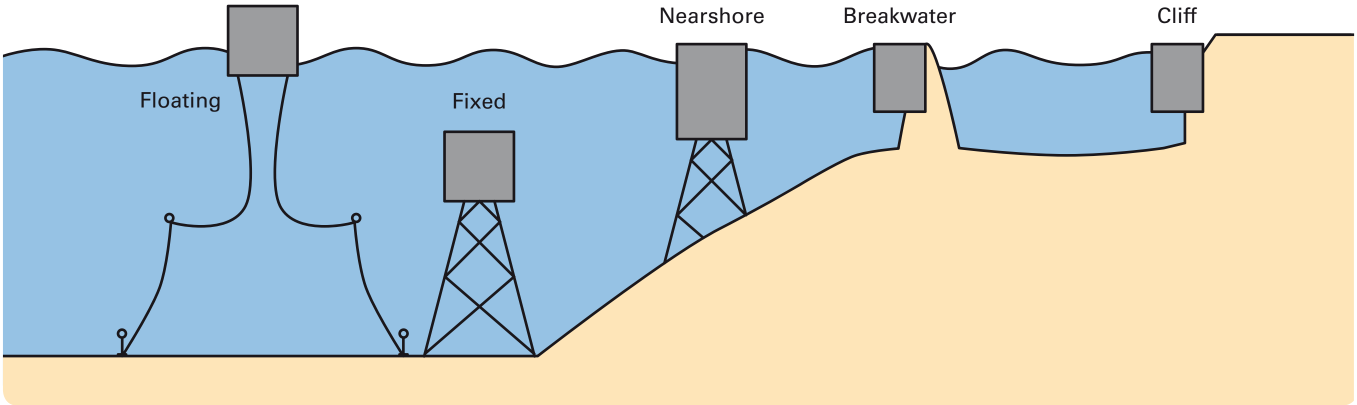
Source: Black & Veatch and Entec, LEK, Carbon Trust.

There are a large number of device types currently in development which makes determining and supporting the most effective emerging devices difficult

- The nature of wave energy will mean that different technology variants will be applicable in different deployment locations (see *Chart 3.4b*). By the end of 2008, there were about 76 wave devices under development, the majority of which were still in the early stages of technology development.
- The devices in development in the UK generally rely on five main technology principles: oscillating wave surge converter, attenuator, overtopping device, oscillating water column and point absorber (although some devices also involve a combination of these different types).
- No single preferred technology type has emerged as yet and hence wave is classified in our technology framework as being in development/demonstration.
- Given the wide range of device types in development combined with the number of different deployment locations/resource types, determining and supporting the most effective emerging devices will be difficult.

Chart 3.4b *Range of deployment locations and technology types for wave devices*

Main location types



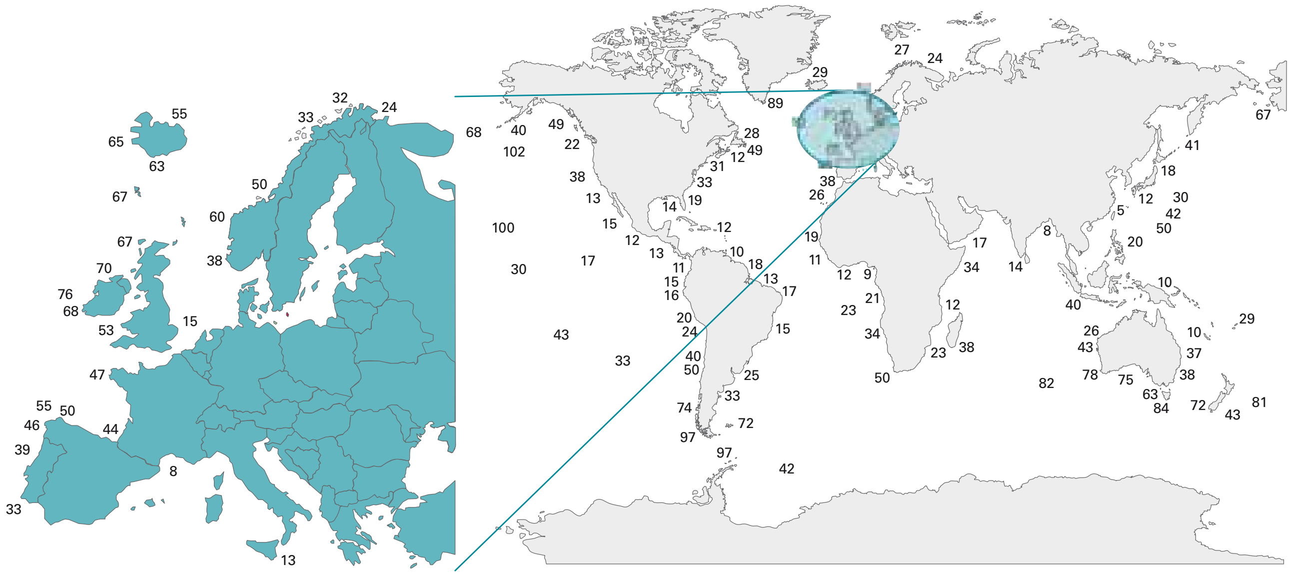
Main technology principles in the UK	Description
Oscillating wave surge converter	Extracts energy caused by wave surges and the movement of water particles – arm oscillates as a pendulum mounted on a pivoted joint
Attenuator	Sits perpendicular to wave direction and rides the waves – selectively constrains movement along its length to produce energy
Overtopping device	Captures water from waves and holds them in a reservoir above sea level which is returned to sea through a conventional low-head turbine
Oscillating water column	Waves cause an enclosed column of water to rise and fall which causes it to compress and decompress a trapped air column which flows to and from the atmosphere via a dual direction turbine
Point absorber	Absorbs energy in all directions through movements at/near the water surface

Source: EMEC, Black & Veatch and Entec.

The UK has a large wave resource and is expected to have a significant portion of global deployed wave capacity – wave power is likely to be an important source of carbon reduction for the UK in the longer term and is likely to be vital for meeting 2050 targets

- The UK has a large potential wave resource. The practical wave energy resource based on current technology types has been estimated at 50TWh/year (about one seventh of current UK electricity consumption). In total this amounts to around 50% of Europe's resource[9]. *Chart 3.4c* shows the global distribution of wave resources and highlights the UK as a key area.
- The deployment scenarios developed for this study are shown in *Chart 3.4d*. The 'mid case'[10] shows the UK with around 25% of total global installed capacity by 2050. This assumes 26GW of installed capacity in the UK by 2050 and global capacity of ~110GW over the same time period. These scenarios also highlight the long term nature of this technology as global capacity does not reach 10GW until around 2030. However, in each scenario the UK is expected to have a significant proportion of global deployed capacity.
- Under the mid case scenario, wave power is likely to be a vital source of carbon reduction for the UK, particularly in the long term, contributing around 30 $MtCO_2$ per annum by 2050.

Chart 3.4c *Average annual wave power in kilowatts per metre of crest width for various sites around the world*



Data source: Ocean Power Delivery.

[9] Source: Scottish Enterprise, 'Marine Renewable (Wave and Tidal) Opportunity Review', 2005.

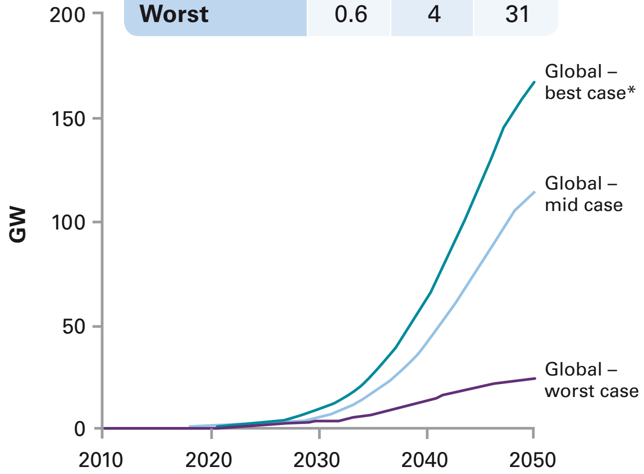
[10] The 'mid case' is our technical consultant's realistic view and takes into account some constraints around availability of financing, site availability, planning delays and grid capacity constraints.

The UK has significant capabilities in the wave industry compared to the rest of the world and along with its significant wave power resources could therefore become the 'natural owner' and lead the commercialisation process for the rest of the world

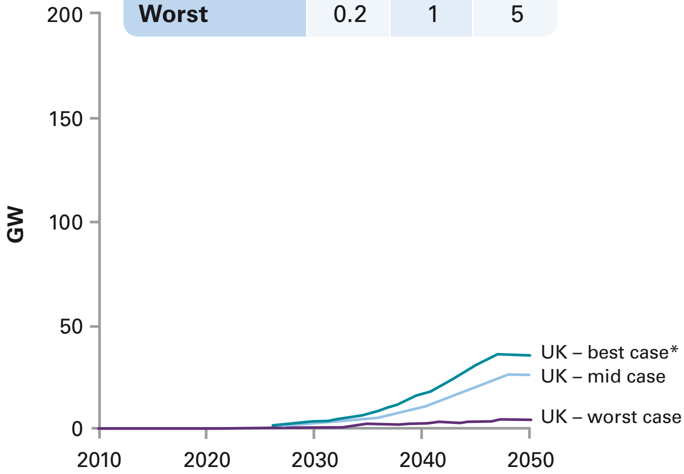
- The high potential wave resource base and high oil prices in the 1970s and early 1980s led to significant investment in the UK's wave industry. Government-led research (through both universities and Government institutions) helped establish the industry in the UK.
- Today, UK universities are a key area for innovation. Historically they have been central to innovation in the marine industry having developed some of the earliest wave technologies.
- The UK has the by far the highest number of dedicated research facilities (24), with the USA, Portugal and Ireland also well represented. It also has two dedicated test facilities, NaREC and EMEC, with 'Wavehub', a new demonstration facility in the South West, planned for 2010.
- The technology development landscape is characterised by small innovative technology development companies generally working in isolation.
- Many of the leading device developers originated in the UK (~17) and they presently enjoy a comparative advantage due to extensive domestic knowledge and experience – this places the UK in a strong position to design and develop wave energy devices.
- A quarter of the world's wave technologies are being developed to some extent in the UK. The USA has the next highest share with 16%. All the other countries developing devices have less than an 8% share.

***Chart 3.4d** Estimated installed capacity and carbon savings to 2050*

Global $MtCO_2$	2020	2030	2050
Best	1.3	13	215
Mid	0.9	9	139
Worst	0.6	4	31



UK $MtCO_2$	2020	2030	2050
Best	0.3	3	43
Mid	0.2	2	30
Worst	0.2	1	5



*Assumes grid capacity issues are resolved, in addition to an adequate supply of development and deployment funding.
Source: Black & Veatch and Entec.

- *Chart 3.4e* summarises the UK's strengths across the wave supply chain. The UK is likely to develop a good market share of the global wave industry, and this will generate significant value added to the UK economy. The majority of the resource is in Scotland, which has a strong manufacturing industry. Other more specific examples of factors which support the UK's ability to gain a high market share include:
  - as the device body is a relatively large and empty vessel, such a structure is likely to be built in close proximity to the assembly and deployment point which would suggest a large share of the domestic market;
  - there are examples of UK manufacturing success in industries relevant to the wave industry, including oil & gas and shipping;
  - the UK's offshore experience from maintaining oil and gas facilities in the North Sea is valuable for wave device operations and maintenance which would also suggest a large domestic share; and
  - the UK has engineering and manufacture expertise in the complex systems required for the power take off system which are high value and can be exported globally.

***Chart 3.4e** Summary of UK supply chain strengths*

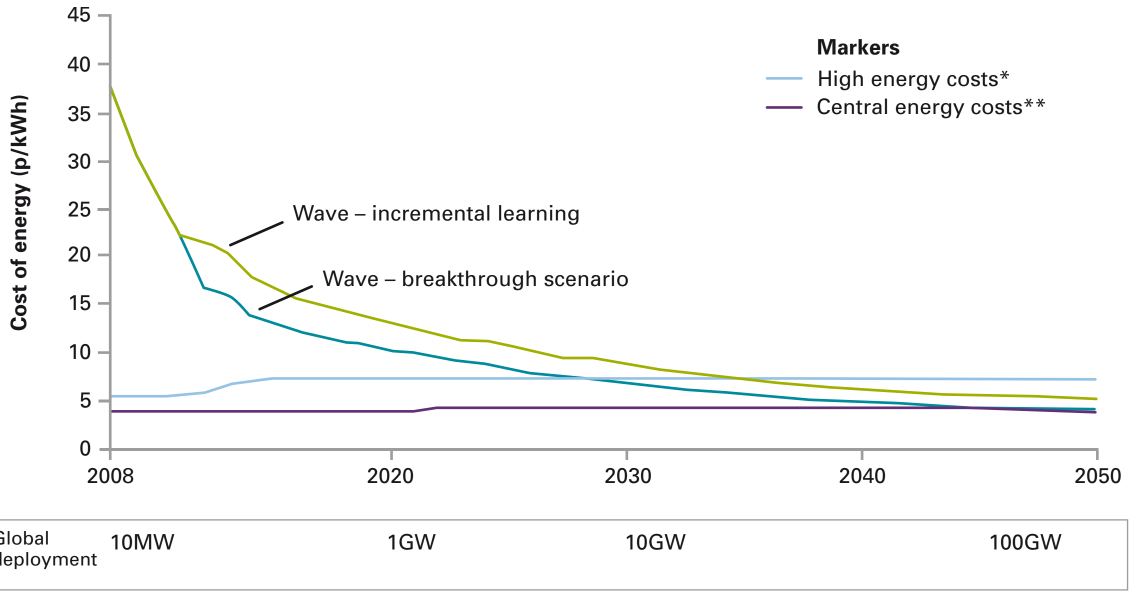
Market	**Estimated UK market shares (% 2020→% 2050)**				
	Research and development	Engineering and design	Manufacturing	Installation	Operations and maintenance (O&M)
Domestic	88%→50%	97%→85%	90%→70%	96%→60%	85%→65%
Export	32%→20%	26%→13%	29%→9%	17%→5%	10%→5%
UK ability to capture share	• Academically the EPSRC identifies the SUPERGEN consortium (of five UK universities) as a key area of strength • A further 19 universities also have a research focus on marine technologies • UK also has two dedicated test facilities for new devices – NaREC and EMEC	• Many of the leading device developers are from the UK and they presently enjoy a comparative advantage due to the extensive domestic knowledge and experience • Carbon Trust's Marine Energy Accelerator is helping develop key component technologies and the supply chain in areas that should lead to cost reductions • This places the UK in a strong position to design and develop wave energy devices	• Large/empty device body vessel is likely to be built close to assembly and deployment point • UK has had other similar successes e.g. oil & gas and shipping • Resource is in Scotland, which has a strong manufacturing industry • UK has expertise in complex power take off systems • Unlikely to produce mass components like control systems and moorings	• Legacy of shipping industry provides considerable dry dock facilities across UK • Existing offshore operators need to invest in growing their fleets, or new companies need to emerge • Crane barges and heavy lift barges may be required for some devices and will be subject to high demand (offshore wind and oil & gas) • Tugs/barges less subject to these issues	• The UK's offshore experience from maintaining oil and gas facilities in the North Sea is valuable for wave device O&M • Need for local port access will be dependent on device • Some will require 'on-site' O&M and therefore limited to small vessel launching for access to the device • Off-site O&M will need port access throughout life • Will compete with offshore wind

Source: Black & Veatch and Entec.

While the UK has a significant competitive advantage, the costs of innovating wave may still outweigh the benefits due to the long timescales and high costs involved – a technology breakthrough could significantly reduce these costs and create net economic benefit

- Our analysis (set out in *Chart 3.4f*) shows that wave power does not commercialise before 2050 under the incremental learning scenario at central forecast energy costs. The deployment costs, the area under the learning curve (net of the marker price costs for gas CCGT), are significant at £10bn (in net present value terms). This is mainly due to the high initial cost and the relatively slow rate of deployment which means that learning effects take a long time to bring down the price to be cost competitive with the marker price. Some form of deployment support will therefore be required throughout this period in order to ensure that projects are commercially viable to developers. For example, 2 ROCs makes wave power commercially viable by the early 2020s and higher multiples could bring this date further forward (e.g. Scottish Executive is consulting on providing 5 ROCs).
- *Chart 3.4f* also illustrates the potential difference which technology breakthroughs could make. Based on an additional investment over the next few years of around £100m, technology breakthroughs could be found leading to a step change in costs and a different learning curve with deployment costs reduced to ~£6bn or less depending on the level of breakthrough achieved. Such technology breakthroughs could come either in the device itself or in a combination of enabling technologies such as moorings or power take off systems. *Chart 3.4g* highlights the importance of this £4bn cost reduction in terms of the net economic benefit assessment.
- The UK has potential for competitive advantage and can expect to capture high market share of both the domestic and global market. But the value added to national income out to 2050 is less than it might be because:
  - the market only reaches peak deployment rates at the end of the 2040s and so the values are heavily discounted; and
  - the global export market potential is smaller than some other technologies (e.g. about 10% of the size of offshore wind).

***Chart 3.4f** Global cost evolution of wave energy – mid deployment case*



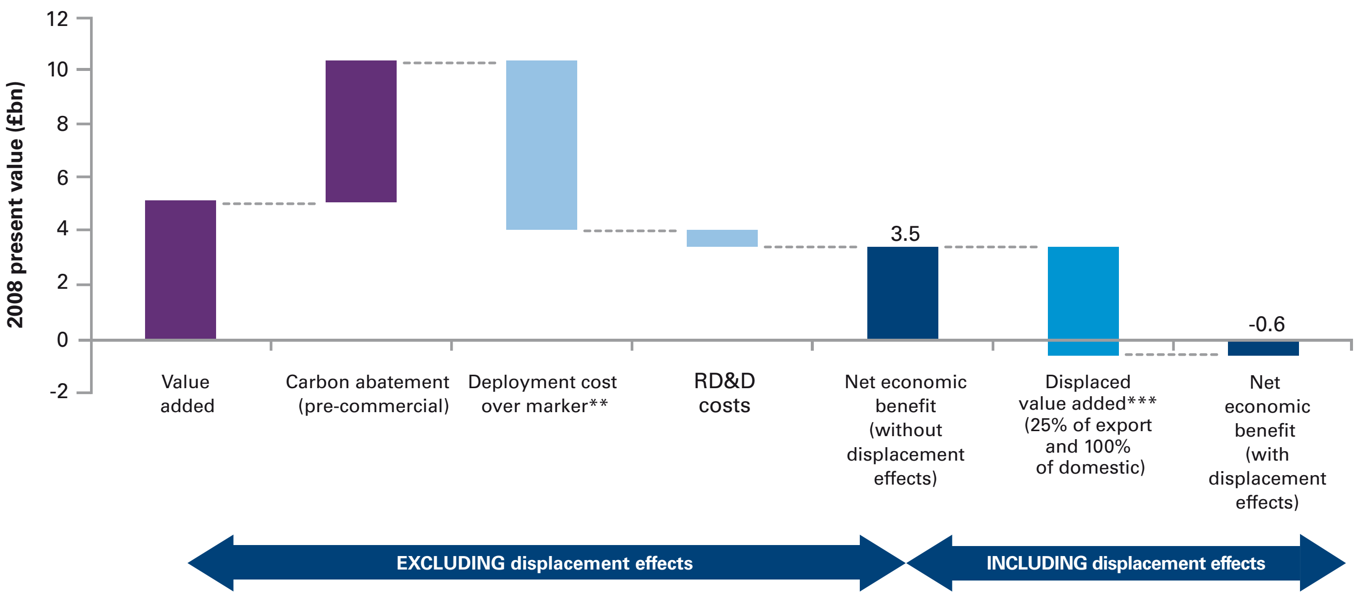
*CCGT generation starting at 5.4p/kWh in 2010 rising to 7.1p/kWh in 2030 for BERR high-high case.
**CCGT generation starting at 3.92p/kWh in 2008 and rising to 4.2p/kWh in 2030 (extrapolated to 4.48p/kWh in 2050) for BERR central case.

N.B. Based on starting cost from the Marine Energy Challenge. The Marine Energy Accelerator will update cost figures both for current costs and the scope for cost reductions and accelerated learning effects.

Source: Black & Veatch and Entec.

- *Chart 3.4g* shows the potential value added to be around £5bn in present value terms. Adding the benefit derived from carbon and netting off the costs of RD&D and deployment results in a gross economic benefit excluding displacement effects of £3.5bn in our basic breakthrough scenario.
- However, as over 70% of the value added is derived from the domestic market and is subject to potential displacement effects (see Chapter 2) wave shows an overall net economic cost of £0.6bn after displacement effects are taken into account. Nevertheless, a number of jobs will have been created with total UK wave jobs peaking in the 2040s at c.16,000 with about 25% of them supporting UK exports.
- This analysis highlights the critical importance of cost reduction and demonstrates the potential benefits of driving innovation as soon as possible by funding technology development in order to drive a significant step change in costs. Further analysis shows that if the technology breakthroughs could generate an additional 10% step change in cost of wave power then the economic benefit becomes positive (c.£0.7bn).

***Chart 3.4g** Net economic benefit of wave energy in the UK to 2050**



*Breakthrough scenario, high UK market share, central deployment and central energy prices; N.B. further cost reduction of ~10% could lead to positive economic benefit.
**Includes balancing, load factors and grid costs; assumes zero transmission reinforcement cost.
***Allows for the fact that labour and capital used in this LCT might otherwise have been productive in another part of the economy (see chapter 2 for further details).

Source: Black & Veatch and Entec, Carbon Trust.

In order to commercialise wave power, the UK needs to focus on addressing funding gaps and improving the system for gaining planning permission and permits, particularly with regard to environmental permits

Funding gaps

- Challenge: Analysis of the investment needed to get: wave power through the early deployment stage shows that there are significant funding gaps in the innovation landscape (which is shown diagrammatically in *Chart 3.4h*). These gaps would need to be filled by a mixture of private investment and funding support. *Chart 3.4i* attempts to quantify the gaps as follows:
  - Development and demonstration stage – Since the BERR Technology Programme is no longer a source of funding, there appears to be a funding gap of ~£90m at the development and demonstration stage (marked 'A' in *Chart 3.4i*) although the ETI is likely to have an impact in the demonstration stage. These stages are important for finding the step change technology breakthroughs which would make wave generation technology more cost effective more quickly.
  - Early deployment stage – Analysis also reveals a lack of overall funding to get wave power through the early deployment stage. This includes ~£450m over and above the funding available through the Marine Renewables Deployment Fund (MRDF) (marked 'B' in *Chart 3.4i*) and a further gap of ~£0.8bn post MRDF (marked 'C' in *Chart 3.4i*) based on ongoing deployment support of 2 ROCs.

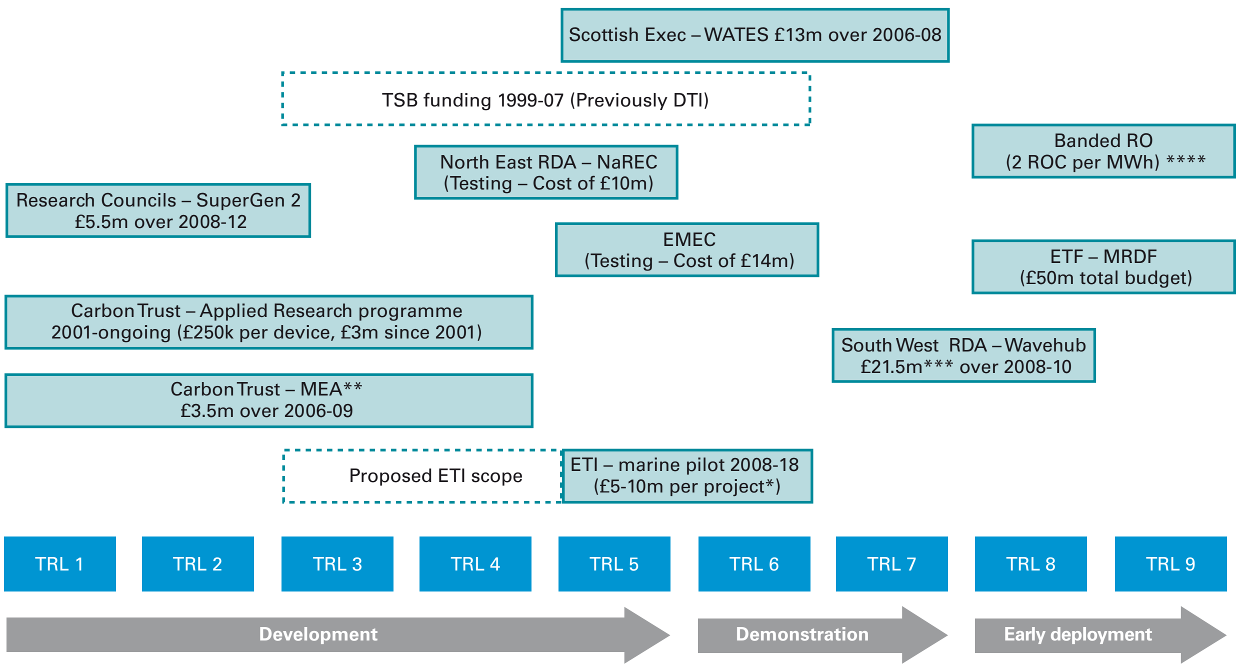
  Whilst to date the private sector has shown a willingness to invest in wave power, overall the current support levels appear insufficient to incentivise device operators to continue to invest in wave technology given the scale of these gaps. This may therefore jeopardise the likelihood that wave will make it to large-scale deployment. The size of the prize may also be significantly reduced by the probability that the device will not be successful and possible knowledge spillover effects (see Chapter 4 for further details on these effects).

- Potential solutions:
  - Restructure the present funding arrangements to provide a continuous path for developers, filling the highlighted funding gaps. A public body currently active in the wave innovation programme should assume a position that aims to coordinate device development from R&D to demonstration with an appropriate scale of funding.
  - Requirement for a gating process inserted into the selection process to ensure devices that may potentially lead to a step change are supported and to maximise the effectiveness of support.
  - Provision of a portion of the prize closer in time for developers. Options may include higher ROC banding (e.g. 5 ROCs proposed in Scotland), a feed-in tariff, an intermediate prize, or inclusion in a Government sponsored demonstration scheme. Funding should only be released over time and subject to clear success criteria.

Planning, permitting and grid

- Challenge: There is no UK-wide coordinating body to help facilitate the planning and permitting process for testing and demonstration sites, distracting developers from their core role of developing the technology. Developers have to spend a considerable portion of their efforts on environmental permitting, which is prolonged and expensive as the technology is new to regulators. After 2020 grid capacity constraints are expected to be a significant limiting effect on the deployment of offshore energy devices. Some of the grid issues facing wave are different to offshore wind – the lack of transmission capacity between Scotland and England is more of an acute issue due to the resource location and there is less clarity over priority sites. However, Carbon Trust's offshore wind study recommends how changes to planning and Government approach will tackle UK grid challenges for renewable energy generation.
- Potential solutions:
  - A 'one stop shop' planning process could replace the existing lengthy, expensive and confusing planning process. It could also feed into and help coordinate longer term grid upgrade planning.
  - The UK should follow Scotland's lead in undertaking a UK-wide Strategic Environmental Assessment, allowing future planning around potential sites to be undertaken.

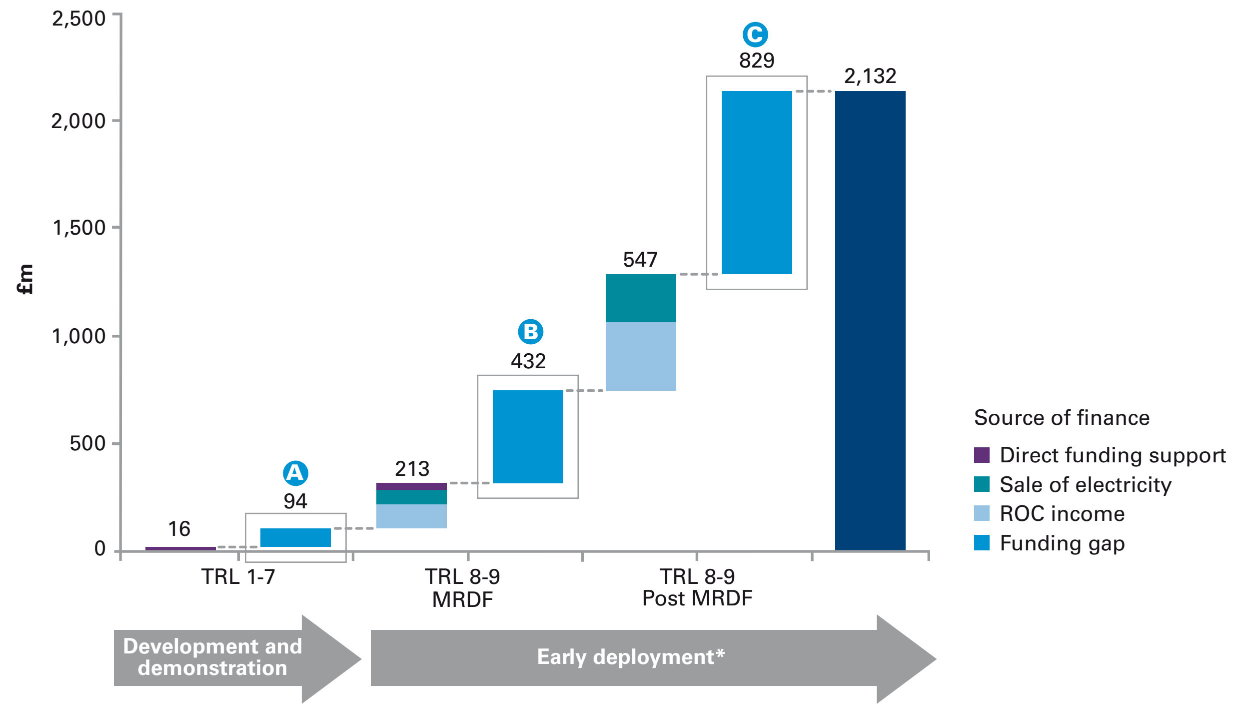
***Chart 3.4h** Funding for wave device development*



*Total ETI funding is £1bn over 10 years, which will cover a wide range of LCTs and only some will cover wave.
**Marine Energy Accelerator.
***c.50% is expected to come from the European Regional Development Fund.
****5 ROCs consultation (in Scottish waters where operator not in receipt of Scottish or UK Government grant).

Source: Black & Veatch and Entec, LEK analysis.

***Chart 3.4i** Cumulative support required in UK to reach early deployment**



*Investment analysis assumes process of selection which starts with 21 devices in the development phase, 13 of which make it to the demonstration phase, then 11 devices enter MRDF (at 10MW scale) operating for five years of which nine devices go on to operate post-MRDF (at 20MW scale) for a further 10 years – giving total operating capacity at this stage of 180MW.

Source: Black & Veatch and Entec.

As wave power is required to meet targets, the key action for the UK therefore is to minimise costs through cost effective innovation support – and particularly to find technology breakthroughs which could reduce the deployment costs significantly

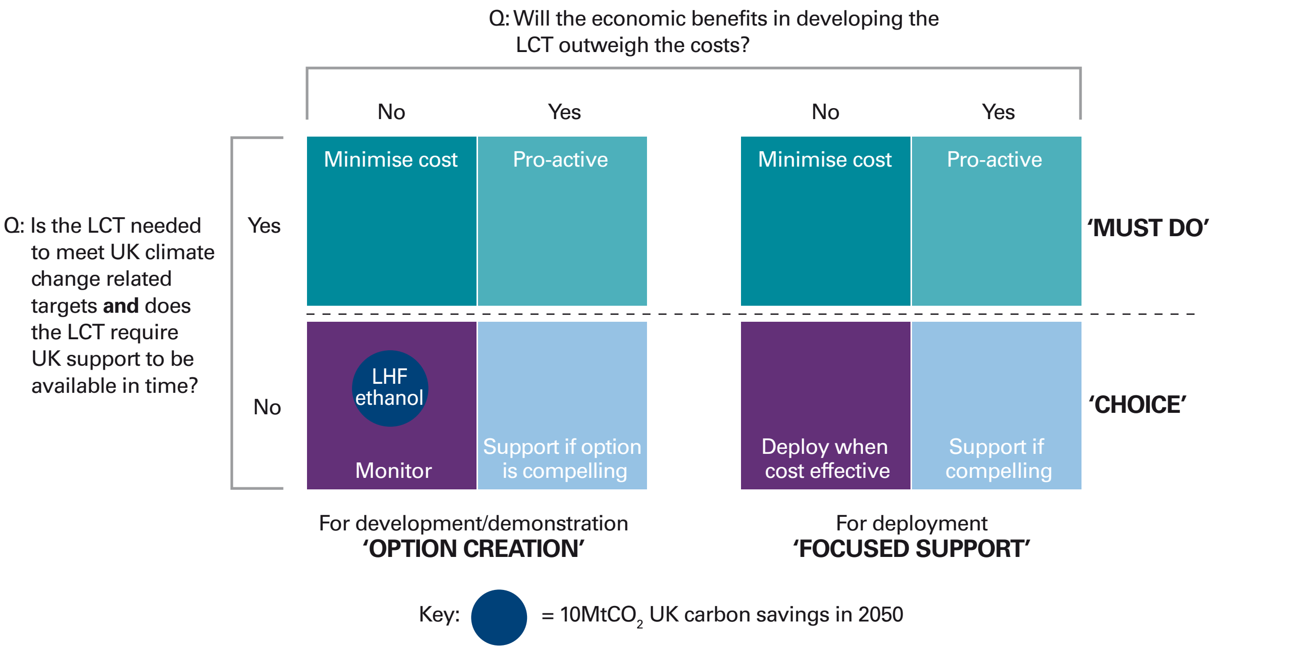
- In summary, from our analysis we conclude that wave power:
  - Is in the development/early demonstration phase.
  - Has a potential net economic cost (including displacement effects) of £0.5bn in present value terms out to 2050 (although further cost reductions could create positive net economic benefit).
  - Is important for meeting the UK's carbon target and needs UK support to be available in time with potential UK carbon savings of 30Mt CO_2 by 2050.
- Our framework (see *Chart 3.4a*) therefore suggests that the key action for the UK is to minimise costs of the technology through cost effective innovation support. In particular, there is a need to support activities which may find technology breakthroughs which could lead to a step change in costs.

3.5 Ligno-cellulosic ethanol based on hydrolysis and fermentation (LHF ethanol) – an advanced biofuel

Conclusion: UK should monitor developments in LHF ethanol, recognising that a different stance may well be appropriate for other advanced biofuels

- LHF ethanol is at the demonstration stage, with the US leading efforts to commercialise the technology.
- LHF ethanol could achieve high penetration in transport fuels and so save up to c.25MtCO_2 in the UK by 2050.
- The UK has significant academic capability in LHF ethanol, but more limited industrial strength to develop, demonstrate and construct commercial plant.
- As a consequence, the UK is unlikely to generate net economic benefit unless feedstock costs are low or energy prices are high.
- UK stance should be to monitor development and recognise that the UK may be positioned differently in other advanced biofuels.
- If the UK wishes to commercialise advanced biofuels more widely, the UK should vigorously and rapidly implement plans to strengthen market incentives and develop an RD&D strategy for the UK.

Chart 3.5a *LHF ethanol in the context of our framework*



Note: Economic benefit assessment includes displacement effects.
Source: E4tech, LEK, Carbon Trust.

LHF ethanol is at the demonstration stage, with the US leading efforts to commercialise the technology

- LHF ethanol is the production of ethanol using a hydrolysis and fermentation process employing ligno-cellulosic feedstocks such as non-food crops or wastes. It is one of many advanced processes to make biofuels from non-mineral sources involving new or emerging process technology. It is also one of a number of routes to produce ethanol from biomass; some are well established (e.g. ethanol from sugar cane), while others are advanced technologies still in development.
- Advanced biofuels are being developed because, if successful, they will have cost, carbon and resource availability (e.g. less food competition) advantages over most (but not all) current biofuels.
- LHF ethanol is one of the most developed advanced biofuel technologies with c.20 demonstration plants built or planned, considerable interest among developers and, based on our assessment, a good chance that it will be ready for mass deployment mid next decade.
- Development activity is primarily concentrated in the US with active companies such as Poet, Verenium and Bluefire and some 85% of all planned or built demonstration plants. This activity has been encouraged by substantial federal grants and a Presidential target to make advanced bio-ethanol cost competitive with gasoline by 2012.

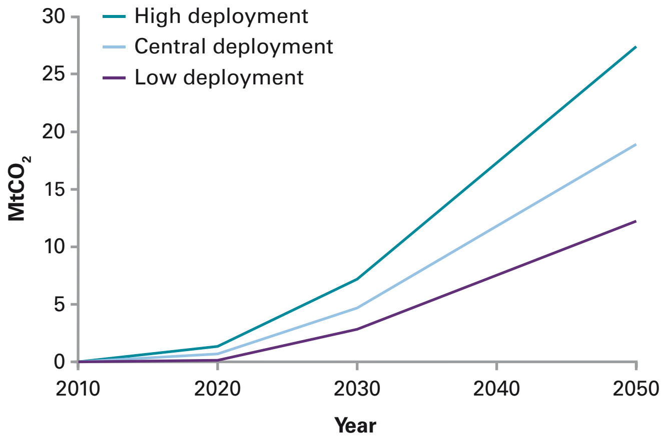
LHF ethanol could achieve high penetration in transport fuels and so save up to c.25MtCO_2 in the UK to 2050

- The market demand for LHF ethanol will depend on the mix of vehicle propulsion systems used (electric, fuel cell, hybrids and high efficiency combustion engines) and the penetration of LHF ethanol into the resultant transportation fuels market.
- In the worst case, LHF ethanol demand could remain extremely small (relative to energy demand in road transportation) if non-combustion engines rapidly predominate, if other biofuels prove more successful or if other routes to ethanol are more attractive.
- We have therefore defined a number of 'success scenarios'. The high scenario is set by technical aspects, particularly the availability of biomass resource, the yield of biofuels and blending constraints of ethanol into gasoline and diesel. In this scenario, by 2050, LHF ethanol could achieve a high penetration in road transport fuels, replacing 50% of gasoline demand and 15% of diesel demand. Central and low scenarios show penetration of 75% and 50% of the high scenario.
- Of the global biomass resource we have assumed to be available in 2050, about 50% is from potentially low cost residues and wastes (some of which are zero or negative cost) and the remainder from energy crops. The global biomass resource estimate we have used, 412EJ/year[11], is in the middle of a wide range of estimates[12] (from c.100EJ/year to 800-1500EJ/year).

[11] Our central estimate is from Smeets et al, 'A quickscan of global bioenergy potentials to 2050', 2004. EJ is exa-joules or 10^{18} joules.
[12] Source: H M Junginger, 'Overview of biomass feedstocks and potential assessments', in preparation.

- By 2050 the UK could save up to c.25MtCO_2 from the use of LHF ethanol (see *Chart 3.5b*). This carbon saving requires more biomass feedstock than is likely to be available in the UK, implying the import of either biomass feedstock or ethanol.
- However, the carbon savings from the use of LHF ethanol depends on a number of factors, most notably the mix of feedstock, conversion efficiency, and impacts of direct and indirect land use change. Our modelling has shown that the impact of feedstock mix and conversion efficiency on carbon savings is likely to be low (+/-7%). However, the impact of direct and indirect land use change is potentially much larger and in the worst cases could eliminate carbon savings. This subject is poorly understood, but is currently being investigated in depth (e.g. the Gallagher Review). To illustrate the possible impact, we have used a representative scenario which shows that land use changes could reduce carbon savings by 15% for LHF ethanol (this reduction is factored into our c.25MtCO_2 estimate). This is based on the following perspectives:
  - Negligible indirect impacts from residue and wastes.
  - Reasonable improvement in crop yields and substantial use of zero carbon stock land for energy crops, so that each hectare of land used to grow energy crops displaces half a hectare of land with carbon stock[13] elsewhere.
  - Good forest protection for greenhouse gases and other reasons resulting in a global scenario where:
    - Only 5% of displaced land is high carbon stock forest.
    - 45% of displaced land is medium stock grassland e.g. land used for agriculture in South America and parts of Africa.
    - The remaining 50% is lower carbon stock land – e.g. in Africa and Russia.
- Although the UK will require biofuels to meet EU Renewable Energy Directive targets, there are numerous alternatives to LHF ethanol both for UK production and imports[14].

***Chart 3.5b** UK LHF ethanol carbon saving including the impact of land use changes**



*Based on a representative scenario.
Source : E4tech.

[13] Refers to the carbon stored in the land (both soil and vegetation).

[14] Importing biofuels does not necessarily have a major impact on carbon emissions – for example, shipping one litre of ethanol from Brazil only emits 8% of the carbon in one litre of gasoline (source: E4tech).

The UK has significant academic capability in LHF ethanol, but more limited industrial strength to develop, demonstrate and construct commercial plant

- There are few academic researchers working on the entire LHF ethanol process as it is complex and requires expertise in a number of specialist areas. Most LHF ethanol research activity in the UK is on specific components of the process. *Chart 3.5c* shows that there are three areas relevant to LHF ethanol where we believe the UK has strong academic capability: genetic manipulation of plants, separation technologies and bioprocess engineering. Capabilities are less strong or coordinated in the other three areas: pre-treatment, hydrolysis and fermentation. However, these are the key areas where breakthroughs are needed, and where there is likely to be most value in intellectual property. However, there is a growing interest in these key areas, part of which is now being coordinated through the Biotechnology and Biological Sciences Research Council (BBSRC) Sustainable Bioenergy Centre.
- On the other hand UK industrial capabilities in LHF ethanol are more limited. Two start-up companies are working on developing a full LHF ethanol route from feedstock to finished fuel in the UK, although other companies are developing other routes to ethanol.
- The UK-based oil majors are active in LHF ethanol as well as advanced biofuels in general. However, their LHF ethanol activities are mostly based outside the UK.

***Chart 3.5c** Overview of UK capability in LHF ethanol*

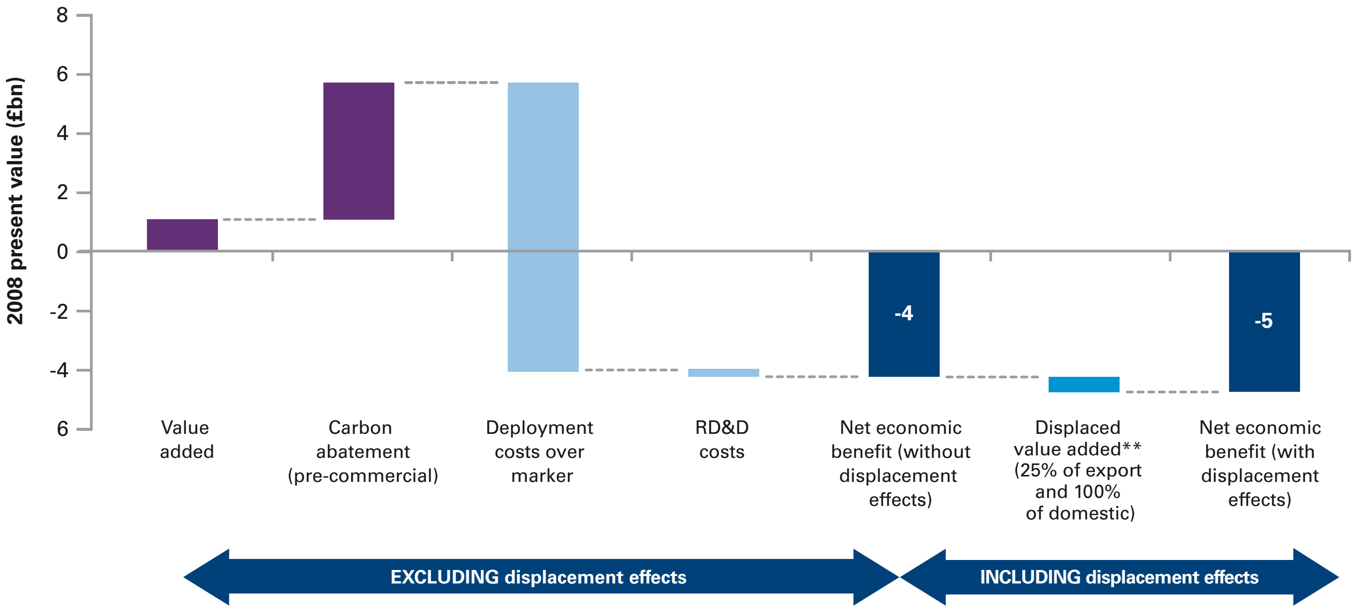
Area	Academic capability	Industrial capability
Genetic manipulation of plants	**High** – world class institutions	**Low** – many companies have left the UK due to restrictive EU/UK stance on GMOs
Pre-treatment	**Medium** – a number of high quality academics working on relevant technologies, now being coordinated through the new BBSRC* Sustainable Bioenergy Centre	**Low** – no companies focused on this area only
Hydrolysis	**Low** – researchers working on underpinning science, but not all strongly linked to biofuels, although some work recently coordinated through the BBSRC* Bioenergy Centre	**Medium** – TMO and Biocaldol work on this, but the vast majority of this work is being undertaken in large non-UK enzyme companies such as Genecor and Movozymes
Fermentation to ethanol	**Medium** – research focused on pentose fermentation comparable with other countries, but not so high profile	**Medium** – TMO and Biocaldol focus on fermentation, and Green Biologics have skills in this area
Separation technologies	**High** – good capabilities in chemistry and process engineering, which are relevant to the development of useful separation technologies	**Low** – little apparent capabilities in novel separation routes for biofuels. Other technologies are commercially available internationally
Bioprocess engineering	**High** – as a result of pharmaceutical and industrial biotechnology capabilities	**High** – as a result of pharmaceutical and industrial biotechnology capabilities

*Biotechnology and Biological Sciences Research Council.
Source: E4Tech.

The UK is unlikely to generate net economic benefit unless feedstock costs are low or energy prices are high

- In our base case (central energy prices, mid learning and feedstock prices and low UK market share), establishing a LHF ethanol industry in the UK[15] would require an investment of c.£10bn in RD&D and deployment costs, but would only generate £5bn in benefits, of which £1bn is value added for the UK (see *Chart 3.5d*). Value added is modest because, although the market for LHF ethanol is large, the limited nature of UK capabilities and the lead of other countries, such as the US, mean that the UK is likely to gain market share only in the domestic market and in the export of R&D and engineering and design services. The latter represent about c.10% of the total value chain (excluding feedstock).
- *Chart 3.5e* shows that LHF ethanol only generates a net economic benefit in the case of low feedstock prices or high energy prices. Other impacts, such as higher learning and higher UK market share, even in combination, do not allow LHF ethanol to generate a net economic benefit.
- Higher energy prices and lower feedstock prices allow LHF ethanol to generate a net economic benefit because they dramatically decrease deployment costs. For example, higher energy prices decrease deployment costs from c.£10bn (illustrated by the light and dark blue shaded areas in *Chart 3.5f*) to c.£0.3bn (illustrated by the dark blue shaded area in *Chart 3.5f*). The high energy price scenario assumes crude oil prices above $100/bbl continuously between now and 2050; currently this is improbable but not impossible. The low feedstock scenario assumes zero costs, i.e. a mix of negative cost wastes (e.g. MSW) and low cost residues. Although quantities of these exist, there may be limitations in the total amounts available in the short term, thereby restricting potential deployment, resulting cost savings and carbon reductions. For that reason, in *Chart 3.5e*, low feedstock costs are also combined with low deployment, yielding a lower yet still positive net economic benefit.

Chart 3.5d *Net economic benefit to 2050, mid deployment, learning, feedstock and central energy price scenario, low UK market share**

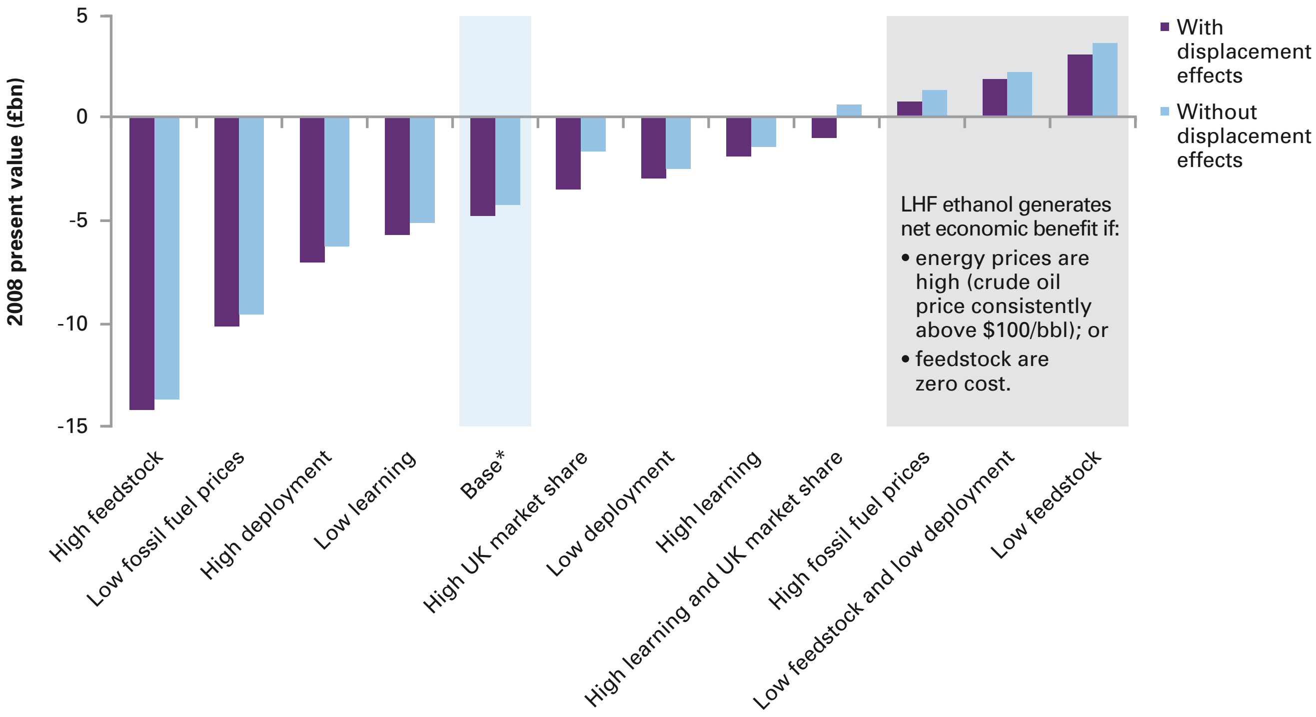


*Proportion of UK demand satisfied domestically follows UK market share.
**Allows for the fact that labour and capital used in this LCT might otherwise have been productive in another part of the economy (see chapter 2 for further details).

Source: E4Tech, Carbon Trust analysis.

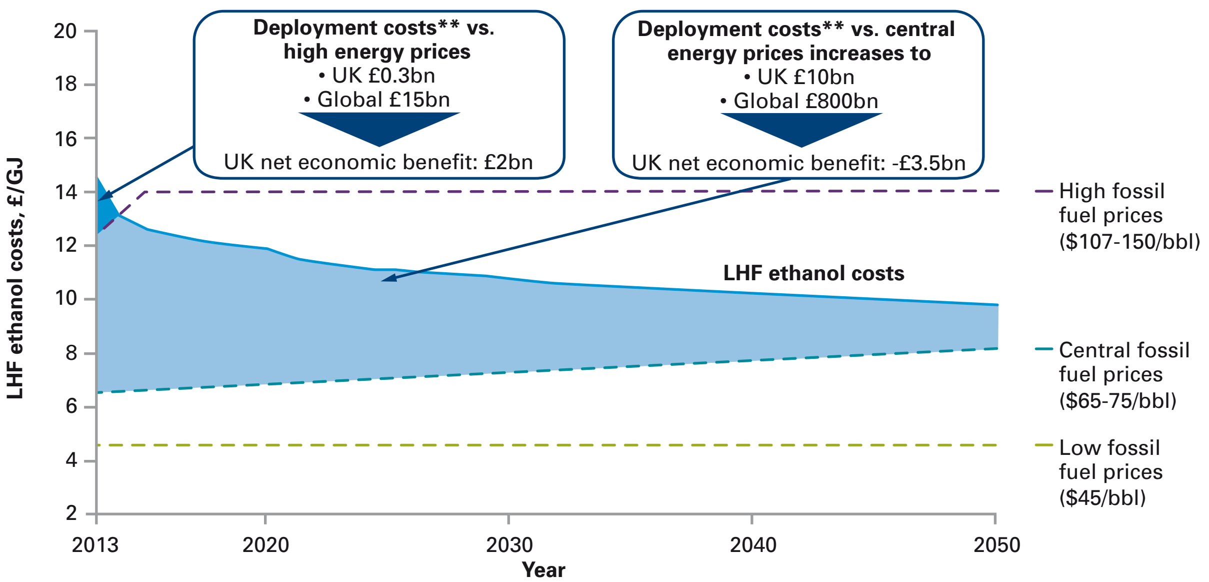
[15] The economic analysis excludes feedstock production. The RD&D costs were assessed by E4tech and set at a level to allow to proactively develop an LHF ethanol industry.

***Chart 3.5e** Net economic benefit to 2050: key sensitivities (2008 present value, £bn)*



*Central deployment, fossil fuel prices, learning, low UK market share and proportion of demand satisfied domestically.
Source: E4Tech, Carbon Trust analysis.

***Chart 3.5f** LHF ethanol production and deployment costs at varying fossil fuel prices**



*Mid learning, feedstock prices and deployment scenario.
**2008 present value; at low fossil fuel prices UK deployment costs rise to £15bn and global deployment costs to £1,300bn.
Source: E4Tech, Carbon Trust analysis.

UK stance should be to monitor development and recognise that the UK may be positioned differently in other advanced biofuels

- From our analysis we conclude that LHF ethanol:
  - Is in the demonstration stage.
  - Does not generate net economic benefit in our central 'success' scenarios, even with high learning and high UK market share.
  - Has the potential to save up to c.25MtCO_2 by 2050.
  - Is unlikely to need UK support to be commercialised.
- Our framework therefore suggests that the UK's stance should be to monitor LHF ethanol and react opportunistically to any material changes in circumstances. It should also be noted that LHF ethanol is just one of a number of advanced routes to ethanol and other biofuels. The prioritisation of those routes, if undertaken, may well show the UK in a different position to that of LHF ethanol.

If the UK wishes to commercialise advanced biofuels more widely, the UK should vigorously and rapidly implement plans to strengthen market incentives and develop an RD&D strategy for the UK

In the UK the innovation system for LHF ethanol is the same as that for all advanced biofuels. The following remarks, therefore, are applicable to all advanced biofuels.

Robustly implement plans to strengthen market incentives

- Challenge: Concerns regarding the sustainability of some biofuels led Government to establish the Gallagher Review. This concluded that policy should support agricultural expansion to produce biofuel feedstock on suitable idle or marginal land and the utilisation of appropriate wastes, residues or other non-crop feedstock and recommended that the rate of increase of the Renewable Transport Fuel Obligation (RTFO) should be slowed. Government responded by changing the obligation level to reach 5% in 2013-14 and reiterated its position that policy should be supportive of more abative and/or more environmentally sustainable biofuels. European legislation also allows for increased support for lower carbon biofuels, and requires that double credits be given to all advanced biofuels under Member State policies. Although the general principles for the support of advanced biofuels are now well established, the detail of the mechanisms are in the process of being implemented. The policy will not be fully effective until the nature of the mechanisms is clear.
- Potential solution: Vigorous and rapid implementation of a robust policy relating to biofuel support and the socio-environmental framework.

Develop an RD&D strategy for advanced biofuels for the UK

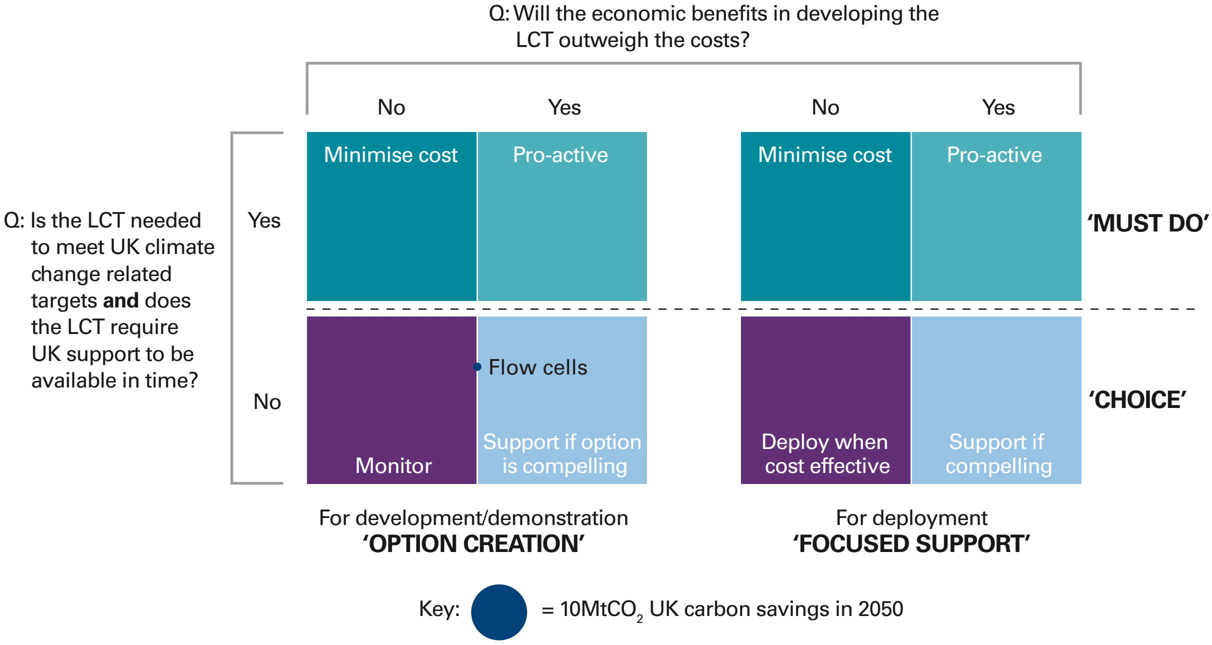
- Challenge: In the UK, RD&D funding has been very low compared with other countries and the UK lacks a coherent overarching RD&D strategy for biofuels. The BBSRC £27m Sustainable Bioenergy centre is a good development, however a number of issues remain including:
  - Limitations with respect to the focus, longevity and coordination of RD&D funding.
  - Concentration of activity – the UK has smaller and less strongly networked research centres than elsewhere.
  - Systems view – need for researchers to have a systems understanding and a strategic view.
  - Knowledge sharing – poor UK networking between researchers, and restrictions due to IP concerns.
- Potential solution: Develop a UK RD&D strategy for advanced biofuels addressing focus, longevity and coordination of RD&D funding and concentration of activity (size of centres and strength of networks).

3.6 Flow cells

Conclusion: UK should support flow cells if they appear compelling when compared with other development/demonstration LCTs

- Flow cells are still in the development/early demonstration stage with a number of potential technology variants based on different fundamental chemistries.
- If the commercial case can be proven and large-scale deployment commences, then flow cells could become cost effective by the middle of the next decade. However there is no clear champion for developing the technology in the UK.
- Despite significant expertise in the fundamental science, the UK will only be able to carve out a niche position in the global market so the net economic benefit and number of jobs are likely to be relatively small.
- Total annual carbon savings are unlikely to be significant in their own right and there are other potential options for balancing the system.
- In order to successfully commercialise flow cells in the UK, the UK would have to change the regulatory framework to allow value aggregation, establish a deployment support mechanism, build demonstration plants and develop performance standards.
- UK stance should be to assess flow cells against other alternatives and provide support if it proves to be a compelling option.

***Chart 3.6a** Flow Cells in the context of our framework*



Note: Economic benefit assessment includes displacement effects.
Source: EA Technology, LEK, Carbon Trust.

Flow cells are still in the development/early demonstration stage with a number of potential technology variants based on different fundamental chemistries

- Flow cell electricity storage devices are based upon a reversible pair of oxidation states, known as electrochemical couples, of which there are currently eight types in development all at very different stages with no clear dominant technology as yet (Technology Readiness Level stage in brackets):

  Later stage chemistries in early demonstration stage:

  - Vanadium/vanadium (TRL 8)
  - Zinc/bromine (TRL 7-8)
  - Polysulphide bromide or Regenesys™ (TRL 5).

  Earlier stage chemistries still in the development stage:

  - Zinc/cerium (TRL 4)
  - Vanadium/bromine (TRL 3)
  - Soluble lead acid (TRL 3)
  - Vanadium Cerium (TRL 2).

- Each chemistry has its own characteristics in terms of energy density, cycle efficiency, lifespan and cost.
- Important aspects of the technology which could help to distinguish the eventual leader are high energy densities which would require smaller size/footprint (e.g. polysulphide bromine) and not requiring the additional expense of a membrane as the charge is held in a single electrolyte (e.g. soluble lead). Also the cost of electrolytes is important and cost volatility can particularly be an issue where there are other key markets for the commodity (e.g. the price of vanadium is heavily linked to the demand for ferrovanadium steel).
- With so many options being progressed, flow cells are still at the development/early demonstration stage with no dominant technology as yet.
- In order for flow cells to meet their full market potential, it is essential that they are proven at large scale. However, it is estimated that by 2008 there was only 11MW of flow cell capacity installed worldwide as compared to a more established technology such as batteries which had around 250MW[16]. The UK has several small-scale demonstration projects in the early stages, including a 250kW project for utility energy storage[17], a smaller 5kW soluble lead intelligent grid management project[18] and the trial of a small 150kW zinc bromine unit for uninterruptible power supply at a substation[19]. However, the vast majority of live demonstration projects are elsewhere with over half of the 30 or so current installations in the US and Japan.

[16] Fraunhofer Institute.
[17] Redox flow battery for utility energy storage (ESD, Econnect, ScottishPower, Swanbarton, University of Southampton).
[18] Redox flow cells for intelligent grid management (C-Tech Innovation, E.ON UK, University of Southampton).
[19] Scottish and Southern project at Nairn.

If the commercial case can be proven and large-scale deployment commences then flow cells could become cost effective by the middle of the next decade. However there is no clear champion to develop the technology in the UK

- Flow cells are unique amongst the six technologies we have looked at in that they have a wide variety of potential applications, some of which enable LCTs and others which are not necessarily focused on LCTs.
- Applications which will help enable the adoption of LCTs include: storage of power from intermittent[20] renewables, customer peak demand shaving and batteries for low carbon vehicles which enable the use of decarbonised electricity to displace petrol/diesel fossil fuels. The focus in this study has been on flow cells as an enabler for intermittent renewables (and particularly for wind farms) – the connection between peak shaving and carbon savings is less clear and flow cells for automotive applications are likely to be at an entirely different scale or require very different application solutions.
- Flow cells can also be used for other non-low carbon applications including: remote area power supplies, remote grid support, resolution of network issues, deferral of network upgrades, uninterruptible power supplies and auxiliary power units.
- The wholesale electricity market rewards certainty and full participation requires advance notification of generation schedules half hour by half hour with 'imbalance penalties' incurred if this schedule is not met. Clearly, this puts wind developers at a disadvantage, but using medium-scale storage could mean that they can control output much more reliably. Therefore they should be able to capture significant additional value for the generation they produce by gaining a higher price in the wholesale market and avoiding these 'imbalance penalties'.
- Generally, the greater the storage capacity available, the greater the certainty in output and the greater the additional revenues available (see *Chart 3.6b*). Based on modelling of a 10MW wind farm, the annual revenue for full day ahead output profile shaping has been estimated at £80 per kW of storage capacity.

***Chart 3.6b** Additional revenue available to a 10MW wind farm*

Certainty

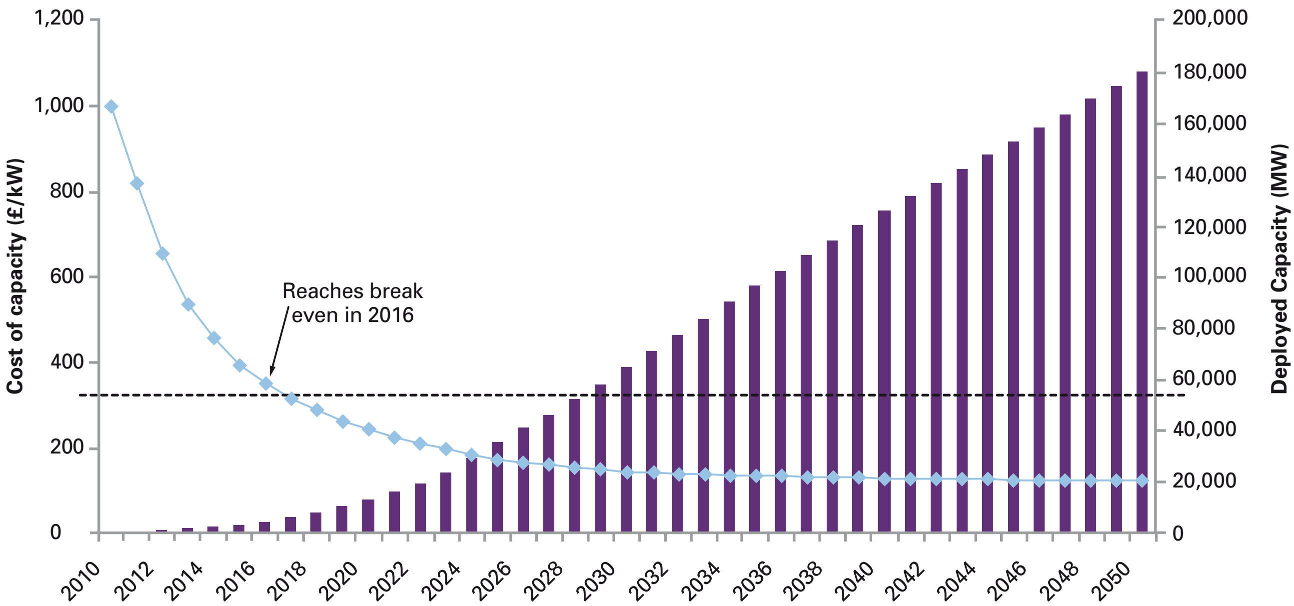
Commercial activity	Electricity storage capacity	Additional % revenue (% range)	Total additional annual revenue	Annual revenue per kW of storage
Simple buffering applications	5MW for 6 to 10 hours (30 to 50 MWh)	20% (2% to 35%)	£75,000	£15
Combined buffering and arbitrage	6MW for 6 hours (36MWh)	30% (8% to 38%)	£114,000	£19
Day ahead output profile shaping	5MW for 20 hours (100MWh)	110% (100% to 330% at peaking)	£400,000	£80

Source: Regenys Utility Scale Energy Storage – The Value of Energy Storage within the UK Electricity Network. DTI New & Renewable Energy Programme, 2004.

[20] Intermittency is more correctly termed as variability, although intermittency is the more widely used term.

- However, the additional capital investment of purchasing flow cell storage adds significantly to the costs of a wind farm development. If a 10% internal rate of return is assumed, in order to reach a break even point such that the additional capital cost of storage can be justified, the capital costs would need to reach around £350 per kW from a current cost of around £1,000 per kW.
- Based on our learning rate assumptions[21] and deployment model[22] the cost of flow cells is estimated to reach this break even point by 2016 (see *Chart 3.6c*). This fairly rapid commercialisation is largely due to the current lack of installed capacity, the predicted rapid increase in installed wind and a high initial learning rate which combine to reduce costs quickly.
- There is also the potential that larger scale capacity (or smaller capacity installations acting in combination) would allow developers to compete with Open Cycle Gas Turbine (OCGT) and pumped storage for standing reserve in the Ancillary Services market which has even higher potential additional commercial value of up to £120 per kW capacity per year. This would potentially bring forward commercialisation even further and unlock carbon savings of avoided conventional standing and spinning reserve.

Chart 3.6c *Learning curve for flow cells*



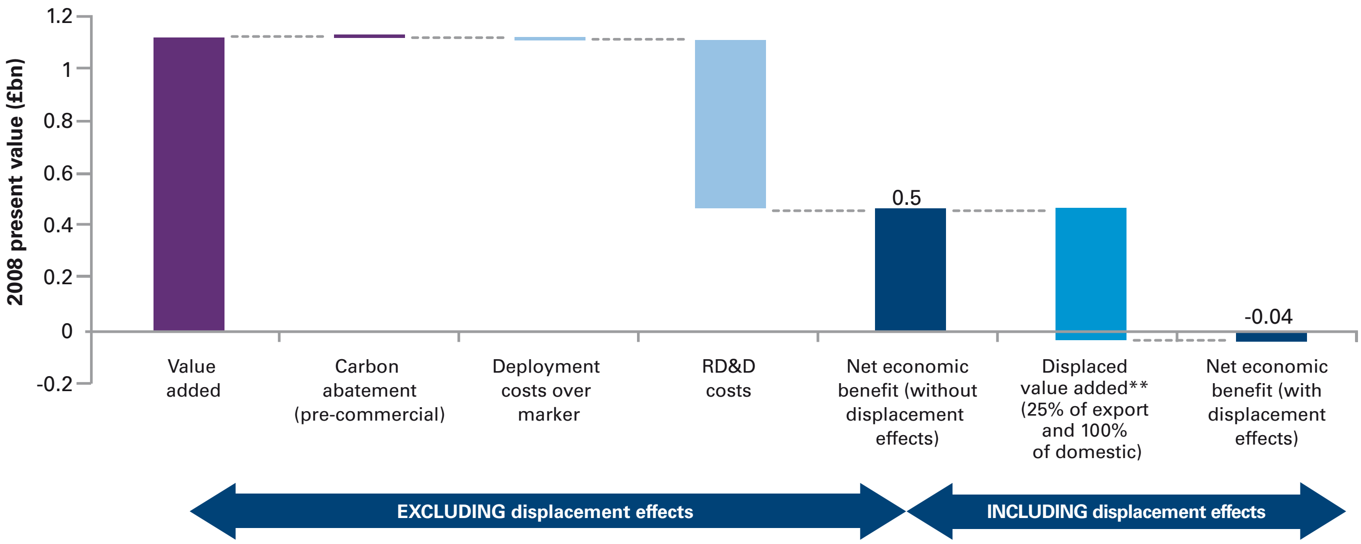
Source: EA Technology, BCG, Carbon Trust.

[21] Learning rate of 20% through until 2030 at which point it reduces to 10%.

[22] This is largely driven by the global wind capacity model developed for offshore wind.

- This 'service' could be provided by an independent operator acting on the system as a storage agent providing services for multiple customers - both providing output certainty to a number of wind developers and system balancing for the network operator. In this way, they might be able to aggregate sufficient value to make the project commercial. However, they would currently have to be classed as a 'generator'[23] requiring a generation licence which significantly adds to the costs. It is still unclear whether such a role is commercially viable without 'at-scale' demonstration.
- Alternatively, the network operator (either transmission or distribution) could act as the storage agent at an aggregate system level. However, currently the regulatory regime provides insufficient clarity over the ownership and operation of energy storage systems and their treatment within the regulatory regime.
- So despite the potential, there remains the question as to who will lead the technology through to commercialisation. While costs are estimated to have the potential to drop quickly the current high costs mean it is still uneconomic and without a specific incentive or deployment support mechanism this investment is unlikely to come from the private sector. In other countries, electricity markets have a clearer commercial driver for storage (e.g. in the US for security of supply given the highly dispersed and remote nature of some of the grid system) and so it is more likely that the technology will develop elsewhere.
- Nevertheless, if this additional value could be captured it could be an important factor in reducing the cost of wind generation, allowing it to be more attractive to new developers, commercialise earlier and ultimately require less support. This could lead to additional capacity sooner and therefore a greater wind share than would otherwise have been the case, thereby saving additional carbon.

***Chart 3.6d** Net economic benefit to 2050 with and without displacement effects**



*High learning rate, high UK market share, central deployment and central energy prices.
**Allows for the fact that labour and capital used in this LCT might otherwise have been productive in another part of the economy (see chapter 2 for further details).

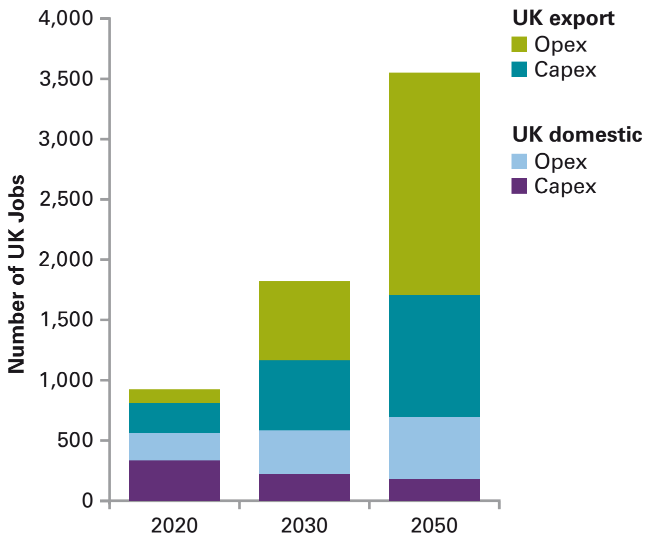
Source: Technical consultants, Carbon Trust.

[23] Unless below 50MW capacity in which case it could be treated as a licence exempt generator.

Despite significant expertise in the fundamental science, the UK will only be able to carve out a niche position in the global market so the net economic benefit and number of jobs are relatively small

- As seen already, the majority of significant development and demonstration programmes are happening outside the UK. North America is currently the leading market for flow cell innovation, particularly for vanadium and zinc bromine chemistries. The UK lags somewhat behind, with no clearly defined funding programme and, as yet, only a few small-scale flow cell demonstration units.
- However, there is a considerable amount of expertise in the UK particularly in the fundamental science with a few small companies and the University of Southampton at the forefront of research and development into zinc cerium and soluble lead acid systems. The University of Southampton also has internationally recognised expertise in electrochemical power sources. There are also a number of small developers and a number of utilities with interests (e.g. E.ON, ScottishPower and Scottish and Southern).
- The DTI's 2006 GlobalWatch Mission Report on Electrical Energy Storage Systems concluded that the UK has a credible storage technology base with specific and internationally recognised expertise and capabilities in battery storage, specific flow cell technologies, power conversion systems, balance-of-plant and overall systems integration. Still the vast majority of activity is happening elsewhere where there are greater commercial drivers (particularly in North America and Japan), so other countries are more likely to take the lead. For example, the US has recently announced a major package for smart grid technology under the American Recovery and Reinvestment Act which includes an additional $615m for storage monitoring and technological viability.
- Given the relatively small global market size (~£7bn by 2050) and the low predicted UK share of the global export market (3% by 2050), then overall net economic benefit is low and flow cells is likely to be a niche market for the UK, the industry supporting around 3,000 jobs by 2050 (see *Charts 3.6d* and *3.6e*).

***Chart 3.6e** UK flow cell industry jobs**



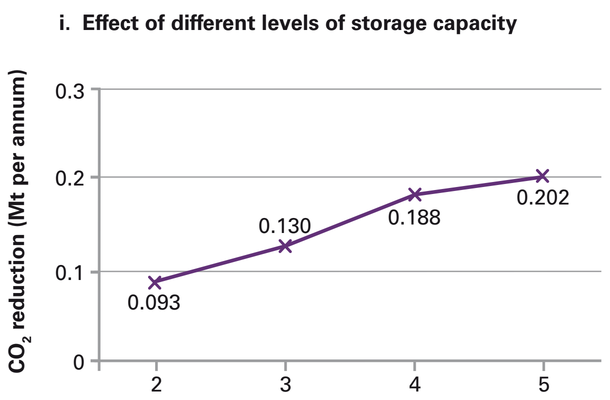
*High learning rate, high UK market share, central deployment and central energy prices.

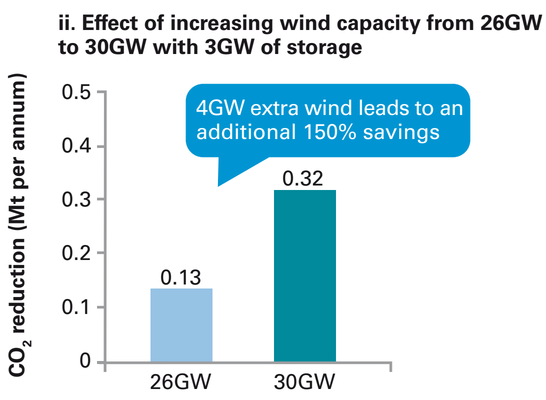
Source: EA Technology, BCG, Carbon Trust.

Total annual carbon savings are unlikely to be significant in their own right and there are other potential options for balancing the system

- Principally, UK carbon savings from increased energy storage on the electricity system would come from stored energy displacing the use of more carbon intensive conventional fuel reserve plant to balance the system in peak demand periods.
- Currently this balancing activity is carried out by introducing a combination of:
  - Spinning reserve – part-loaded conventional fossil-fuelled plant which suffers increased efficiency losses of 10-20% (includes coal).
  - Standing reserve – OCGT plant and pumped hydro storage (principally at Dinorwig).
- Increasing the amount of standing reserve available could reduce the amount of partly loaded generators running (the committed spinning reserve) therefore increasing the overall system efficiency. Indeed just using more OCGT standing reserve instead of spinning reserve would result in significant carbon savings in itself as it avoids these efficiency losses and also offsets the use of higher carbon coal plant spinning reserve.
- The need for additional balancing services increases as more and more intermittent renewables capacity comes onto the system and so this reserve capacity will become more important. This would be further amplified if there is also a significant increase in the amount of nuclear capacity (or new coal with CCS) which is incapable of following demand profiles. Clearly, therefore, the more energy storage can offset the use of OCGT in the standing reserve market, the more additional carbon savings will be realised.
- Assessing this potential for carbon savings requires complex modelling of the UK electricity system. Any model has to take into account a number of interacting factors including: the overall capacity of intermittent renewables (and the effect of increasing capacity over time), the level of available energy storage on the system, the level of generation flexibility in the system and the amount and type of standing reserve and spinning reserve available as an alternative to balance the system.
- *Chart 3.6f* shows the outputs of modelling undertaken by the Manchester Centre for Electrical Energy (MCEE) for the DTI Technology Programme and shows how results varied based on some of the factors above. Under the most appropriate medium flexibility generation system scenario:
  - Carbon savings from increasing the installed storage capacity are fairly proportional up to a system limit i.e. in the left hand graph doubling the storage capacity from 2GW to 4GW doubles the carbon savings whereas adding an additional 25% to 5GW only further increases savings by ~7%; and
  - Increasing the total wind capacity on the system using the same amount of storage significantly increases its carbon effectiveness i.e. in the right hand graph increasing wind capacity by 25% from 26GW to 30GW leads to an additional 150% of carbon savings from the same 3GW of storage.

Chart 3.6f *Modelling of carbon reduction of wind energy storage**

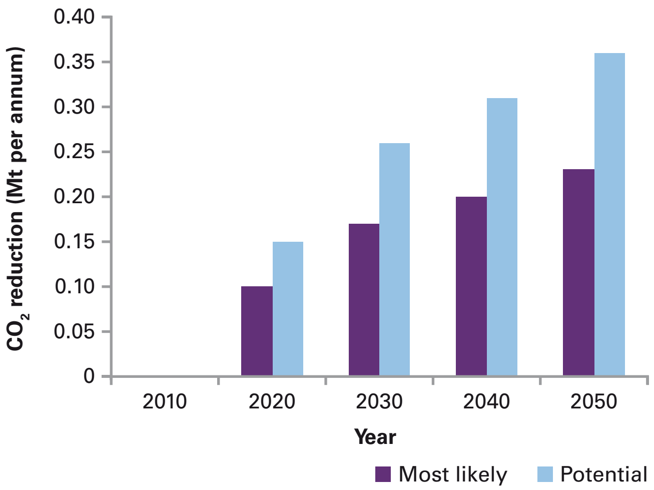




*Medium flexibility generation system.
Source: DTI Technology Programme, 'The future value of Electrical Energy Storage in the UK with Generator Intermittency', 2004.

- For our analysis of potential carbon savings, we derived estimates using the MCEE modelling[24] based on the wind capacity model we developed for offshore wind and our consultant's estimates of storage deployment and flow cell market share. This analysis estimates that under the most likely scenario, carbon savings could rise to 0.23MtCO_2 by 2050 (see *Chart 3.6g*).
- There are other options to balance a system with increasing intermittent renewable capacity. Whilst there are unlikely to be many suitable additional pumped hydro-storage sites available, incentives could be given to increase the availability of OCGT standing reserve and demand side management (i.e. customers reducing demand). Further interconnectors could be added to the continent to open up a 'supergrid' under the theory that the wind will be blowing somewhere across a 'depression-sized' grid, or multiple wind farms could simply be directly connected to each other to aggregate and 'firm up' their output. In any case, energy storage (and flow cells) will have to compete commercially alongside these other options.

***Chart 3.6g** UK flow cell carbon savings**



*High learning rate, high UK market share, central deployment and central energy prices.

Source: EA Technology, BCG, UMIST, Carbon Trust.

In order to successfully commercialise flow cells in the UK, the UK needs to change the regulatory framework to allow value aggregation, establish a deployment support mechanism, build demonstration plants and develop performance standards

Fragmented revenues

- Challenge: As discussed above, in the UK it is difficult to access all the sources of revenues for electricity storage because the industry is no longer vertically integrated, making the investment case less attractive. The current high cost of electricity storage systems requires clear revenue streams and payback periods to attract investment. However, the existing regulatory regime in the UK does not clearly allow a potential developer or operator of a facility to aggregate these revenues.
- Potential solution: A change in the regulatory framework could see specialist 'energy storage' market participants which could aggregate sufficient value to make the function economic and sell services through strategically located, large-scale energy storage systems which would work with multiple wind farms to regulate output in order to:

  (a) help them to capture the additional value from the wholesale electricity trading arrangements;

  (b) compete with conventional capacity for peak demand services; and

  (c) provide additional services to the network operator on a commercial basis.

  This would require both changes to the existing regulatory framework (e.g. the Balancing and Settlement Code) as well as innovative commercial arrangements between multiple parties.

Insufficient deployment support

- Challenge: In the deployment stage, overall support levels appear insufficient to incentivise developers to invest in flow cell technology. At the current time there are no deployment incentives or regulations specific to promoting the uptake of flow cell/energy storage technologies.
- Potential solution: Develop new mechanism to support flow cells in the deployment stage – this would probably need to be a new mechanism specifically designed for electricity storage given its unique commercial drivers in the market.

[24] Electricity system with 30GW of wind, medium flexibility generation system (most likely) and 3GW of energy storage (i.e. ~10% of capacity) competing for standing reserve with gas-fired OCGT.

Limited availability of demonstrators

- Challenge: There are no large-scale demonstrators available within the UK for potential investors to view and/or assess. As a technology that has not yet been introduced at any scale to the UK, stakeholders have expressed a need for a large-scale demonstration unit so that potential investors can see the benefits of energy storage within the UK system. As a comparison, there are currently two large units in the US, a ZBB Energy ZBESS 500 unit installed at Pacific Gas and Electric Co. sized at 2MWh and VRB's VRB-ESS unit installed at Pacific-Corp, Utah, also sized at 2MWh.
- Potential solution: High profile large-scale demonstration projects undertaken within the UK, possibly in conjunction with independent accreditation (as discussed below). This could help overcome concerns and encourage support and take-up by UK utilities. Such a demonstrator could be undertaken as a consortium project, funded through Government with contributions from industry, power utilities and other associated stakeholders and agencies.

Performance standards

- Challenge: There are no recognised performance standards in the UK and no significant field trials have been carried out to date, therefore investors and utility customers have to rely on results provided by the developer themselves.
- Potential solution: Coordination between Government and industry to set in place industry standards for the expected performance of flow cells that allow easy comparison of product performance. This could be done at a national, European or international standard level. International standards are probably the most appropriate, given that the greatest progress to date in flow cell technology has been in the US. However this would take a long time to put in place. Alternatively, independent accreditation could be given by a recognised expert or organisation.

The key action for the UK therefore is to assess flow cells against other alternatives and provide support if they prove to be a compelling option

- From our analysis we conclude that flow cells are still in the early stages of development. While the technology could play a role in enabling more intermittent renewables onto the electricity system, there are other alternatives and overall the carbon case and potential for economic benefit are fairly marginal. There is also no obvious 'champion' for developing flow cells.
- Our framework (in *Chart 3.6a*) therefore suggests that the UK's approach should be to assess flow cells against other alternatives and provide support if they prove to be a compelling option.

Part B
Key findings

Why and how the UK should commercialise LCTs

4. The case for UK support of LCT innovation

There is a clear case for the UK to support the development of Low Carbon Technology (LCT). This support will put the UK in a better position to address climate change and reap economic benefits.

Summary

- The UK needs to have access to innovative new and emerging LCTs to be able to meet its carbon reduction targets.
- However, market failures inherent to these types of technologies mean that private sector involvement alone may not bring forward sufficient investment to commercialise these technologies in time to meet carbon targets. Therefore, there is a need for public sector support.
- In general, innovation of LCTs is a global game. In at least four of our sample of six LCTs, the great majority of the innovation effort will be undertaken outside the UK, supported by other governments.
- The UK has a choice, therefore, to play an active and leading role in the innovation of one or more LCTs or to wait and deploy LCTs developed abroad.
- Our study shows there is no generic answer to this question but rather at least two specific cases in which active involvement is justified:
  - Innovating a LCT which is vital to meet the UK's carbon targets and would not be available in time without the UK's support; and
  - The creation of economic benefit for the UK.
- Detailed analyses of our sample of six LCTs has shown that the UK, by being an active player in technology development, could well generate significant net economic benefit and/or unlock technologies that will make a material contribution to UK carbon reduction goals and are unlikely to be available in time without UK support for innovation.

UK needs new and emerging LCTs

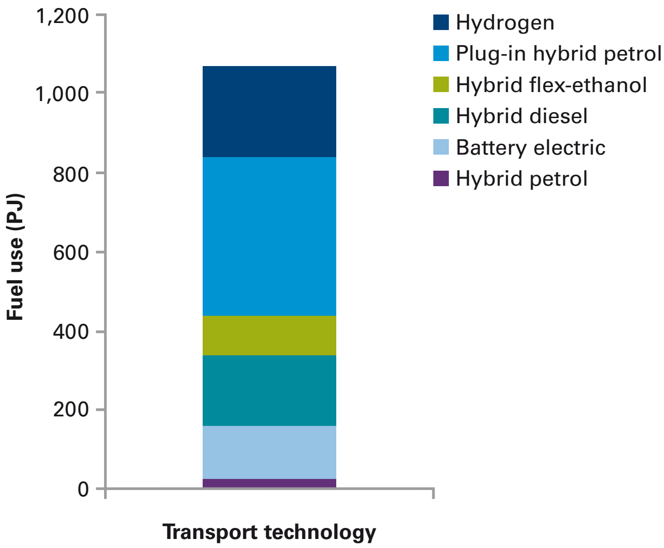
The UK, along with most other developed countries, requires innovation in LCTs in order to achieve drastic cuts in carbon emissions by 2050. For the UK, this has been best illustrated by the work of the Committee on Climate Change (CCC) which shows that existing technologies, including energy efficiency, onshore wind and nuclear, will only take us part of the way towards our target. We need, therefore, new and emerging LCTs, such as offshore wind power, to become commercially viable so that they can be deployed at scale.

This can be shown by looking at the CCC's 2050 projections for, say, the transport sector. *Chart 4a* shows the CCC's forecast of how the energy required to meet our transport needs in 2050 could be met by different technologies assuming a target of 80% carbon reduction.

New technologies which are not yet commercial, such as hydrogen and electric vehicles, become an important part of the transport system, along with plug-in hybrids.

As there is necessarily considerable uncertainty around the innovation of any specific technology, including technical, economic and market risks, the UK will need to have available LCT options where the total potential carbon savings are greater than those required to meet carbon reduction targets.

Chart 4a *Breakdown of Committee on Climate Change scenario of UK transport technologies in 2050 by fuel use (central energy prices)*



Source: MARKAL Modelling undertaken for the Committee on Climate Change.

LCT innovation needs public support

With a clear need for LCT innovation, why does the private sector not fulfil that need as it does in many other parts of the economy? The answer is because of failures in the 'market'. In addition to general market failures for technology innovation, there are specific LCT market failures which, together with the urgency of the issue, mean that market signals such as a carbon price will not generate enough investment to commercialise LCTs.

This is well illustrated by the development of Combined Cycle Gas Turbines (CCGT), the most successful electricity generation technology of the last two to three decades. Although it is often thought that CCGT is a good example of market-driven innovation, the history of the CCGT reveals that a large amount of state involvement was crucial in its development.

CCGT as a state-supported technological success

Combined cycle gas turbine (CCGT) technology has been deployed rapidly in the UK power sector since privatisation in 1989/90. This deployment was driven by a combination of low capital costs, high thermal efficiency, short construction times and the availability of relatively cheap natural gas. In addition to generating a substantial proportion of UK electricity, this technology has also driven significant reductions in UK carbon emissions.

It is often thought that this technology is a good example of market-driven innovation in response to changed circumstances following privatisation and the introduction of competition. However, the history of CCGT reveals a large amount of State involvement in its development. Much of the advanced technology that has increased the efficiency of CCGT power plants to the current level of 55-60% was supported by military R&D programmes – particularly in the USA. Other forms of support for jet engine development included 'launch aid' for specific products – for example, the Rolls Royce RB211 engine.

Military funding and other forms of support for jet engines from the 1950s onwards resulted in new materials, blade cooling techniques and advanced aerodynamic design that were subsequently transferred to the power generation gas turbines that form the heart of CCGT power plants.

The role of Government funding in CCGT technology development has not been confined to jet engines. In Japan, advanced industrial gas turbines were developed by Mitsubishi with support from the Government's Moonlight project – a strategic programme that provided targeted support to specific technologies over a prolonged period.

The resulting technology found its way into Mitsubishi's largest and most efficient gas turbines. In the USA, the Advanced Turbine Systems (ATS) programme of the Department of Energy was equally important. This directed RD&D programme was responsible for co-funding the development by GE and Westinghouse of more efficient power generation gas turbines which are now being deployed in commercial markets.

Source: Science and Technology Policy Research Unit, University of Sussex.

General innovation market failures have an important impact on LCTs

Several market failures are endemic to innovation and their impact on low carbon innovation can be particularly important. The European Commission recognises four market failures as potential justifications for State intervention in innovation[1]:

Spillovers

Innovation often generates wider benefits for society as a whole (or positive externalities). For example, research has shown a link between increased basic R&D and the productivity of the economy as a whole. Because private investors do not always gain from these wider benefits, projects which generate large social benefits may not be taken forward as they are unprofitable.

Appropriability

In order to profit from their innovations, firms must be able to appropriate or gain the benefits they create. It can be difficult to exclude others from using the innovation and to make them pay individually for the benefit they receive, therefore firms may give up projects as a result.

Coordination and network failures

Firms rarely innovate alone, however, there may be problems that impair the ability of the firms to coordinate or at least interact, and so deliver innovation. A wide range of problems may arise, including: firms' difficulties in committing to collaborative R&D, and inadequate access by smaller firms to the innovation system (which may be caused by a wide range of factors).

Imperfect or asymmetric information

Imperfect or asymmetric information often leads to the wrong decisions about the level or direction of innovation. This can occur due to the limited resources of innovators, or because there are structural barriers to information flow. In the low carbon arena the nature of future regulations and incentives has a strong bearing on market demand, yet the medium-term outlook is often opaque and may be subject to change by successive governments.

LCTs face additional market failures

In addition, there are market failures specific to LCTs which limit the returns available to innovators, and thereby deter private sector investment in LCT innovations.

In, for example, electricity generation, these include the nature and length of the learning process, infrastructure, existing market distortions and lack of competition[2]:

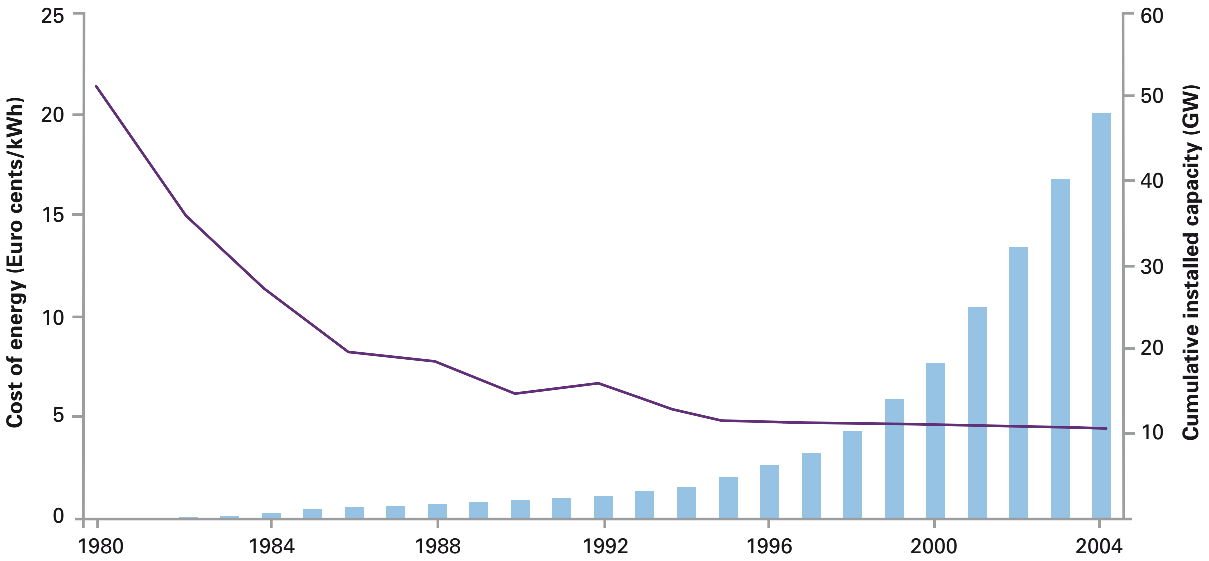
Nature and length of the learning process

The nature of the learning process for the commercial development of electricity generation technologies means that there is typically a very long lead time before they become commercially viable (this feature has wider impacts on this study and is discussed further in the next section). The willingness of the private sector to invest over these kinds of timescales is impacted by:

- **Lack of niche markets/early adopters:** Electricity as an end-product is homogenous and sold at a fairly common market price – only very small numbers of consumers are willing to pay the full premium associated with carbon-free electricity. Therefore, additional costs cannot be passed onto the 'early adopter' consumers in the early market stages, as can be done in other markets like LCD televisions. An innovating firm would have to sell initially at a loss in the hope of recouping this later once the technology is commercially viable.
- **Risk averse suppliers:** Suppliers can be heavily regulated in this sector and averse to taking the risk of developing new and uncertain technologies.
- **Effectiveness of intellectual property protection:** Intellectual property protection is not always effective, exacerbating the spillover effects discussed in the previous section. In particular, learning in this sector is iterative, based on feedback between R&D activities and the experience of actually trying out a technology.

[1] Source: Oxera, 'Innovation market failures and state aid: developing criteria', 2005.
[2] Source: The Stern Review, 'The Economics of Climate Change', 2006.

***Chart 4b** Growth of onshore wind power worldwide**



*The bars show worldwide cumulative installed capacity and the line indicates costs of energy.

Source: BTM Consult, 2005; Chapman and Gross, 'The technical and economic potential of renewable energy generating technologies: Potentials and cost reductions to 2020', 2003; Milborrow, Windpower Monthly vol 22, No.1.

Infrastructure

National grids are tailored towards the operation of existing, centralised power plants and favour their performance. For example, new generation technologies employed at a local level may require significant investment in distribution systems or offshore technologies may require new grid infrastructure to be built.

Existing market distortions

In many economies, direct and indirect subsidies distort the market in favour of existing fossil fuel technologies.

Lack of competition

Often limited competition exists in electricity markets due to the limited number of generation companies and the 'natural monopoly' feature of distribution.

Similar market failures apply in other low carbon sectors such as transport, heat and energy efficiency.

Timebound carbon targets and long lead times for LCT development highlights the urgency for support

A feature of energy technologies, including many LCTs, is that they tend to have very long development lead times. For example, it took onshore wind power around 25 years to progress from demonstration of alternative designs to selection of a dominant design that has since progressed to full scale deployment (see *Chart 4b*), although still requiring public sector support in most markets in the world.

Such long timescales to commercialisation can deter investors given the high degree of technology, market and political risk.

These long lead times also have implications for the ability to meet long-term carbon targets. New energy technologies will need to be ready at the latest by 2040 to allow time for deployment to make an impact by 2050. Using the experience of onshore wind, this would mean that a technology path for emerging LCTs would need to be clear by 2015 if it is to have a significant impact by 2050.

This increases the urgency associated with technology development, and in turn the requirement for public support, if LCTs are to make a difference by 2050.

Carbon price alone will not be enough to drive innovation and commercialisation of LCTs

A carbon price is an effective addition to a policy framework, valuing the positive externality of the emissions saved by low carbon technologies.

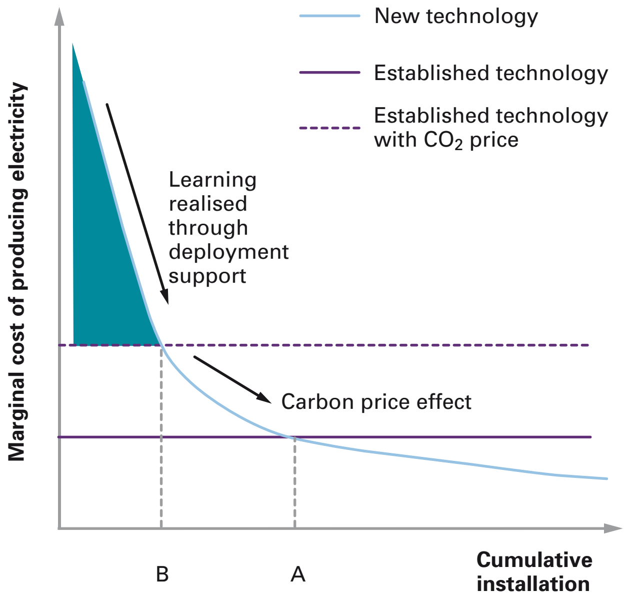
However, in early stages of development it is often not economic to develop LCTs to the point of market adoption, even with a carbon price. Public support, both funding and removal of non-market barriers, is required. This principle was articulated in the Stern Review[3] and is illustrated in *Chart 4c*:

"The diagram summarises the link between the two elements of climate policy. The introduction of the carbon price reduces the learning cost since the new technology, for example a renewable, in this illustrative figure becomes cost effective at point B rather than point A, reducing the size of the learning cost represented by the area between the dotted and solid purple lines. Earlier in the learning curve, deployment support is required to reduce the cost of the technology to the point where the market will adopt the technology. It is the earlier stages of innovation, RD&D, which develop the technology to the point where deployment can begin. Across the whole process, non-market barriers need to be identified and, where appropriate, overcome."

Reliance on a carbon price alone could lead to the same problems experienced under the Renewables Obligation in recent years in which a single level of support, regardless of technology, favoured the uptake of mature technologies. The Renewable Obligation hasn't pulled through earlier stage technologies as hoped (such as offshore wind) and has been over-rewarding later stage technologies (such as onshore wind). This was reviewed in detail in the Carbon Trust's study 'Policy Frameworks for Renewables', which argued for technology-specific levels of deployment support. The Government has since decided to differentiate the level of support by group of technology (known as 'banding').

Provision of sufficient and appropriate support for technology development (beyond a carbon price) creates an environment which encourages the private sector to invest, while still relying on market competition to provide the stimulus for cost reductions.

Chart 4c *Interaction between carbon pricing and deployment support*



Source: The Stern Review, 'The Economics of Climate Change', 2006.

[3] Source: The Stern Review, 'The Economics of Climate Change', 2006.

Import or innovate?

It is unlikely that sufficient investment in low carbon technology innovation will be provided by the private sector without public support due to the variety of market failures outlined above. This implies that public support must be provided by one or more countries to fund the LCT innovation required to achieve emission reductions. However, in general, innovation of LCTs is a global game. In many LCTs, the great majority of the innovation effort will be undertaken outside the UK, supported by other governments. The question, therefore, is whether the UK should provide public sector support or rely on other countries to do so, then either importing the most cost effective LCTs in order to meet climate change related targets or when they become cost effective in their own right.

This issue was highlighted in the Stern Review:

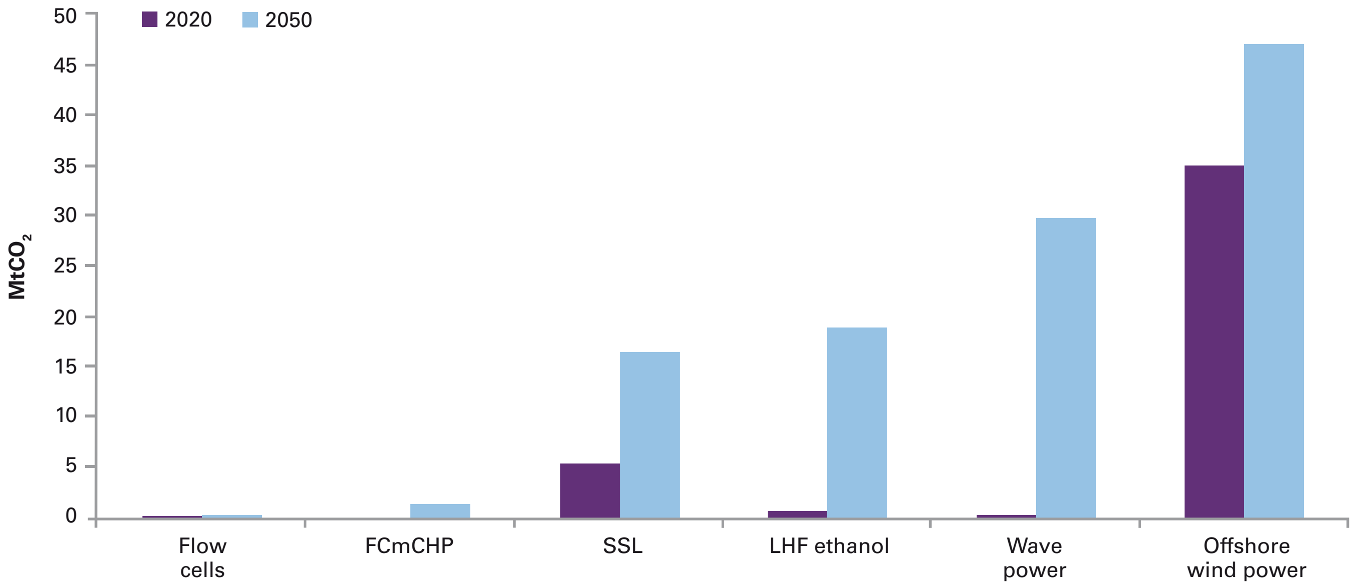
"Significant cross-border spillovers and a globalised market for most technologies offer an incentive for countries to free-ride on others who incur the learning cost and then simply import the technology at a later date."

As it is often viable to rely on other governments to support the innovation of LCTs and then import technologies developed abroad, under which circumstances should the UK actively seek to support the innovation of LCTs?

Through the course of this study we have identified two cases in which active involvement is justified.

- Innovating a LCT which is vital for meeting the UK's carbon targets and would not be available on the international market in time without the UK's support.
- Creating net economic benefit for the UK.

***Chart 4d** Carbon savings 2020 and 2050 by technology**



*Mid deployment scenario and emission factors of 0.38 $kgCO_2$/kWh for supply side technologies and 0.43 for demand side technologies.
Source: Technical consulta nts.

At least two LCTs are needed to meet carbon targets and are unlikely to be available from abroad without UK support

Looking at our sample of six LCTs, which were chosen to be representative of the range of challenges faced by emerging LCTs, both wave power and offshore wind power are needed to meet carbon targets and are unlikely to be available from abroad in time.

Needed to meet targets

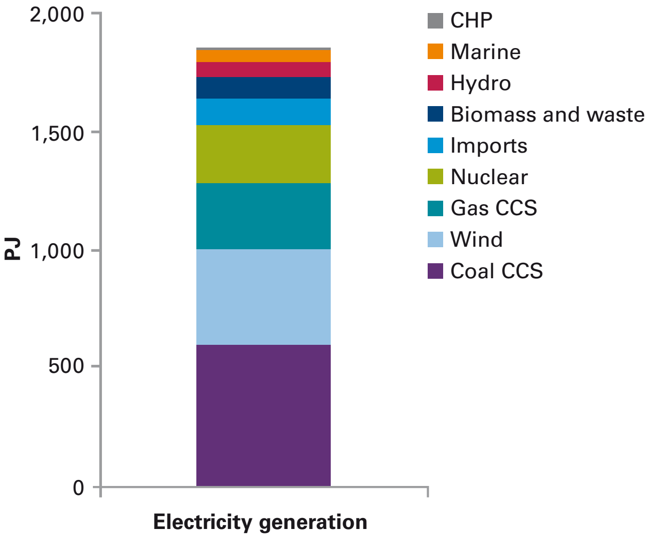
A number of the LCTs in our sample could make a material contribution to the overall carbon savings the UK requires (c.140-200MtCO_2e by 2020 and 500MtCO_2 by 2050, against a 2005 baseline). *Chart 4d* shows our estimates for carbon saving from our sample of six technologies. Simple inspection shows that, by 2050, offshore wind power, wave power, SSL and LHF ethanol could generate material savings.

Over this timeframe there is, of course, significant uncertainty. We therefore examine a number of scenarios under which the UK meets its 80% carbon reduction target to identify whether a technology appears in a number of instances. This is best done on a sector basis.

Looking first at the electricity generation sector, the 2050 CCC projections (see *Chart 4e*) show a reliance on both wind and marine. The amount of wind power implies a heavy reliance on offshore wind power. In the CCC 80% reduction trajectories, wind power generates about c.400-450PJ of electricity, but spatial and other constraints are likely to limit onshore wind power to about 100-150 PJ[4], and so the remaining 250-300PJ would come from offshore wind power. Similarly for marine, the CCC trajectories show up to 60PJ of electricity generation. Although this could be all served by the Severn Barrage, because of the high degree of uncertainty around this single project, we have not included it in our central scenario. A more reasonable assumption is that tidal (barrage and stream) could deliver 30PJ[5], leaving the other 30PJ to wave. The 2020 EU renewable energy target creates a further driving force for the uptake of offshore wind (see section 3.2).

Turning to the transport sector, CCC projections for 2050 show up to c.100PJ of ethanol is used as transport fuel in the UK (see *Chart 4f*). Although this demonstrates a need for biofuels, that requirement could either be met by imports or by production in the UK using technologies other than LHF ethanol. A similar situation exists for the biofuel component of the 2020 renewable energy targets.

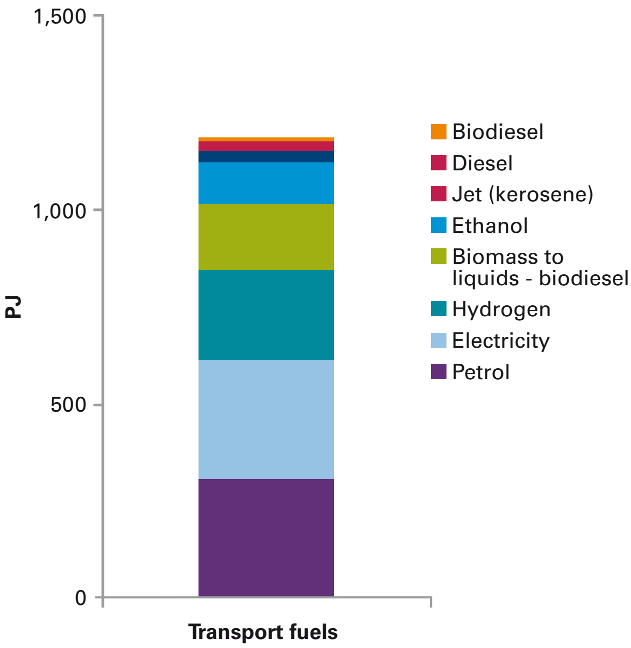
Chart 4e *Breakdown of UK electricity generation in 2050, Committee on Climate Change core scenario**



*Assuming 32% renewables in 2020 and central energy prices.

Source: MARKAL Modelling undertaken for the Committee on Climate Change.

Chart 4f *Breakdown of UK transport fuels use in 2050, Committee on Climate Change core scenario**



*Under central energy prices.

Source: MARKAL Modelling undertaken for the Committee on Climate Change.

[4] Carbon Trust 'Offshore wind power: big challenge, big opportunity', 2008.

[5] Assumes all the economic tidal stream resource (see Carbon Trust, 'Future Marine Energy', 2006) or 2/3 of the tidal stream resource plus a small (1GW) Severn barrage scheme.

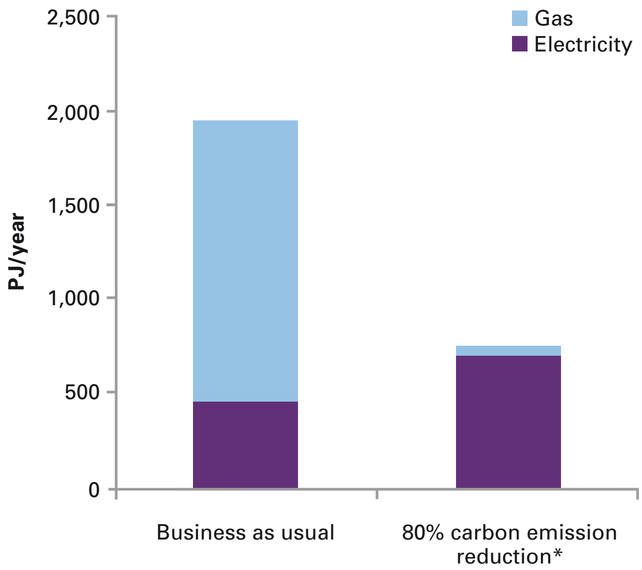
CCC projections do not explicitly cover the heat sector. However, they do cover the residential sector, a significant part of the potential for FCmCHP. These show that gas-based heating is substituted by electrical heating (see *Chart 4g*), with FCmCHP not entering the scenario because rapid grid decarbonisation reduces its carbon saving[6]. This supports the findings of our analysis (see section 3.3). In the draft Renewable Energy Strategy, DECC did not identify FCmCHP as a key heat technology to meet the 2020 renewable energy targets[7].

Two pieces of research establish that carbon savings from the lighting sector will be required both for near and long-term targets. SSL will inevitably be a major contributor to any savings required from lighting (alongside improved controls, sensors, etc.). Firstly, CCC's projections for 2020 show that across domestic and non-domestic sectors, cost effective energy efficient lighting will be needed to contribute significantly towards the 2020 target. Secondly, the Carbon Trust will shortly be publishing an in-depth analysis of the implications of an 80%+ reduction in carbon emissions from non-domestic buildings for both policy makers and industry. It will show that there is little choice long term in the range of measures that need to be deployed in non-domestic buildings – almost all available measures will have to be implemented to meet the long-term target. Furthermore, almost all cost effective measures will have to be implemented by 2020 if emissions are to travel along a trajectory to 80% by 2050. As SSL will probably be cost effective by the middle of the next decade, then it will certainly need to be in large-scale deployment by 2020.

There does not seem to be a clear carbon case for flow cells. Flow cells have the potential to help manage system variability relating to increased intermittent renewables capacity and, in so doing, save carbon by enabling stored renewable electricity to meet peaks in demand, rather than using high carbon conventional reserve capacity. However, in terms of system management, CCC projections (see above) indicate a penetration of intermittent renewables of 25% by 2020, which is manageable within the current system[8] and over the longer term flow cells are not the only or most advanced alternative technology to manage high levels of intermittent electricity generation.

Flow cells would therefore have to compete against a number of alternatives, including increased use of open cycle gas turbines (OCGT) as standing reserve, other storage technologies such as batteries and wider grid interconnections. Furthermore, modelling suggests that the carbon savings will not materially contribute to targets in comparison with other more established ways to manage high levels of intermittent electricity generation such as additional OCGT as standing reserve (c.0.2MtCO_2 by 2050).

Chart 4g *Breakdown of residential sector final energy demand by fuel type, 2050*



*Assuming 33% renewables in 2020 and central energy prices.

Source: AEA, 'MARKAL-MED model runs of long-term carbon reduction targets – phase1', 2008.

[6] Source: Committee on Climate Change; personal communication, 2009.

[7] Source: BERR, 'UK Renewable Energy Strategy Consultation', 2008. To deliver a 14% target for renewable heat, a mix of technologies will be needed across residential, business and public sectors. The mix of energy put forward in the draft strategy include biomass, heat pumps, solar water heating and biogas.

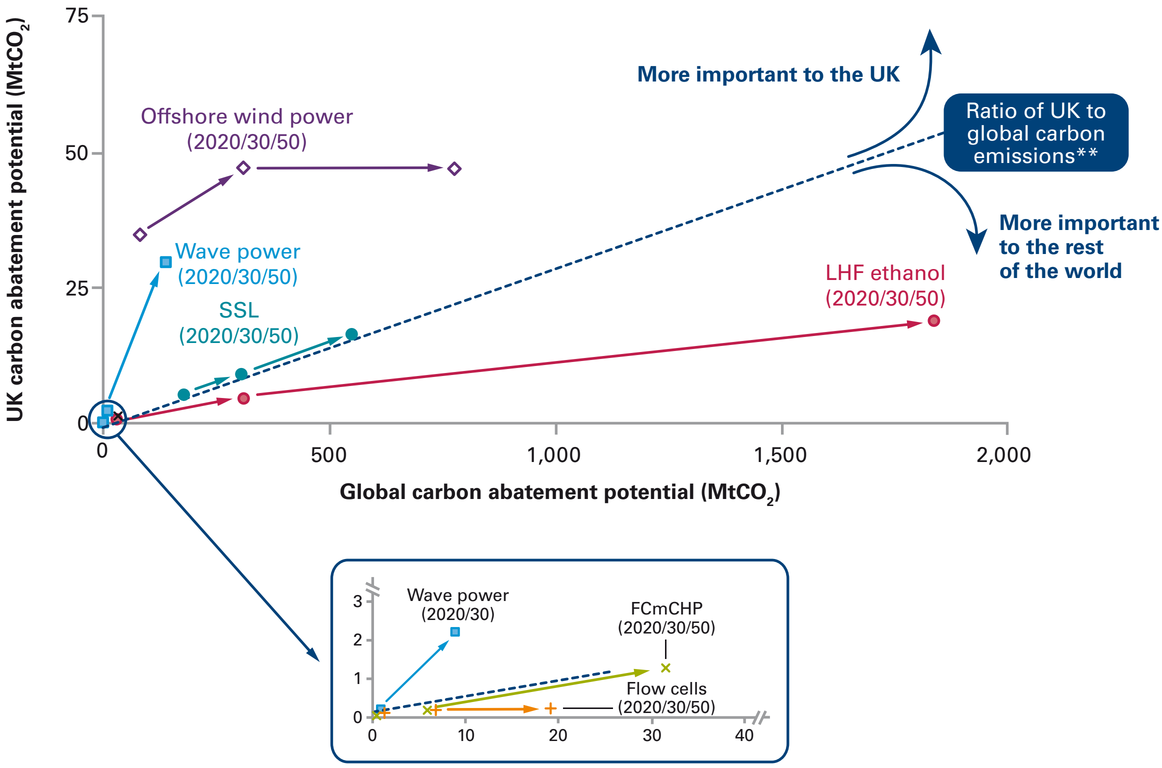
[8] Source: Carbon Trust, 'Offshore wind power: big challenge, big opportunity', 2008.

Based on the above analysis, we have classified the LCTs in our sample of technologies according to the UK's need for each in order to meet carbon targets (see *Chart 4h*). There is clearly some element of judgement in this classification, so we frame our conclusions in terms of likelihoods. This overall judgement is supported by analysis of the relative carbon abatement generated by our sample of LCT in the UK compared with the rest of the world (see *Chart 4i*). This shows that, relatively, the carbon abatement from offshore wind power and wave power is much more critical to the UK than the rest of the world. On the other hand, LHF ethanol is, relatively, much less important to the UK, because growth in demand for transport fuels is expected to be greater outside the UK.

Chart 4h *Classification of our sample of six technologies according the UK's need for each in order to meet climate change related targets*

Needed to meet targets?	2020	2050
Strong likelihood	• Offshore wind power	• Offshore wind power • Wave power • SSL
Potentially	• SSL	• LHF ethanol
Low likelihood	• Wave power • FCmCHP • Flow cells • LHF ethanol	• FCmCHP • Flow cells

Chart 4i *UK and global carbon abatement by potential technology**



*Mid deployment scenario. **Gradient based on the ratio of global to UK carbon emissions from the use of fossil fuels in 1990.

Source: Technical consultants, Energy Information Administration, International Energy Annual 2006, updated 2008, Carbon Trust analysis.

Availability from abroad without UK support in time to meet targets

Availability to meet 2020 targets

Of our sample of LCTs, offshore wind power and, potentially, SSL, seem necessary in order to meet 2020 targets.

To meet 2020 targets the UK needs to start deploying offshore wind now. Investment in innovation will reduce the cost and increase the likelihood of meeting the target. The option of buying in the technology when cost effective or fully commercialised is not available as that will be too late (see section 3.2 for further details).

SSL, which might also be needed to meet the UK's 2020 target, is likely to commercialise without the support of the UK. The investment required for SSL to reach cost competitiveness is being put forward by the major lighting manufacturers (e.g. Philips and Osram, which already hold over 25% market share in LEDs, including non-lighting applications). These companies, which are based outside the UK, are driving forward SSL because of a combination of the threat of new regulations and the potential for high learning rates leading to cost reductions and increased margins for manufacturers. As a result widespread deployment is likely to commence by 2014 in time for the UK to achieve significant savings by 2020 (see section 3.1 for further details).

Availability to meet 2050 targets

In addition to offshore wind power, wave power is likely to be needed to meet the 2050 target. UK support is likely to be needed to pull through this technology as:

- The UK has one of the best resource endowments in the world, for example the UK represents c.50% of total European resources and is one of the key locations worldwide where high power wave fronts are situated close to a populous area – see section 3.4.
- The UK is the base for a high proportion of the developers' worldwide (see *Chart 4j*).

In contrast, we expect LHF ethanol, flow cells and FCmCHP to commercialise in a timely fashion without UK support because the main development efforts are occurring outside the UK, backed by significant public funding from, among others, the US, Germany and Japan.

Chart 4j *Global and UK technology developers, 2009*

Technology	Number of developers globally	Proportion in the UK*
Wave power	~75	~25%
Flow cells	~20	~15%
LHF ethanol**	~20	~10%
Offshore wind power***	~10	~10%
FCmCHP	~30	~7.5%
Solid state lighting^	~5	~0%

*Developers with principal or significant RD&D or engineering facilities in the UK.
**Developers with facilities greater than 1 million l/year.
***Turbines only.
^Five major LED lighting manufacturers – device only (excludes luminaires).
Source: Technical consultants, Carbon Trust analysis.

In summary, our analysis indicates that offshore wind power and wave power are examples of LCTs which the UK must develop as they are likely to be needed to meet UK climate change related targets and are unlikely to be available from abroad in time without UK support (see *Chart 4k*).

LCT innovation can create economic benefit

Detailed analysis of our sample of six LCTs has shown that the UK could well generate significant net economic benefit by being an active player in technology development and through the delivery of effective innovation and economic development policies.

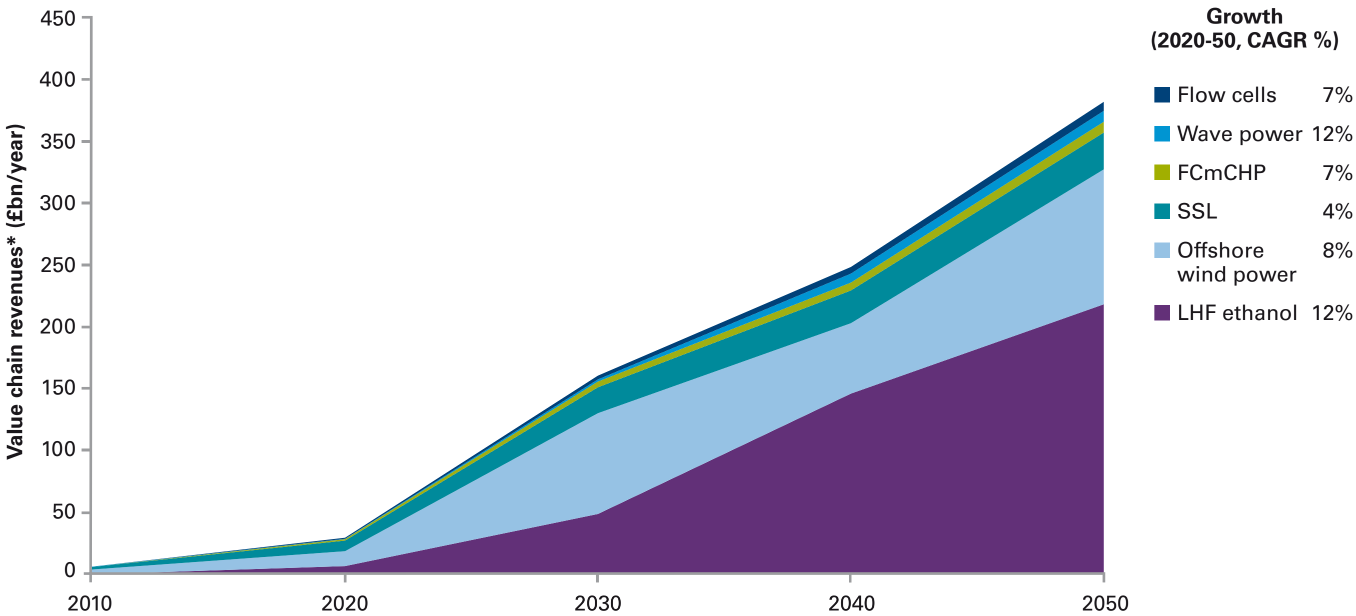
It should be stressed that this evaluation of net economic benefit is not an exact science as it involves a large number of imponderables over a long period of time (our analysis goes to 2050). However, it does allow the key uncertainties to be identified, a variety of plausible scenarios to be created and a judgement to be made on the likelihood of a technology generating a positive net economic benefit for the UK.

Chart 4k *Classification of our sample of six technologies according to UK need and availability from abroad*

Technology	Needed to meet UK climate change related targets?	Not available from abroad in time without UK support?	
Offshore wind power	✦✦✦	✦✦✦	• Must develop
Wave power	✦✦✦	✦✦✦	
SSL	✦✦✦	✦	• Choose to develop based on economic benefit • Import when cost effective
LHF ethanol	✦✦	✦	
FCmCHP	✦	✦	
Flow cells	✦	✦	

Key: ✦✦✦Strong likelihood ✦✦Potentially ✦Low likelihood

Chart 4I *Projected global market revenues by LCT, 2010 to 2050**



*Includes sale of equipment, installation and operations and maintenance; excludes feedstocks and sales of energy, mid deployment, central energy price and high learning scenario, in real terms at 2008 prices.

Source: Technical consultants, Carbon Trust analysis.

These are sunrise industries with substantial opportunities for the UK

High growth potential leading to major global markets

In general our sample illustrates the very substantial market potential for LCTs. *Chart 4I* shows that in total the global market for these LCTs could be worth around £400bn/year in 2050. LHF ethanol could be the largest market, worth up to £200-250bn/year followed by offshore wind power (c.£110bn/year) and SSL (c.£30bn/year). Wave power, FCmCHP and flow cells are expected to be smaller but nevertheless substantial markets (£7-10bn/year each). These figures include all the revenues generated by the development, fabrication, installation and operation and maintenance of the LCT, excluding feedstocks and sales of the energy output.

As these markets are small or non-existent at present, they are expected to enjoy rapid growth of between 4-12%/year to 2050, driven by substitution into vast high carbon product markets.

It should be noted that these are 'success' scenarios in that they assume that these technologies are 'technically successful'[9] and capture a significant proportion of their potential. As such they provide a good test of whether the LCT can deliver positive economic benefit for the UK. For further details on the potential global markets for these LCTs see their individual summaries in Chapter 3.

Substantial UK revenue and jobs potential

The ability of the UK to exploit these markets is driven by both the natural location of the economic activity and the strengths the UK brings to these markets[10]. A number of the value chain activities will always be largely served by UK-based companies, for example, the installation of devices and their operations and maintenance in the UK. One possible exception is the installation of offshore wind turbines which could be done from non-UK North Sea ports. For our sample of six LCTs, installation and operations and maintenance range from 30% to 80% of total domestic value chain revenues, although are typically about 50%.

[9] Based upon passing proofs of principle, concept, viability, scalability and durability.

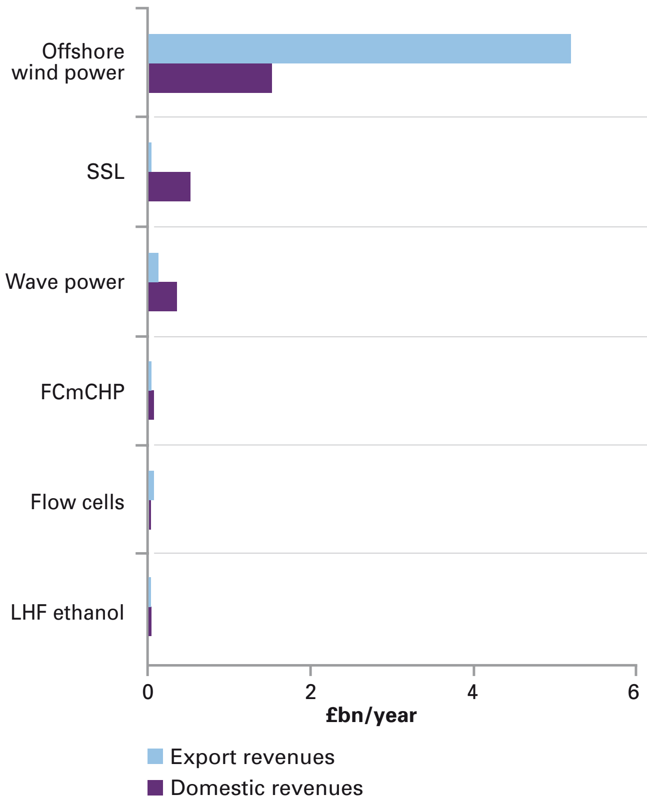
[10] When referring to the UK we mean economic activity undertaken in the UK, whether UK-parented or not, serving both the domestic and export market. UK parented companies whose economic activity is based outside the UK are excluded.

Other parts of the value chain, typically R&D, engineering and design, and manufacturing and fabrication, are more open to trade. This is dictated by whether importing is technically feasible and, among other factors, the costs of transport being small compared to economies of scale. There are both opportunities and threats for the UK in these parts of the value chain – opportunities to generate export sales for UK-based companies and the threat of import penetration into the UK market. These typically represent about half of value chain revenues. In some cases, only a portion of the global tradeable sector of the value chains is accessible to companies based in the UK. For example, FCmCHP units can be exported across Europe but not to other regions due to the cost of transport and differences in technical standards.

The UK's ability to exploit the tradeable sector of these value chains depends on the key strengths it brings, compared to companies based in other countries.

Our views of the UK's key strengths and hence the potential for the UK to capture market share are summarised in *Chart 4m*. This shows that the UK can capture a very significant portion of the domestic value chains for all the LCTs in our sample, ranging from 80% for wave power and FCmCHP to 60% for LHF ethanol. In those LCTs where the UK has marked strengths such as wave power, offshore wind power and to a certain extent FCmCHP and flow cells, we expect a significant share of the tradeable part of the global market – particularly as in those LCTs the market for device exports is probably limited to Europe due to transport costs and other factors.

Chart 4m *UK companies' domestic and export revenues, key strengths and global value chain share of market by LCT, 2030**



	Market share of UK companies (%) Domestic	Export	Key UK strengths
Offshore wind power	65	10	• Resource base • Largest market to 2020 • Offshore expertise (from oil and gas)
SSL	75	0.5	• Research base • Niche luminaire and lighting design
Wave power	80	10	• Resource base • Home to many leading developers • Research base and test facilities • Offshore expertise (from oil and gas)
FCmCHP	80	2	• Fuel cell research base • Leading developers
Flow cells	60	5	• Legacy of major developments • Research base
LHF ethanol	60	0.1	• Research base in plant genetics, separation technologies and bioprocess engineering

*Mid deployment, central energy prices, and high learning and UK market share scenario.
Source: Technical consultants, Carbon Energy Trust analysis.

The market shares above, together with our central scenario of global market size (see section 4.5.1), allows us to estimate both UK revenues and, using typical ratios, UK jobs (see *Chart 4n*).

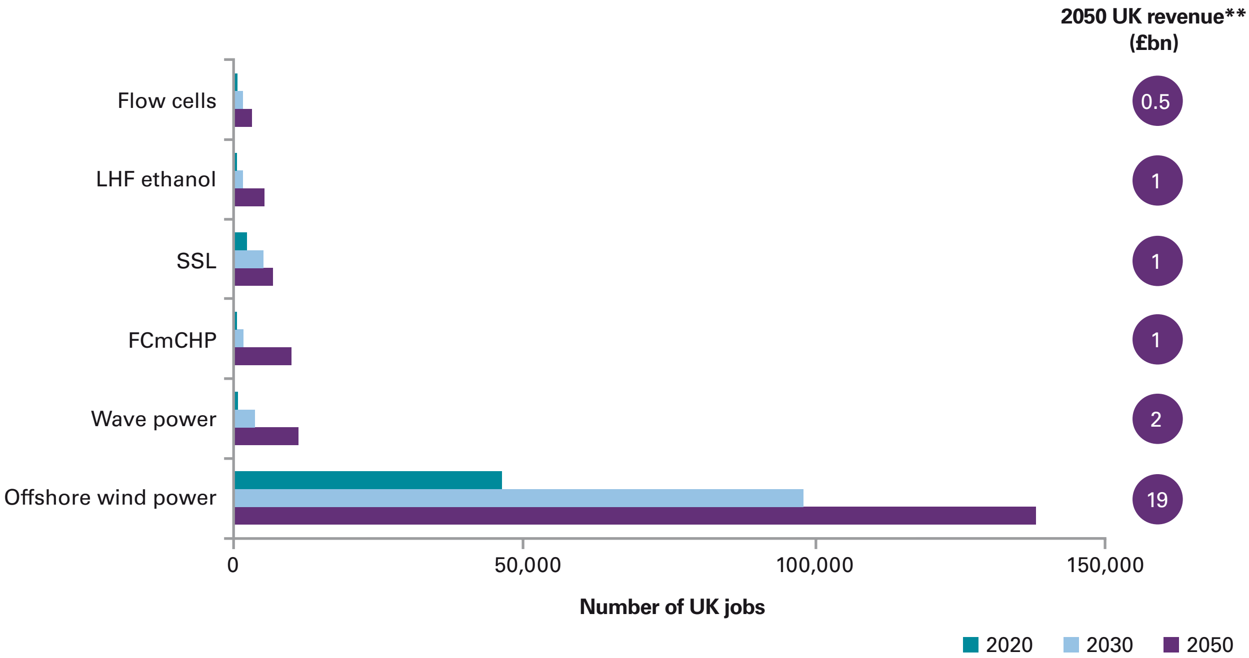
Our representative sample of six LCTs have the potential to create up to 175,000 direct 'green jobs' and generate revenues of up to ~£25bn per year by 2050. The UK is likely to have the significant competitive advantage in the secondary service sector – particularly in areas such as finance and legal services. This will create jobs in addition to the direct jobs shown in *Chart 4n*. Most of the technologies in our sample are too embryonic to assess the level of secondary service jobs. However, it is possible to do so for offshore wind power as its development is further advanced. Including service jobs increases offshore wind power jobs in 2020 and 2050 from up to 50,000 and 135,000 to up to 70,000 and 220,000 respectively[11], illustrating the potential for service jobs in other similar technologies (e.g. wave power, LHF ethanol and flow cells).

Of the six sample technologies we examined, the majority of the UK revenue and job creation potential is in offshore wind power. Offshore wind power combines both a large global and domestic market with the potential for the UK to develop a strong base, building on existing skills and attracting key manufacturers. The UK could be the global market leader.

LHF ethanol and SSL are expected to be major markets globally, but in general, the UK is more likely to develop niche positions or focus on part of the value chain.

Wave power, FCmCHP and flow cells are likely to be somewhat smaller markets – although, in the case of the first two, the UK could be the leader or among the leaders, respectively.

Chart 4n *Estimated UK direct job creation by technology**



*Excludes displacement; mid deployment, high learning, high UK market share scenario.
**Revenue to UK based companies from the sale and operation of technology equipment, excludes sales of the output (e.g. electricity), at 2008 prices.
Source: Technical consultants; Carbon Trust analysis.

[11] Source: Carbon Trust, 'Offshore wind power: big opportunity, big challenge', 2008.

We have used a rigorous yet innovative approach to assess net economic benefit

In consultation with DECC economists, we have conducted a rigorous cost and benefit analysis of LCT innovation. We believe that this is the first time that such an analysis has been attempted in such a detailed way. We have estimated the net UK economic benefit generated by innovating each of our sample of six technologies compared with the alternative of importing the technology when it is cost effective[12].

There is considerable uncertainty around this assessment of job creation and net economic benefit. This is caused by uncertainties mainly in the effectiveness of innovation, market uptake and economic conditions (such as energy prices and the extent that labour and capital is otherwise fully engaged).

Our assessment included all the relevant costs (public and private sector RD&D spend and the additional cost of the LCT over conventional technology) and the benefits (value-added to national income[13] and carbon benefits) and we have used a number of scenarios to examine the range of possible outcomes. For further details see Chapter 2 – Approach and Methodology.

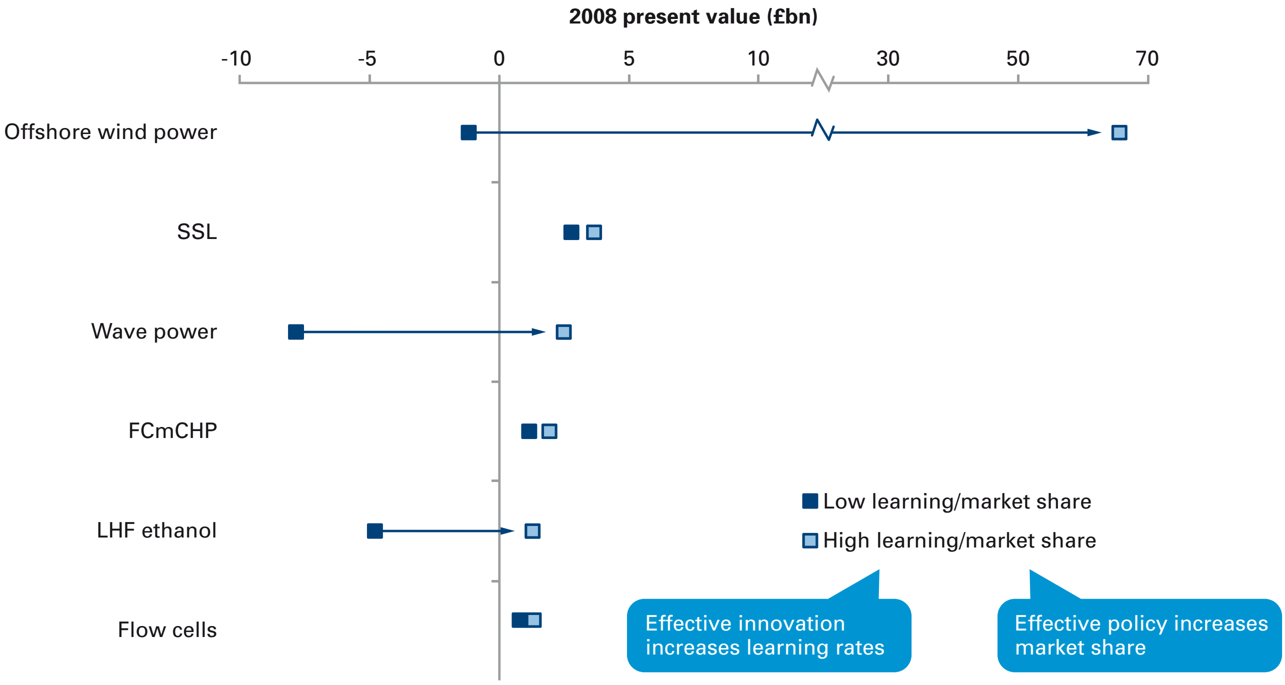
Effective innovation critical to generating economic benefit

Chart 4o shows the results of the net economic benefit analysis excluding displacement effects. This shows that all six technologies can generate economic benefit for the UK although, as with jobs, the major contribution is from offshore wind power. *Chart 4o* also illustrates clearly the importance of effective innovation.

If innovation is effective it will lead to faster learning (and therefore lower costs) and greater UK market share in both export and domestic markets. For example:

- At central energy prices, offshore wind generates an economic cost of around £1bn for the UK at low learning and UK market share. However, with more effective policy it could generate significant net economic benefits of c.£65bn.

***Chart 4o** Net economic benefit to 2050 excluding displacement effects**



*Mid deployment and central energy prices scenario. BERR central scenario assumes crude oil prices of $65-75/bbl.

Source: Technical consultants, Carbon Trust analysis.

[12] Based on comparing UK innovation of an LCT with a scenario of importing it when cost effective, both assessed against a counterfactual of 'business as usual'.

[13] Value added defined as UK salaries plus employers National Insurance contributions plus UK profits.

- Effective innovation policy will help to increase learning rates from the lower end of those exhibited by onshore wind (9%) to the higher end (15%). Increased RD&D, in both new and existing components, and maximised economies of scale will fulfil this potential for cost reduction.
- Effective integration of innovation and economic development activity will also help to attract major existing or new turbine manufacturers to base all of their offshore wind operations in the UK, draw in the associated supply chain, maintain the UK's strong position in services (e.g. finance and legal) and capture 55-60% of installation activity in the UK. This would create a cluster capable of maintaining a strong UK position in the regional European market beyond 2020.

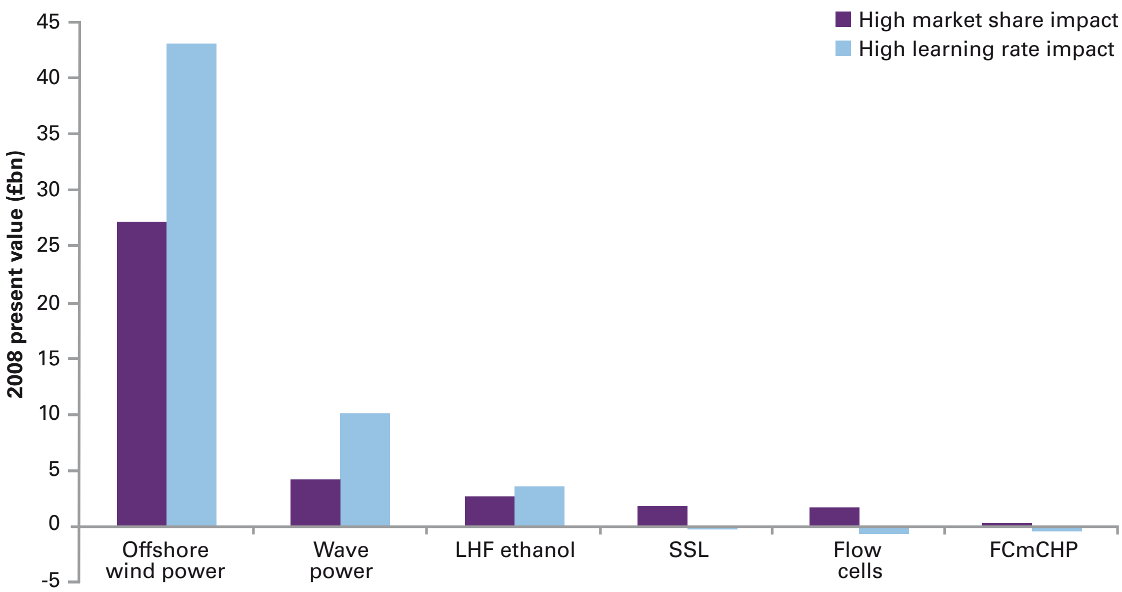
A breakdown of the impact of learning and market share for all six of our sample of LCTs is shown in *Chart 4p*. This shows that both faster learning and increased market share significantly increase the net economic benefit over the low learning/market share case.

In some cases, learning can have a double edged effect. Generally increased learning decreases deployment costs and so increases economic benefit as demonstrated by offshore wind power, wave power and LHF ethanol (see *Chart 4p*). However if a LCT is close to being cost effective, perverse effects can occur.

The reduction in deployment costs caused by increased learning can be outweighed by the decrease in value added through lower costs and therefore lower market revenues in the sector (e.g. FCmCHP). In general these effects are modest.

Our detailed LCT assessments suggests that a number of factors are important in fostering fast learning, including: consistent and seamless support (its opposite, stop-start support is guaranteed to slow learning); and an 'infrastructure' to facilitate learning (such as well targeted, specific networks).

Chart 4p *Impact of high learning and market share on net economic benefit to 2050 excluding displacement effects**



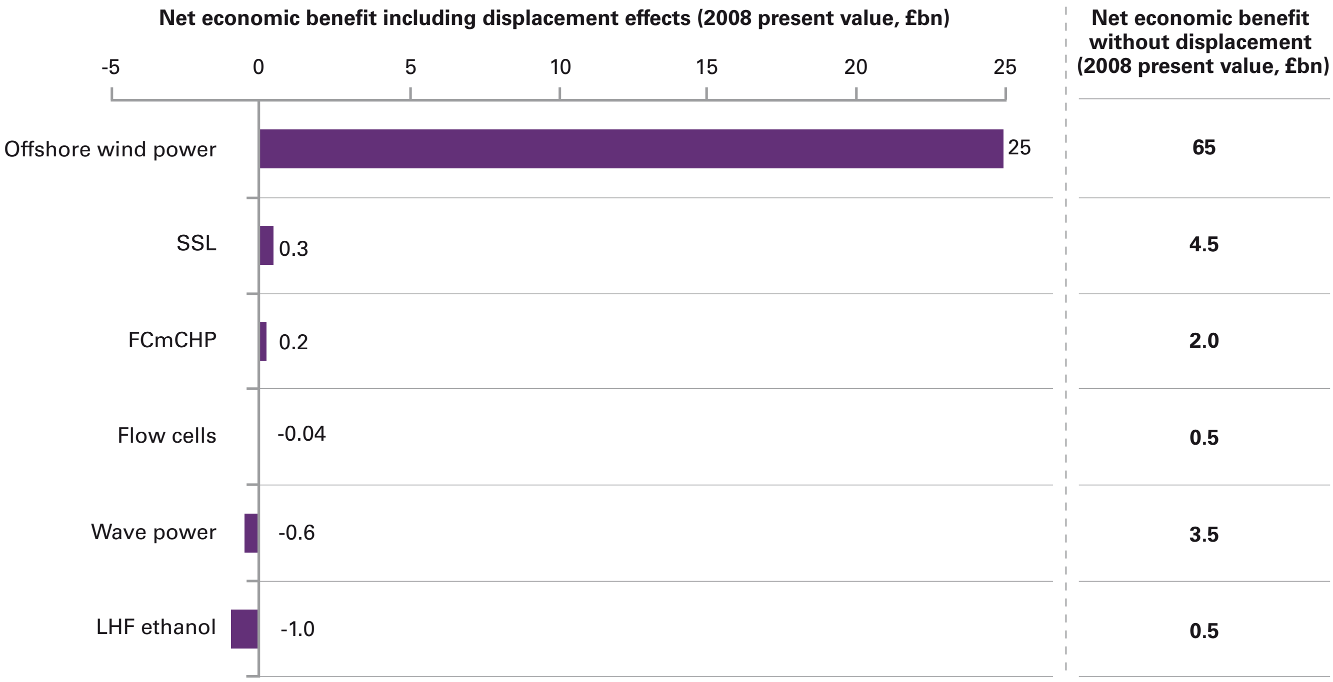
*Mid deployment and central energy price scenario.
Source: Technical consultants, Carbon Trust analysis.

Three of our sample of technologies generate net economic benefit after displacement effects

Displacement effects, which allow for the fact that labour and capital used in LCT-based industries may otherwise have been used productively, also have an important impact. Displacement effects are more likely to be significant when the economy is working at capacity, although this is not the case in times of recession.

Chart 4q shows net economic benefit including displacement effects using fit for purpose assumptions[14] developed in consultation with DECC economists. Even including displacement effects, three of our technologies (offshore wind, SSL and FCmCHP) show positive net economic benefit at central energy prices and assuming effective innovation, with offshore wind presenting the most compelling net economic benefit of c.£25bn.

Chart 4q *UK net economic benefit to 2050 including displacement effects, high learning and market share scenario**



*Mid deployment and central energy price scenario.
Source: Technical consultants, Carbon Trust analysis.

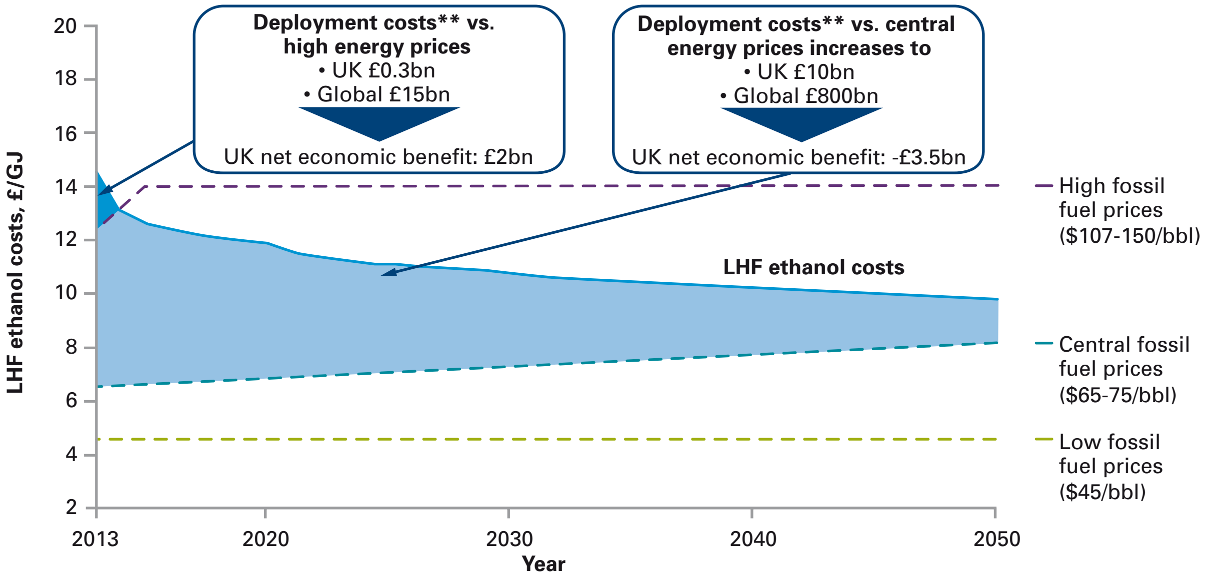
[14] See Chapter 2: Approach and Methodology.

High energy prices dramatically increase economic benefit

Finally energy prices can have a significant impact. For example, at central energy prices LHF ethanol is a drain on the UK economy; a cost of c.£3.5bn to 2050. However, at high energy prices, it could generate a net economic benefit of around £2bn. This is driven mainly by lower deployment support costs (vs. mineral-based transport fuels). This is effectively illustrated by the 'area under the curve' in *Chart 4r*, which shows the costs of LHF ethanol falling with time.

In the high fossil fuel price scenario, LHF ethanol becomes cost effective (and therefore no longer needs public subsidy) in the next decade, but does not become cost competitive until after 2050 in the central energy price scenario[15].

Chart 4r *LHF ethanol production cost and required deployment support at varying fossil fuel prices**

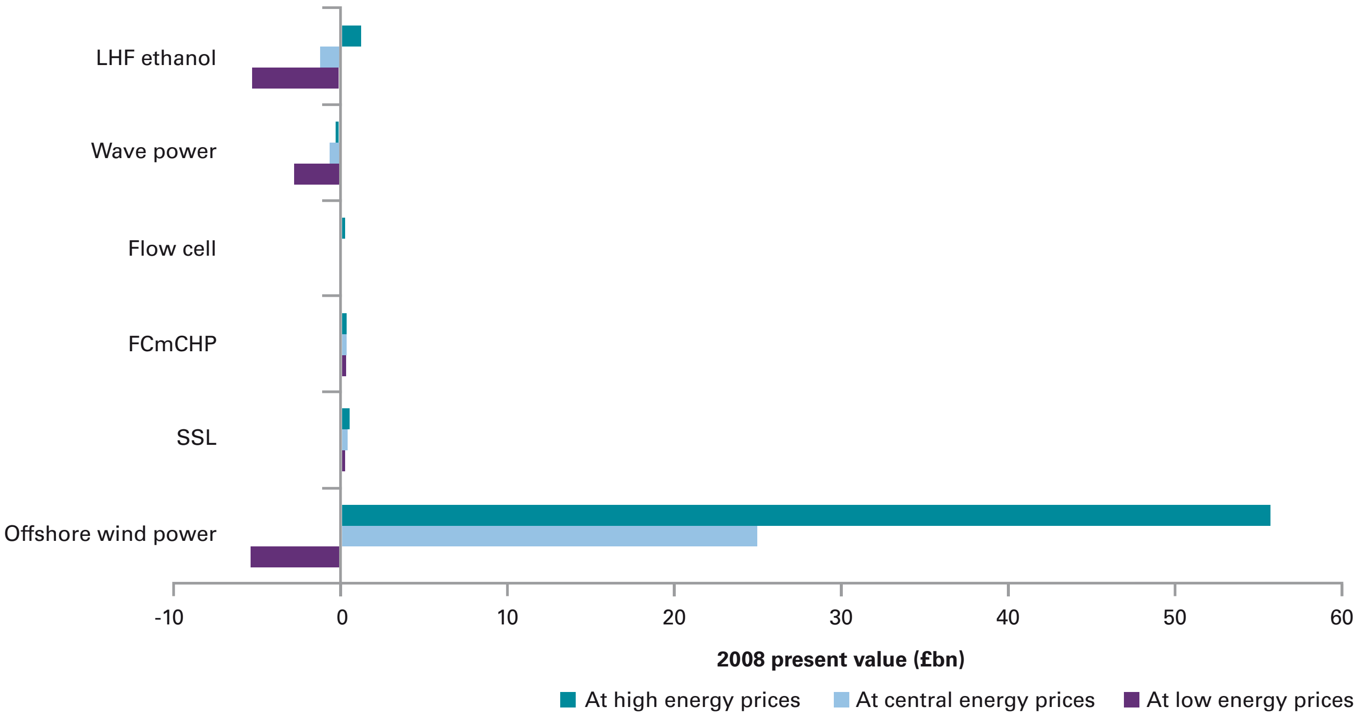


*Includes displacement effects, mid deployment, central feedstock prices, mid learning and high UK market share scenario.
** 2008 present value.
Source: Technical consultants, Carbon Trust analysis.

[15] All at central feedstock prices which show prices dropping slightly from £2.5/GJ in 2010 to £1.5/GJ in 2050.

The impact of high and low energy prices is particularly material for offshore wind power, LHF ethanol and wave power (see *Chart 4s*), with none of these generating a net economic benefit at low energy prices. Flow cells, SSL and FCmCHP economic benefit is far less affected by energy prices. For example, FCmCHP is not significantly affected as its economics are driven mainly by the difference between gas and electricity prices rather than their absolute level.

Chart 4s *Variation of net economic benefit to 2050 (including displacement effects) with energy prices**



*Using mid deployment, high learning and high UK market share scenario.
Source: Technical consultants, Carbon Trust analysis.

Other reasons potentially exist to justify LCT support

Two other reasons also justify UK support of LCT innovation, although they have not been a focus of the quantitative analysis that underpins this report:

- Increased deployment of LCTs which contribute to security of supply and would not be available in time without the support of the UK.
- Establishing or reinforcing the UK's leadership role on climate change as an international collective action issue.

(a) Security of supply

Countries have differing levels of energy security that may lead to justification of support for a technology on grounds of security of supply. For example, the USA presently provides high levels of support for biofuels innovation as a potential long-term solution to its dependence on foreign oil for transportation, and Denmark originally supported wind development principally for security of supply reasons[16].

As noted in the Stern Review, security of supply issues support the promotion of both renewable energy technologies – because these are generally local (e.g. wind, solar, wave) – and energy efficiency technologies which reduce demand for energy imports. While this study has not addressed security of supply issues for the UK in detail, there is a strong overlap with carbon reductions.

(b) Leadership role

Climate change is a global collective action problem. Taking a leadership role may catalyse greater efforts world-wide and, in the long term, prove an effective use of resource, albeit one that is based on political rather than an economic judgement. Accordingly, it has not been a focus of the analysis and is not taken further in this study.

[16] Source: LEK.

5. The cost of innovation and the need for prioritisation

The large number of LCT options, the high cost of commercialising LCTs and finite UK resources means the UK needs to prioritise its support of LCTs.

Summary

- There are a wide range of LCTs which might potentially be used by the UK to reduce carbon emissions.
- The costs required for the UK to innovate LCTs are very considerable – particularly when they reach the large-scale deployment stage. Given that the UK accounts for just 1-2% of RD&D spend in IEA member countries, we can only have a material impact in a limited number of LCTs. So it is not possible for the UK to support all LCTs through until commercialisation.
- Therefore, in order to make smart investment choices, the UK needs a prioritisation framework. We have tested our framework, which is based on the potential importance to carbon targets and net economic benefit differentiating between earlier and later stage technologies, and found that it is a potentially useful tool.
- Government has already started to move in this direction, for example, the recently announced competition for CCS. However, with around 50 technology families, all at different levels of maturity, there is a need for a more thorough and transparent prioritisation process which analyses all relevant LCTs in a consistent manner.

Many LCT options

There are a wide range of LCT options for the UK, all of which could contribute a certain degree to meeting carbon targets. Therefore there are a vast number of possible portfolios of technologies which could be supported. The six technologies we have assessed represent just a small proportion of the LCTs which might potentially be used by the UK to reduce carbon emissions.

The Carbon Trust, through its Low Carbon Technology Assessment (LCTA) (see *Chart 5a*) currently recognises around 50 different types of LCTs stretching from mature technologies which are competitive without subsidy (such as large hydro), to the very early stage technologies which are mainly in the R&D stage (such as advanced PV), almost all of which have innovation requirement and, potentially, could be supported by the public sector.

For ease of analysis within the LCTA, some technology families have been aggregated to broader technology categories, such as industrial processes and buildings materials, and so the number of technologies is actually much greater. For example, building materials encompass a wide range of insulation materials (e.g. rock wool, glass wool, polystyrene, polyurethane, polyisocyanurate, etc.) all produced from different raw materials using very different processes and often installed in very different ways.

Within each technology family, there are often a large number of different variants or device types. For example, in wave power, there are three different resource types (nearshore, offshore and shoreline) and at least five fundamentally different technology types (oscillating wave surge converter, attenuator, overtopping device, oscillating water column and point absorber and some devices also involve a combination of these different types). This has led to over 70 different devices being in development. Similarly with biofuels, the wide range of feedstocks and conversion technologies means that there are a large number of paths which can be used, each requiring different fundamental technologies.

Chart 5a *Technologies reviewed in the Carbon Trust 2007 Low Carbon Technology Assessment*

Category	Technology families
Demand-side: buildings	Building control Building cooling Building heating Building materials Lighting
Demand-side: industry	Industrial equipment (general) Industrial process/system (general) Industry-specific equipment Industry-specific processes
Transport	Biofuels Hydrogen for road transport Improved road vehicles
Enabling technologies	Alternative hydrocarbons Buildings design Electrical energy storage Electricity transmission and distribution Grid connection and balance of system Hydrogen production Hydrogen storage Information systems for energy users Thermal energy storage

Category	Technology families
Supply-side: renewables	Advanced photovoltaics (PV) Biomass for heat Biomass for electricity Conventional PV Geothermal Large hydro Offshore wind Onshore wind Small-scale wind Small hydro Solar thermal electric Solar water heating Tidal: lagoons and barrages Tidal stream Wave: nearshore Wave: offshore Wave: shoreline
Supply-side: fossil fuels and nuclear	Carbon capture and storage Cleaner coal Coal mine methane Fuel cells: large static Fuel cells: portable Fuel cells: small static High efficiency Combined Cycle Gas Turbine (CCGT) Large-scale Combined Heat and Power (CHP) Nuclear fission Nuclear fusion Small-scale CHP

All of these technologies have the potential to save carbon in the UK, although both the quantum of carbon saving and associated cost/benefit will depend on various factors, including the availability of relevant natural resources (such as wind or sunlight), current infrastructure and the current and potential future costs of the technology.

This is also an ever-expanding list as fundamental scientific research and new technologies open up further options. Therefore, any list of options for support needs to be reviewed regularly and on an ongoing basis.

High costs of commercialisation

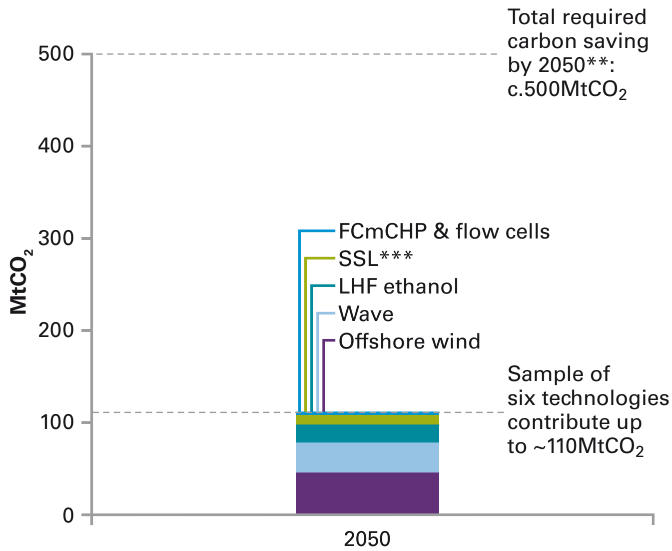
The costs of LCT commercialisation can be very high. Very significant investment is needed to fully commercialise an LCT – taking it through from research and development to demonstration (collectively known as RD&D) to supported and then commercial deployment, at which point a technology is cost effective. For example, in order to commercialise offshore wind the UK would need to spend up to £65bn[1] (2008 present value) in total until 2050 alongside similar investment from other leading countries, such as Germany.

Looking at our sample of technologies, we estimate the UK would need to spend around £90bn and possibly up to £180bn to 2050 (2008 present value) to take a significant role in innovating these six technologies. Furthermore, these six technologies would only deliver less than a quarter of the carbon saving the UK requires by 2050 (i.e. ~110MtCO_2 out of a total of 480MtCO_2 (see *Chart 5b*).

The wide range in potential costs illustrates the uncertainties involved in technology development, such as the likely learning rate and the nature of technological breakthroughs, if any.

However, in our sample those impacts are dwarfed by the impact of fossil fuel prices. When fossil fuel prices are high, LCT technologies, in comparison, are less expensive, reducing the public sector subsidy required. As can be seen in *Chart 5c*, this most affects the energy generating technologies, with LHF ethanol seeing by far the greatest impact.

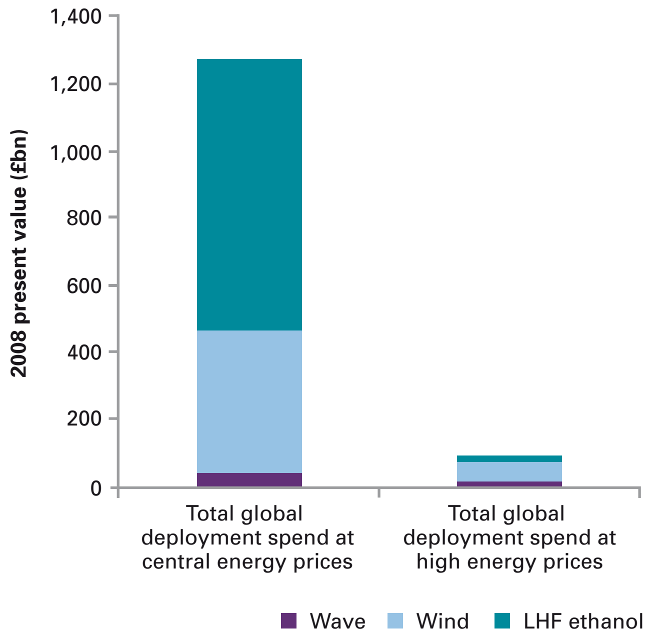
Chart 5b *Annual carbon saving required by the UK in 2050 vs. potential from our sample of six technologies**



*Abatement based on central deployment and standard emissions factors; these savings are not additive.
**vs. 2005 emissions, assuming 80% reduction on 1990 emissions in 2050.
***Incremental savings of SSL versus CFLs.

Source: Technical consultants; Committee on Climate Change, Defra, Carbon Trust analysis.

Chart 5c *Total global deployment support required for commercialisation at central and high energy prices for our sample of six technologies*



Note: SSL, FCmCHP and flow cells together comprise less than 1% of total spend.

Source: Technical consultants; LEK/Carbon Trust Analysis.

[1] This figure represents the additional cost to the UK economy as a whole at central energy prices and learning. With low energy prices and low learning this could rise to ~£105bn. Due to market failures, most of this is funded by consumers through policy initiatives such as the Renewables Obligation or, to a very small extent, taxpayers.

The UK's ability to provide support is limited by the level of resources it is able to commit to RD&D and deployment of LCTs.

It is difficult to determine with precision the current levels of public sector support given the varying time periods over which support is granted, the varying degrees of focus of mechanisms on LCTs and the variety of funding routes, but some high level findings can be drawn.

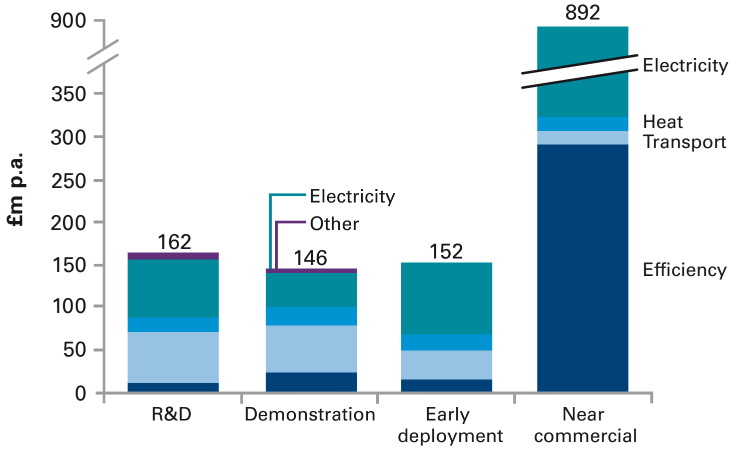
Chart 5d shows an indicative breakdown of the annual level of UK low carbon expenditure across technology stages and major emissions sectors. Total funding in 2007 was in the order of £1.4bn per year[2] and is concentrated on electricity (principally through the Renewables Obligation) and efficiency measures. While this will rise as the Renewables Obligation targets increase in coming years, clearly the UK would not be able to support too many LCTs at the required scale even with a significant increase in support funding.

Funding is also concentrated in the latter stages of deployment as the technologies near commercialisation, through the provision of subsidies for deployment of technologies that are mature, but not fully commercial, such as onshore wind. There is then a significant drop-off in funding to the early deployment stage, where deployment support is required to help demonstrated technologies mature and begin to move down their learning curves. Public support for the demonstration stage is slightly lower than at the R&D stage and the lowest across all four stages.

The degree of private sector investment in LCT innovation is extremely difficult to assess and we have not identified any reputable published figures. However, it is generally accepted the private sector financial contribution to LCT innovation is greater than the public sector support in the R&D and demonstration phases, although this is by no means clear in the large-scale deployment phase. Based on our sample of six technologies, some LCTs will commercialise largely through private sector investment (e.g. SSL), although this is likely to be the exception rather than the rule.

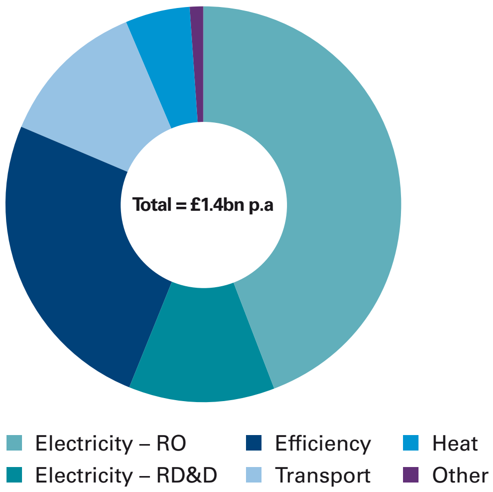
Chart 5d *UK public expenditure by technology stage of development and sector, 2007*

UK low carbon public expenditure by technology stage



Source: LEK.

Breakdown of total UK low carbon public expenditure by sector



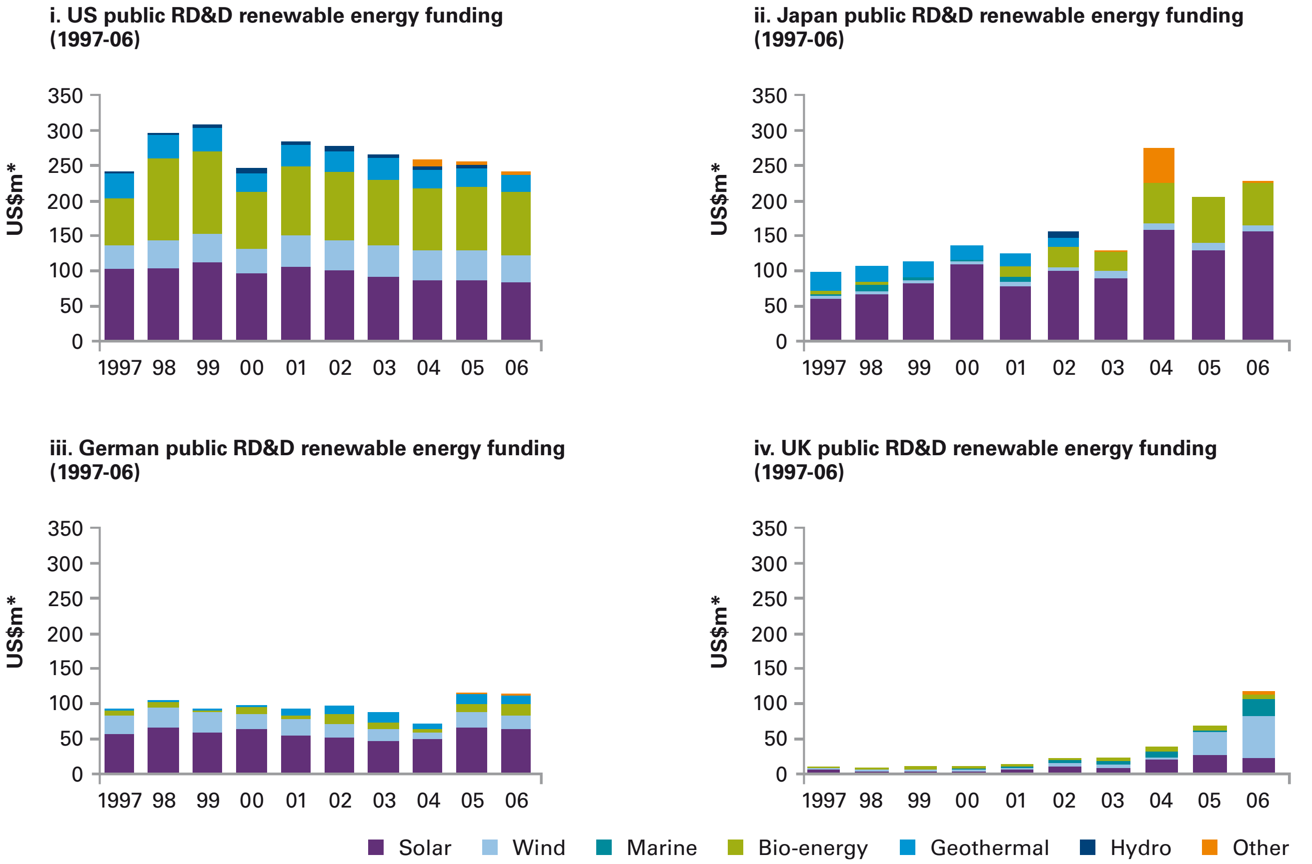
Source: LEK.

[2] Funding by UK consumers and taxpayers for RD&D and deployment costs, based on analysis for the Carbon Trust by LEK, prior to Budget 2009.

In terms of an international comparison, *Chart 5e* shows a comparison of RD&D funding for renewable energy in Japan, Germany, the US and the UK based on data collected by the IEA. On these figures, UK funding has increased sharply recently, but is about half of Germany's and roughly a quarter of the US and Japan. Overall energy RD&D in the UK was $134m[3] in 2005 or about 1.3% of total energy RD&D in IEA member countries.

Care needs to be taken in interpreting these figures as UK data excludes mechanisms such as the RO, which provides funding for demonstration as well as deployment, whereas similar mechanisms may be included in the figures of other countries. Given the high costs highlighted by our analysis, it is clearly not possible for such a small proportion of overall global spend to be able to support all potential LCTs through until commercialisation.

Chart 5e *Renewable energy RD&D funding in four OECD economies*



*2006 exchange rate.
Source: IEA.

[3] Source: IEA, at 2006 exchange rates.

Differentiated approach needed by stage of development

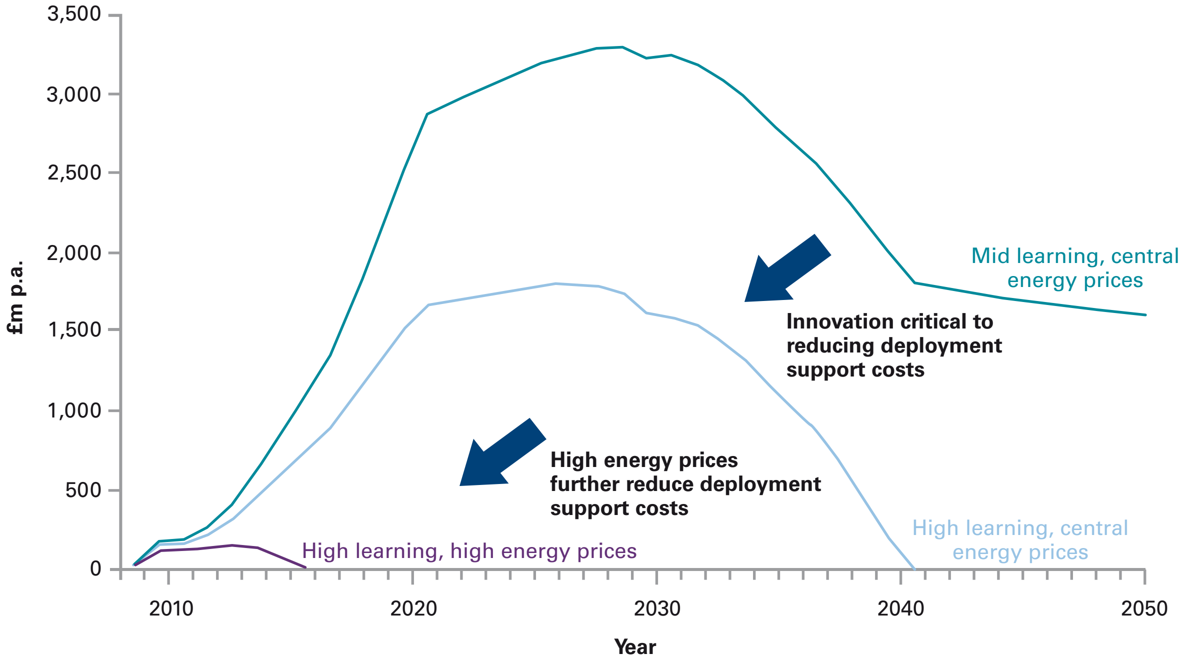
The nature and level of support required differs significantly depending on the level of technology maturity.

Required levels of public support for an LCT increase across its development lifecycle until the late stages of commercialisation, at which point funding can begin to be withdrawn. This is illustrated by our analysis in *Chart 5f* which shows how the cost of deployment varies with time for offshore wind, which is in the early part of large-scale supported deployment. The different lines show the impact of effective innovation and energy prices.

For offshore wind, under fast learning at central energy prices, the UK costs of deployment rise from around £150m/year in 2009 to a peak of just over £1,500m in 2020 and then decline as the costs of new turbines drop and older, less efficient turbines are retired. The total cost of deployment using these assumptions is around £20bn.

The overall costs are far higher if innovation is not accelerated. Under the mid learning deployment scenario, costs peak at c.£3,000m per year and the total cost is around £65bn (in present value terms). The UK costs of RD&D to help stimulate accelerated learning are much lower at around £0.5-1.0bn. The relatively small investment in RD&D is critical to reduce the overall deployment support costs. As illustrated in *Chart 5f*, high energy prices would further reduce the required support.

Chart 5f *UK deployment support costs for offshore wind power**



*Undiscounted at 2008 prices, excludes system costs.

Source: BCG; Carbon Trust analysis.

This phenomenon is replicated among most of the rest of our sample of six technologies. *Chart 5g* shows that typically, the cost of deployment can be around 40 times that of RD&D.

This means that in developing a portfolio or programme of support for LCTs, the following issues need to be taken into account:

- **Early stage –** supporting LCT innovation in the RD&D phase requires lower funding levels. However, there is also a high degree of uncertainty as to whether technologies will develop. Multiple options could therefore be supported to ensure that sufficient LCTs reach later stages of commercialisation, without needing excessive levels of public funding.
- **Deployment stage** – supporting LCTs which have reached the large-scale deployment phase[4] is an order of magnitude more expensive. The UK will have to choose very carefully which of the LCTs it brings into (large-scale) supported deployment as, given the costs, it may only be able to afford a small number of such technologies at the same time.

Chart 5g *UK RD&D and deployment support costs to 2050 – central scenario and range**

Technology	**UK RD&D costs to 2050*** (2008, present value, £bn)	**UK deployment support costs to 2050*** (2008, present value, £bn)
SSL**	0.1	0.1
Offshore wind	0.8	64
FCmCHP	0.06	0.1
Flow cells***	0.4	0.02
LHF ethanol	0.2	10
Wave	0.6	10
Total (Range)	**~2 (1 to 3)**	**~85 (3 to 175)**

*Figures in table represent central scenarios, ranges given for total including learning, deployment and fossil fuel price scenarios. The total central estimate of £87bn (present value) is equivalent to annual costs of c.£4bn/year to 2050.
**SSL is close to commercialisation so the remaining deployment costs are small.
***Main challenge is in RD&D – high potential learning rate means low deployment cost once large-scale deployment begins.

Source: Technical consultants, Carbon Trust analysis.

[4] The point at which a LCT reaches large-scale supported deployment depends on the characteristic of the technology. For example, wave power is likely to increase in scale of deployment gradually, from current installed scale (~1MW) to 2-5MW to 15-25MW, to 50MW and onwards toward commercial sized farms. LHF ethanol, on the other hand is likely to jump directly from initial demonstration plant to full scale plant.

A prioritisation framework is needed

All this would seem to suggest that in order to make smart investment choices, there is a need for the UK to carefully prioritise its support for LCTs as the public sector costs of supporting the innovation of an LCT can be very high compared with the resources available and there are many different LCTs which could require support. As seen above, this prioritisation decision is particularly important when LCTs reach the large-scale deployment phase as the cost of support rises dramatically.

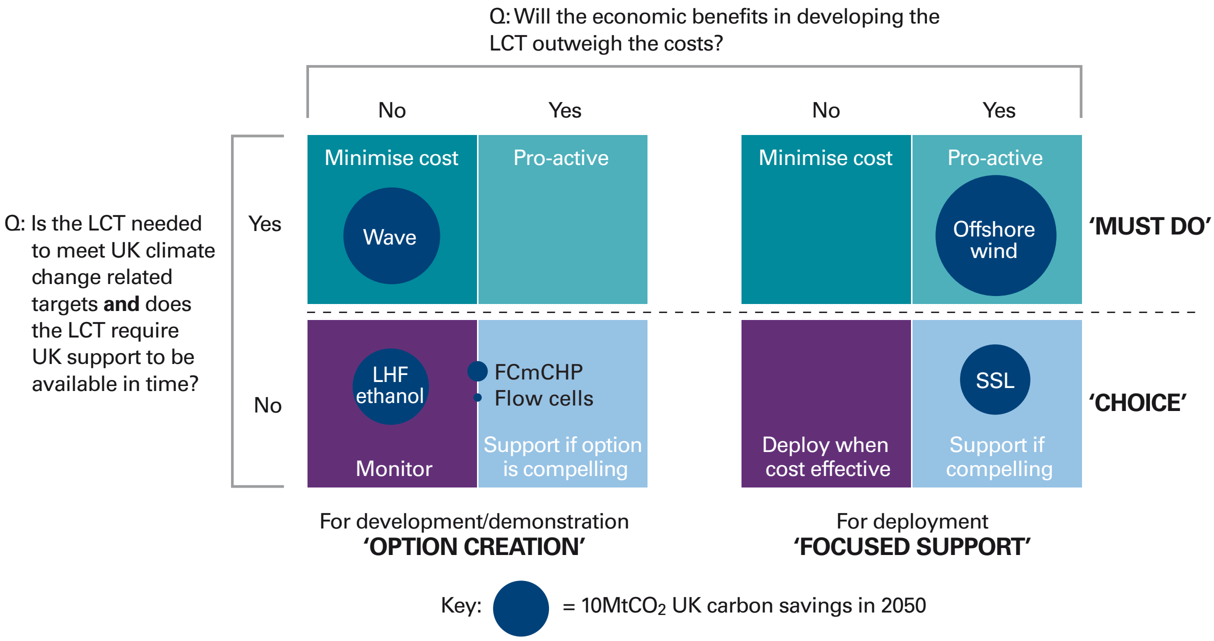
Therefore, the UK LCT innovation system should be enhanced by prioritising public sector support and communicating transparently the relative importance of different technologies from a UK perspective, allowing private sector players to make decisions in an informed manner.

We have developed a potential framework based on contribution to UK carbon targets and net economic benefit (see Chapter 2). *Chart 5h* shows our sample of six technologies plotted on the prioritisation framework (details on each technology can be found in Chapter 3).

The two elements of this framework are whether a LCT is needed to meet UK carbon reduction targets and is unlikely to be available in time without UK support; and whether the LCT will or is likely to generate net economic benefit for the UK.

The framework also distinguishes between earlier stage development/demonstration technologies where the aim is to generate technology options and later stage technologies where the aim is to focus on cost effective supported deployment. This distinction is made by plotting technologies at these different development stages on separate prioritisation matrices.

Chart 5h *Prioritisation of the six technologies covered in this study**



*Estimates of carbon abatement and economic benefit are based upon each LCT passing proofs of principle, concept, viability, scalability and durability.

Source: Technical consultants; LEK, Carbon Trust analysis.

The technologies we have looked at span all three categories of response:

'Must do' – pro-active/minimise cost (Green)

- Offshore wind power is needed to achieve the UK's 2020 renewable and carbon targets and is unlikely to be ready in time without UK support as the UK is one of two leading markets. Despite potentially large deployment support costs, the UK may well generate net economic benefit by exploiting a large export market and attracting inward investment by turbine manufacturers to complement existing offshore and services skills and leveraging the potential to develop a strong position along the value chain. The UK's approach should be to actively innovate/ deploy and seek to exploit economic benefit by encouraging investment and service activity.
- Wave power is likely to play an important part in the radical decarbonisation of UK electricity by 2050. The UK has a significant amount of the total global resource, and is home for many of the leading developers. Therefore, it is unlikely to be available without UK support in development, demonstration and deployment. The economic case, based on export of engineering and design skills and manufacture of high value added components, is not as strong as offshore wind power, but may improve significantly if the worldwide size of the market is larger than expected or an earlier/major technology breakthrough is achieved. The UK's approach should be to pursue this technology option focusing on further early demonstration and improving the cost effectiveness of the technology.

'Choice' – support if compelling (Blue)

- SSL is likely to commercialise rapidly irrespective of UK support as the market is global and development is driven by multinational companies with a global perspective. As deployment support costs are now likely to be quite small, the UK could generate net economic benefit in niche markets and parts of the supply chain (e.g. specialist luminaire design and manufacture), however, even in the best case this is unlikely to be substantial. Deployment of SSL represents a material and cost effective carbon opportunity in the near-to-medium term. The UK's approach should be, at minimum, to deploy at scale when the technology is proven and cost effective and in preparation remove all relevant barriers at minimum cost.
- Neither FCmCHP nor flow cells will need UK support to commercialise in a timely fashion. Markets outside the UK are attractive, some major developers are based abroad and other countries have substantial support programmes in place. Both carbon savings and potential economic benefits are relatively modest in the context of the other technologies studied. The UK's approach should be to assess these technologies against other alternatives and provide support if they prove to be a compelling option.

'Choice' – monitor /deploy when cost effective (Purple)

- LHF ethanol has a significant carbon prize, but international activity is very substantial (the US, Germany, etc.) so the UK is unlikely to have significant impact on the development of the technology. The UK's approach should be to monitor developments – note the UK may well be better placed in other advanced biofuels.

In broad terms, technology development timings mean that early stage LCTs are less likely to achieve scale deployment to assist the UK with its 2020 targets, while all technologies would have an opportunity to make an impact in a 2050 timeframe.

The mix of focus between earlier and latter stage technologies will depend on a number of factors including the urgency of near-term targets, the relative range of potential costs, and other potential resource constraints.

Key conclusions on LCT prioritisation

We believe there is a strong case for the implementation of explicit prioritisation of the UK's support for LCT innovation. The framework described here could assist in determining the LCTs that the UK should prioritise and the appropriate UK stance.

The framework helps with 'what' not 'how'. Establishing clear priorities will ensure resources are targeted at areas where the UK has an opportunity to lead and will help attract private sector investment. The precise allocation of resources among prioritised LCTs needs to be informed by the requirements of individual technologies themselves. This is because they will each be at different points in their development cycle and many needs are technology specific.

Definitive prioritisation and resulting actions however can only be fully established when all likely LCTs have been assessed against this or another equivalent framework. Detailed technology assessments to determine the status of each promising LCT should therefore be undertaken to allow informed judgments to be made both on prioritisation and resource requirements. Furthermore, prioritisation needs to take into account technology breakthroughs generating greater than expected cost reductions, larger markets for current applications and additional revenue from 'spin off' applications.

Initial steps being taken by Government have already started to move in this direction, for example the recently announced competition for CCS. However, with 50 or so technology families, all at different levels of maturity, there is a need for a more thorough and transparent prioritisation process which analyses all relevant LCTs consistently.

Using an explicit framework such as the one tested here will help attract private sector investment to the prioritised technologies because it demonstrates both analytically that the technologies have commercial promise and also that there is a commitment from the UK to support them.

6. The need for technology specific solutions

Analysis of the six LCTs in our sample shows that each has its own innovation challenges which need addressing and that there are very few general solutions.

Summary

- Key challenges within the current innovation system range from the difficulties and complexities of developing and supporting credible end markets, to the scale and continuity of public and private funding across development stages.
- However, the majority of ways in which the current innovation system can be improved are highly technology specific and cannot be addressed generically.
- There is, therefore, a need to accelerate the move towards customised LCT support for innovation – this should go beyond traditional technology push programmes and also cover barrier removal and market pull.
- This will need joined-up Government action in order to build confidence within industry and the investment community.

Key challenges in end market credibility and appropriate technology funding

Our analysis of the sample of six technologies shows the current innovation system is typified by a number of challenges around the end-market and public technology development funding.

End market challenges revolve mainly around the design and delivery of the policy framework – reflecting both the need to create markets for LCTs and the difficulty of doing so – including the nature and strength of the incentives put in place. For example, in SSL, its better performance is not well reflected in Building Regulations; in flow cells the financial value generated by storage is not easy to aggregate in the current electricity markets; and in LHF ethanol real uncertainties are undermining the impact of the incentive mechanism. Other main policy design and delivery challenges include the impediments to the deployment of LCTs created by the planning and other infrastructure systems (e.g. wave and wind).

Challenges in public technology development funding revolve around the level and nature of public support. The best example is wave power. We have quantified the public sector support required to bring forward wave power in the UK and compared it with the public sector support available (see *Chart 3.4h*). This shows a funding gap at the development and demonstration stages. There is both a lack of technology funding overall and a lack of continuity of funding along the innovation chain. Most of the other technologies also exhibited challenges in this area, with solid state lighting the notable exception.

All technologies need at least one specific action

We have developed potential solutions to the key innovation challenges faced by each of the sample of six LCTs which are summarised in *Chart 6a*. Our analysis indicates that all of these technologies need at least one significant action or solution that is specific to the technology itself to move it towards commercialisation. For example, both solid state lighting and flow cells require standards to compare performance, however the standards themselves are technology specific and targeted at a different audience (consumers vs. industrial customers).

Similarly LHF ethanol, offshore wind power, flow cells and wave power all require robust market pull mechanisms. However, our analysis and recent experience has shown that all four will need tailored instruments offering different levels and types of support.

Generic solutions are not enough

There are some solutions that are more generic – removing planning barriers for major LCT electricity generation is the clearest example. However, generic solutions alone are not enough to address the innovation challenges faced by any of the six LCTs we have looked at.

The diversity of solutions has led many to try to simplify the situation and group solutions into broad categories. This can be useful (e.g. for high level communications) but the tendency to group solutions may lead to mis-targeted efforts and wasted resources.

Chart 6a *Policy solutions required for commercialisation by technology*

Technologies	Technology specific policy solutions	Generic policy solutions
Solid state lighting	• Influence EU regulatory lighting actions under the Energy using Products (EuP) Directive	• Stimulate easier uptake (e.g. public procurement to demonstrate business case, etc.)
	• Introduce industry standard that allows easy product comparison	• Improve education/awareness of energy efficiency
	• Enforce appropriate point of sale labelling portraying lifetime savings	
Fuel cell micro CHP	• Develop field testing demonstration programme of FCmCHP	• Implement Government intention to address microgeneration challenges (metering, export pricing, etc.)
	• Review Building Regulations procedures to reflect the benefits of FCmCHP	
Flow cells	• Introduce deployment mechanism (almost certainly specific to storage)	
	• Develop specific electricity storage demonstration projects	
	• Change regulatory framework (e.g. the Balancing and Settlement Code) to allow aggregation of potential value to be captured by storage participants	
	• Establish industry performance standards	
LHF ethanol	• Vigorous and rapid implementation of a robust policy relating to biofuels support and the socio-environmental framework	
	• Develop an RD&D strategy for biofuels addressing focus, longevity and coordination of R&D funding and concentration of activity (size of centres and strength of networks)	
Offshore wind power	• Invest additional public RD&D of £100m-600m to 2020	• Extend duration of the incentive mechanism (proposals in Renewable Energy Strategy)
	• Integrate 1-3 demonstration sites with development of R&D/manufacturing cluster(s)	• Robustly implement plans to simplify process for grid connection and planning process (reviews in progress)
	• Make the most economic wind farm sites available without negatively impacting economic and environmental concerns	
	• Set the scale of the incentive mechanism to motivate developers. Track costs and adjust for electricity price changes to maximise efficiency (proposals in Renewable Energy Strategy and Budget '09)	
Wave power	• Address funding gaps, with greater coordination and a focus on innovations leading to step change cost reduction	• Depending on the detailed nature of the offshore wind solutions above, these may deal with some of the grid, planning process and incentive mechanism issues
	• UK-wide Strategic Environmental Assessment allowing future planning around potential sites (building upon work in Scotland)	

Customise support

To be effective technology support needs to be customised. This means putting in place all the solutions needed to move a technology to commercialisation. A real risk is that only some of the solutions are addressed, severely reducing the effectiveness of technology support. For example, commercialising FCmCHP requires three key solutions: UK field trials; changes to Building Regulations procedures; and removal of generic microgeneration barriers (metering, export pricing, etc.).

If only two of these are successfully addressed, say field trials and generic microgeneration barriers, then FCmCHP will still continue to struggle to commercialise as unchanged Building Regulations will hinder its adoption.

For prioritised technologies, the solutions required for successful commercialisation go beyond the traditional ‘technology push’ activities (e.g. grant funding of demonstration projects). *Chart 6b* clearly shows that all of our technologies require solutions which can be classified as ‘barrier removal’ (e.g. amending regulations such as product standards) or ‘market pull’ (e.g. deployment mechanisms such as the Renewables Obligation). However, for technologies where the stance is to deploy when cost effective, then barrier removal should be the focus of the UK’s commercialisation activities, particularly if they are critical to meeting UK targets.

Initial steps being taken

Government has already started to move in this direction with, for example, the proposed banding of the Renewables Obligation, offering differentiated support to stimulate the deployment of specific technologies. However, this change is occurring on a case-by-case basis and there is some way to go, notably in:

- Establishing clear accountability for designing and implementing customised cross-departmental technology support for prioritised LCTs covering market pull, technology push and barrier removal in a coherent way.
- Addressing all the key innovation issues for an LCT in an appropriate sequence.
- Ensuring all key players (including Government departments, agencies and RDAs), are motivated to deliver their actions in a coordinated way and that priorities are managed in a timely manner.

Chart 6b *Classification of policy solutions required to stimulate innovation by technology*

Technology	Push	Barrier removal	Pull
Solid state lighting		✓	✓
Fuel cell micro CHP	✓	✓	✓
Flow cells	✓	✓	✓
LHF ethanol	✓		✓
Offshore wind power	✓	✓	✓
Wave power	✓	✓	✓

Source: Technical consultants, LEK, Carbon Trust analysis.

Note: A tick indicates the presence of one or more solutions in a category, based on Chart 6a.

Needs joined up Government

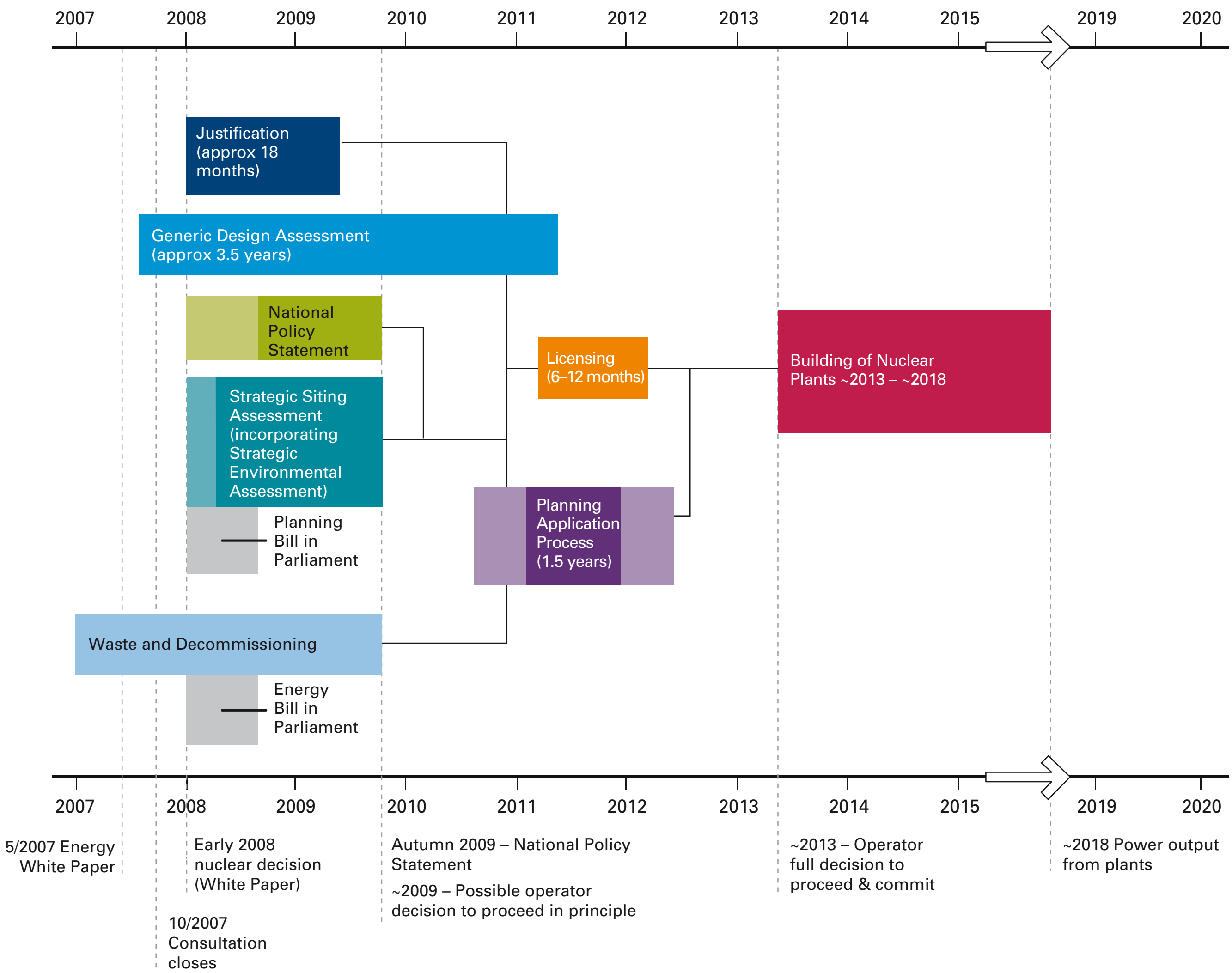
The design and delivery of customised technology support will go beyond what is traditionally considered as innovation and will cut across a number of departments and other organisations. For example, a FCmCHP field trial would come under the auspices of DECC or the Environmental Transformation Fund and the regulatory changes under DCLG. Creating and implementing joined-up programmes is always a challenge for Government. However it is now more feasible to embark on this course because:

- Technology prioritisation will reduce the size of the task, increasing focus and reducing the number of measures to be put in place.
- The recent formation of DECC has eliminated one of the main areas of co-ordination and created the potential for a more powerful voice across Government.

This type of joined-up technology support is not without precedent. For example, the deployment of nuclear power stations has been very strongly supported by the former Secretary of State John Hutton, who indicated the Government was going to 'clear the decks' of regulatory obstacles[1]. This was then followed-up by specific plans to address barriers to deployment (see *Chart 6c*).

Such clarity of intention combined with carefully planned specific action has undoubtedly created confidence among utilities and others to begin to invest significantly in nuclear power. This provides a benchmark for other LCTs.

Chart 6c *Indicative pathway to possible new nuclear power stations*



Source: BERR 'A White Paper on Nuclear Power', January 2008.

[1] Source: Financial Times

Part C
Implications for UK policy

A new approach to LCT commercialisation

7. Technology focused approach

7. Technology focused approach

Technology prioritisation, customisation of support and better integration of innovation and business activities come together to create a new technology focused approach to the commercialisation of LCTs.

Summary

- Our key recommendations are to prioritise LCTs, customise commercialisation support for priority LCTs and integrate innovation and economic development activity.
- These are brought together in a new 'technology focused' approach which will provide a more cost effective way of innovating LCTs in the UK.
- This is clearly distinct from previous policies of picking winners and is compatible with the wider climate change framework.
- It will ensure any UK public money is well spent and increases the likelihood the UK will capture value in the transition to a low carbon economy, as well as deliver its climate change related targets.

Key recommendations

Government needs to accelerate the move away from a focus on technology neutrality and generic mechanisms to a focus on technology priorities and customised support. This will involve:

- Adopting and implementing a framework for prioritising the commercialisation of LCTs from a national perspective. The framework developed during the course of this study could be a starting point.
- Designing customised technology policies and programmes and coordinating the key LCT innovation activities (i.e. market 'pull', technology 'push' and barrier removal), so that comprehensive, joined-up support is provided to priority LCTs.
- Integrating innovation and business support strategies and activities to ensure the economic development potential of LCT innovation is realised.

Taken together, these form a new technology focused approach to the commercialization of LCTs.

Evolution of Government policy to stimulate next generation LCTs

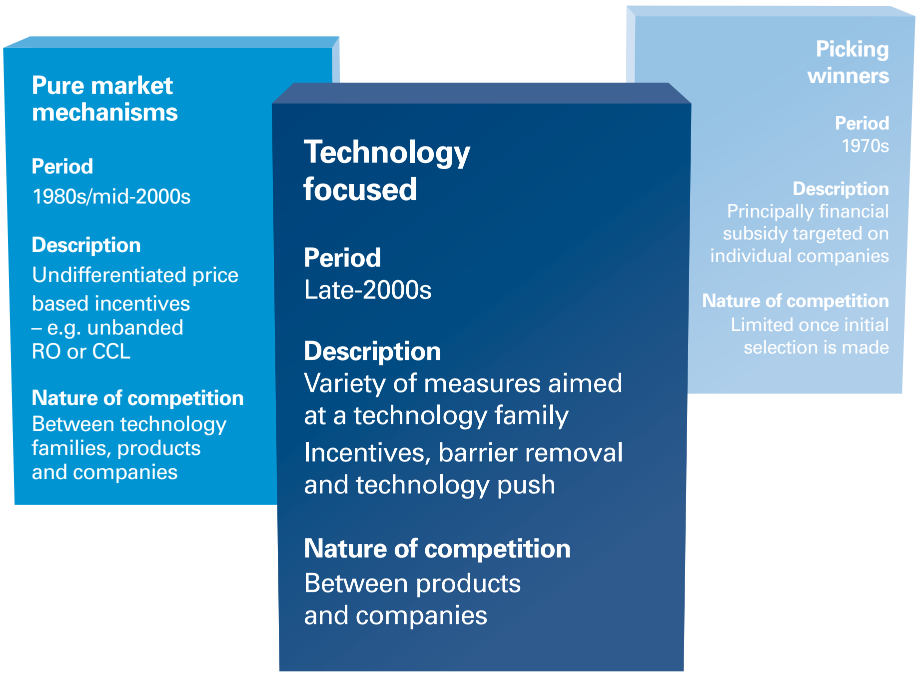
A technology focused approach is best understood in the context of the evolution of Government policy for industry in general and in this area in particular (see *Chart 7a*).

The 1970s was an economically very difficult time for the UK. There was a strong Government view, supported by many stakeholders, that Britain needed to hold on to its manufacturing base, which was still largely UK-owned. When UK industries were proving less internationally competitive, the instinct was to rescue them with direct financial assistance – a policy supported by both the CBI and the TUC. But the industries supported were in sectors where Britain was losing its long-term competitive advantage (e.g. shipbuilding) and so the efforts were expensive in the short term and doomed in the medium term.

As well as seeking to shore up an ailing industrial base, the UK also sought to promote specific 'national champions'. The 'white heat of the technological revolution' (invented in the mid-1960s) was still alive in the 1970s. Government believed that there were several high-tech areas where Britain could lead the world.

Having committed support in these ways, Government then found it difficult to withdraw when costs escalated. The wider risks of institutional 'capture' by the powerful stakeholders remain a real concern.

Chart 7a *Evolution of Government policy to stimulate next generation LCTs*



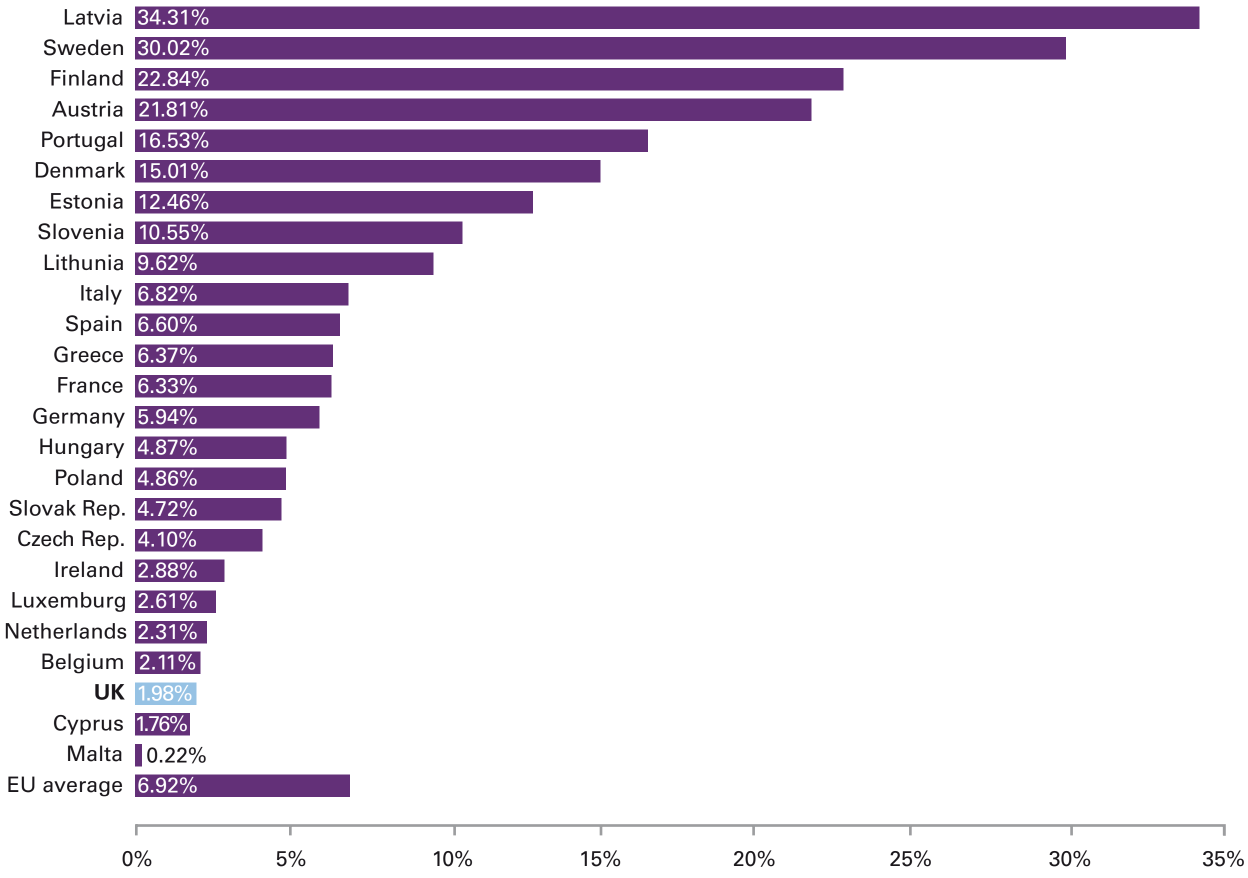
From the 1980s the 'mixed economy' model was fundamentally challenged. In the UK this involved a powerful commitment to private ownership of economic activity wherever possible, and to breaking up monopolies by promoting vigorous competition[1]. In this view the state had failed in economic life, and there was a conviction that private actors and markets would inevitably make better, more economically efficient decisions.

For LCT this radical agenda meant explicit technology neutrality, the establishment of generic market mechanisms, such as the unbanded Renewables Obligation and the Climate Change Levy, and greatly reduced Government funding for energy technology RD&D. As there is now no significant public ownership of energy assets all investment decisions and most RD&D activities are undertaken by private investors.

In many respects this shake-up has been a substantial success. Privatisation-with-liberalisation (private ownership plus competition) together with revenue-based regulation has worked well as a system to optimise the use of existing assets and squeeze costs out of the energy system[2].

However, this approach in isolation has not brought forward emerging LCTs – or indeed sustainable energy in general – as quickly as expected because of the barriers to private sector investment in LCT innovation described in Chapter 4. For example, the UK lags behind most of the rest of the EU in the deployment of renewable energy (see *Chart 7b*).

***Chart 7b** EU renewable energy as a percentage of primary energy, 2006*



Source: EurObserv'ER.

[1] Scrase I. and MacKerron G. (2009) 'Lock-in'. In Scrase I. and MacKerron G. (eds) Energy for the Future. A New Agenda. Palgrave Macmillan, Basingstoke, pp. 89-100.

[2] Helm, D. Energy, the state and the market: British energy policy since 1979, Oxford University Press, Oxford, 2003.

Key features of the technology focused approach

In the past Government has tended to focus on specific policy measures to address innovation issues for LCTs. Examples include the Renewables Obligation which, in its current guise, provides similar support to all emerging LCTs irrespective of stage of development or importance to the UK, and the organisation of innovation bodies (e.g. the Research Councils, Technology Strategy Board, etc.) which are defined primarily by the stage in the innovation life cycle in which they operate. The findings in the earlier part of this report, namely the need for customisation of the innovation system by technology family and the need for greater prioritisation by technology family, argues for Government policy to be realigned along the lines of technology families.

A technology focused approach would comprise the following key features:

- Identification of the priority LCTs through systematic and transparent assessment.
- Recognition of the differences between earlier and later lifecycle stages.
- Design of customised support for each of the prioritised technology families.
- Existence of strong competition for support between companies active within a technology family.
- Careful monitoring and use of a stage gate process with transparent criteria to ensure waste is minimised.

We expand on what each of these would entail over the following pages. We then further highlight how integrating innovation support with regional manufacturing activities will be important to maximise economic benefit.

Identify the priority LCTs through systematic and transparent assessment

Our experience in this study and wider experience in the Carbon Trust and elsewhere has shown that it is possible to prioritise technology families despite the high levels of uncertainty. A systematic approach is needed to identify and assess all the key factors.

The methodology developed in this study uses importance to the UK carbon targets and economic benefit as the way of prioritising LCTs. This could form a basis for a more formal prioritisation, extended to include other Government policy objectives such as security of supply.

LCT prioritisation will have important commercial consequences. It will be important, therefore, that the evidence base for the assessment be open to comment and scrutiny from the private sector and that Government seeks commercially disinterested input to conduct the assessment. Transparency will generate greater confidence among the private sector.

Technology innovation is a dynamic process and the LCT prioritisation should take into account new technology and market developments. This should be balanced with the need to provide enough time for development programmes to bear fruit and to give an appropriate level of certainty to technology investors.

Recognise differences between earlier and later lifecycle stages

In the earlier part of the study, we highlighted that RD&D was on average 40 times cheaper than deployment, albeit with substantial variations across LCTs. At the earlier RD&D stage, there is also a higher degree of uncertainty around the LCT, technically, economically and commercially. This uncertainty reduces (but is by no means eliminated) as an LCT enters the deployment stage.

A technology focused approach would recognise, therefore, that at the RD&D stage the aim is to create a technology option. As there is a high degree of uncertainty at this stage and, relatively, lower development cost, it is effective to take forward more LCTs than may be needed in deployment.

At the deployment stage, it is imperative that only those LCTs which are potentially most cost effective, in terms of net economic benefit and importance for carbon targets, gain large-scale deployment support.

In the deployment stage, investors expect to make a commercial return on their investment. Therefore, any changes in priority must take into account the payback time of any investment and the need to maintain investor confidence.

Design a tailored programme for each of the prioritised technology families

In Chapter 4, we showed how almost all LCTs we examined have an almost unique set of innovation challenges to address. In turn this leads to an almost unique set of solutions that need to be put in place for each technology to facilitate its commercialisation. These solutions will usually require a specific mix of technology push, market pull and barrier removal.

It seems clear from our analysis that failing to address all the key innovation challenges for a particular technology will lead to a waste of both money and time. For example, should the Government or its agencies put in place a field trial for FCmCHP, but not deal effectively and in a timely fashion with regulatory barriers, then development will slow and, in the worst case, make the field trial redundant.

On the other hand, effectively dealing with all innovation challenges for a prioritised technology not only ensures the effective use of resources, but also sends a powerful signal to private sector investors, increasing the likelihood that they will invest in the technology and its supply chain.

Strong competition for support between companies active within a technology family

Technology focus does not mean the end of competition and the featherbedding of technology developers. On the contrary, it provides the opportunity to sharpen the degree of competition, both between companies developing an LCT and different variants of an LCT.

With technology neutral mechanisms, such as the Renewables Obligation prior to the banding of support, the main form of competition is between technologies. When all the technologies are relatively mature that is effective. However, if technologies are at different stages of development, then competition is ineffective. For example, the Renewables Obligation created winners out of landfill gas and onshore wind, but provided little incentive to progress earlier stage technologies, notably offshore wind.

Technology focus will allow the form of competition to be tailored so that it is effective. For example, decisions for R&D grants for new wave devices could be based on specific assessment of their potential and deployment support for FCmCHP could be based on the results of field trials.

A technology focused approach is therefore compatible with a high level of competition and will help sharpen that competition.

Careful monitoring and use of a stage gate process with transparent criteria to ensure waste is minimised

The most critical question facing the technology focused approach is when to stop supporting an LCT. In general, we believe that a stage-gate process with transparent criteria provides a framework for answering that question. A technology focused approach allows technology specific hurdles to be set. Achievement of those hurdles will release further support and funding.

It is important that these hurdles are set in a transparent manner, so technology developers understand the hurdles they must meet, in fact in some countries these hurdles are jointly developed between Government and the private sector.

Implementing such monitoring systems as part of the technology focused approach will help to ensure that waste is minimised.

Generating UK benefit

The technology focused approach should extend beyond technology development and deployment and integrate with manufacturing and regional activities to maximise economic benefit for the UK.

At present innovation activities in the UK are largely unconnected with economic development activity either at the national or local level. The new Low Carbon Industrial Strategy provides an excellent vehicle for bringing these together.

At the heart of these efforts are likely to be the creation of integrated innovation and manufacturing clusters of activity. Both the greatest opportunity in our sample of six LCTs and the best example of what can be done is found in offshore wind.

Our analysis has shown a prize of around a further 30,000 jobs in 2020 that could be created from a pro-active stance to maximising the economic benefit potential of offshore wind. A key element in the delivery of this potential is the development of clusters of activity.

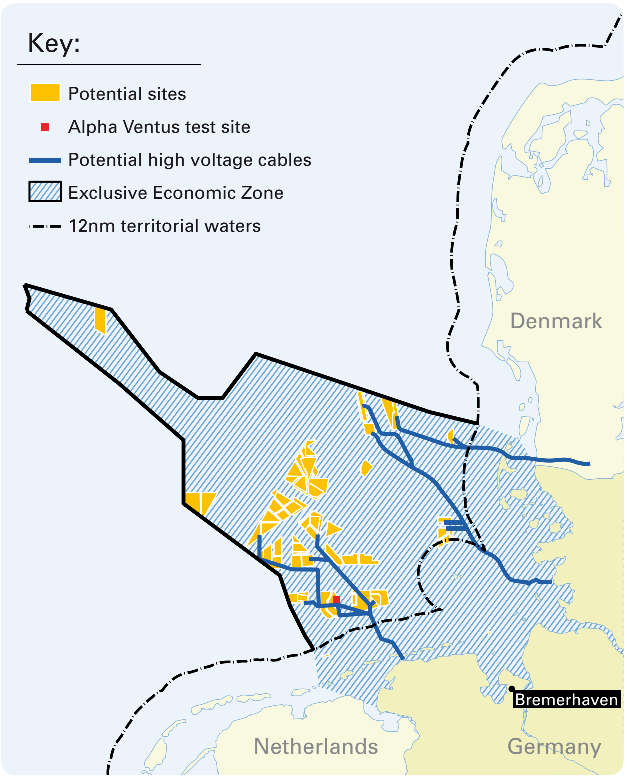
Bremerhaven in northern Germany is an excellent example of an integrated innovation and manufacturing cluster in development (see case study below).

Bremerhaven – offshore wind cluster

Germany has announced plans to develop offshore wind power in the Baltic Sea. Bremerhaven is the nearest large port for the initial demonstration site, Alpha Ventus. At Bremerhaven, all the elements of an innovation and industrial cluster designed to attract inward investment are being put together.

The cluster comprises:

- Alpha Ventus, the key demonstration site for German offshore wind, with the capacity (infrastructure/permits) to expand into a major deployment site.
- Excellent port facilities at Bremerhaven including deep water quays, a roll-on, roll-off terminal and some 40ha of land available for development.
- Manufacturing facilities including all the key parts of the supply chain:
  - Turbine manufacturer (e.g. Multibrid, Repower)
  - Towers (e.g. Ambau)
  - Rotor blade (e.g. Abeking)
  - Foundations (e.g. WeserWind).
- A cluster of R&D facilities including eight research institutes and technology companies, a wind energy research and coordination centre and required infrastructure such as quays, dry docks and laboratories.
- Objective 2 status[3] providing grants of >30% for investment costs and >70% for R&D costs.



Based on maps from: Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency).

[3] One of the objectives of the Structural Fund under the European Regional Development Fund which aims to revitalise all areas facing structural difficulties, whether industrial, rural, urban or dependent on fisheries. Objective 2 is now known as the Regional Competitiveness and Employment Objective.

Technology focus does not repeat the mistakes of the past

A technology focused policy builds on the lessons of the 1960s/1970s in at least two ways. Firstly, it is not seeking to shore up ailing industries where the UK-owned businesses have been overtaken by foreign competitors. From an economic point of view it is about growing UK activity in a sector which, for the public good, must grow in the long term. It is agnostic about the ownership of businesses and seeks to make the UK a good place in which to conduct LCT innovation and develop LCT-based businesses.

Secondly, it does not make specific choices about companies or 'hardware' as was done in the 1970s. On the contrary, it encourages a high level of competition between different types of 'hardware' within a technology family and between different developers.

Looking more broadly, international experience has shown that Government intervention at a sector specific level can be successful and that industrial policy needs to be integrated into the approach.

Professor John Beath, University of St Andrews, concluded that, "over the period since the 1950s, the best performing countries in terms of growth and international trade shares have been those which implemented some kind of industrial policy. For example, the USA maintained its industrial leadership only in areas where there was a significant amount of state intervention and support (e.g. aerospace and defence, nuclear energy, and various fields of electronics)"[4].

Compatibility with the wider climate change framework

The technology focused policy is very much in line with the broad framework articulated in the Stern Review and largely adopted within Government. The Stern Review defined three routes to drive mitigation of climate change: carbon pricing, innovation/technology policy, and regulations/overcoming inertia. The technology focused approach fits into this framework.

Undifferentiated market mechanisms such as the EU ETS provide a carbon price signal to the economy. Stern indicated that a carbon price alone was not sufficient given the urgency of climate change as an issue and the difficulty in establishing a credible long-term carbon price.

Stern indicated that, in addition, innovation/technology policy was necessary to bring forward new LCT as quickly as possible and to overcome a variety of market failures. The technology focused approach we highlight in this report is an effective way of delivering innovation/technology policy.

The final route is regulation/overcoming inertia, as a way, primarily, of driving the uptake of existing LCTs. However, we have identified in this study that regulation is also an important driver of innovation. The technology focused approach will also incorporate aspects of the regulatory route for certain LCTs.

As it is targeted on the specific requirements of a technology, a technology focused policy should therefore result in more cost effective policies and programmes. It is a highly scalable approach, as it is just as effective for one or many LCTs and therefore does not argue necessarily for greater public funding.

A technology focused approach may also prove helpful in the wider international context. If adopted by a number of countries it could provide a basis for international cooperation and provide clarity to investors on the level and location of support for new and emerging LCTs.

Benefits of a technology focused approach

As a minimum, adopting this approach increases the chances that public money is well spent, focusing it on key technologies for the UK and on the requirement of the technology. As a result, a technology focused approach will increase the likelihood of the UK capturing value and jobs from the transition to a low carbon economy as well as ensuring the delivery of UK climate change related targets.

Failing to adopt this approach will mean the UK will not have the right strategic focus for its LCT innovation activities, limiting economic gains, wasting technology support funding and jeopardising the achievement of climate change related targets.

[4] Beath, John (2002), 'UK Industrial Policy: Old Tunes on New Instruments?', Oxford Review of Economic Policy, Vol 18 No 2.

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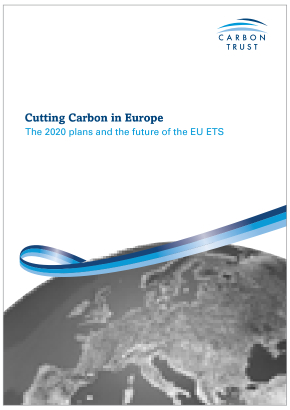

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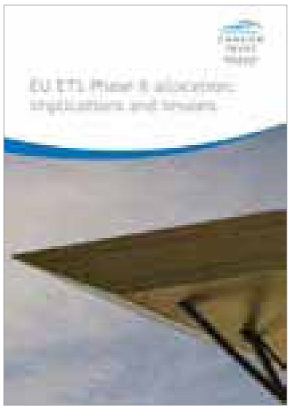
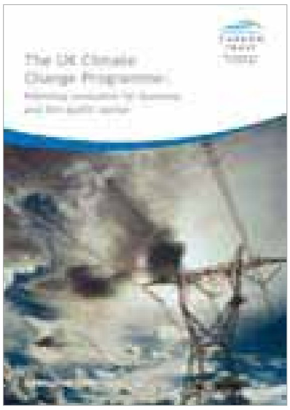


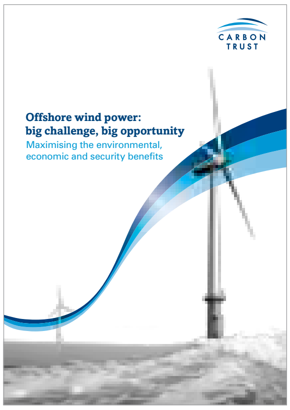
CTC715

EU ETS Phase II allocation: Implications and lessons



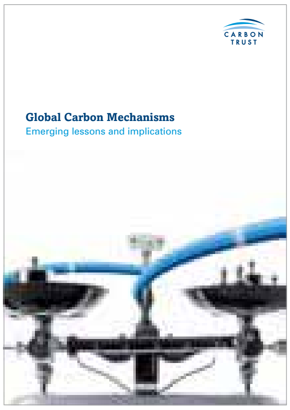
CTC519

The UK Climate Change Programme: Potential evolution for business and the public sector



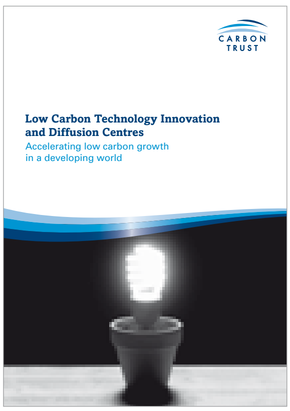
CTC743

Offshore wind power: big challenge, big opportunity. Maximising the environmental, economic and security benefits



CTC748

Global Carbon Mechanisms: Emerging lessons and implications

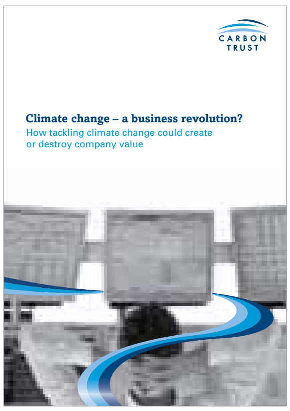


CTC736

Low Carbon Technology Innovation and Diffusion Centres: Accelerating low carbon growth in a developing world

CTC744

Product carbon footprinting: the new business opportunity. Experience from leading companies



CTC740

How tackling climate change could create or destroy company value

The Carbon Trust was set up by Government in 2001 as an independent company.

The Carbon Trust's mission is to accelerate the move to a low carbon economy, by working with organisations to reduce carbon emissions now and develop commercial low carbon technologies for the future.

We cut carbon emissions now

- By providing business and the public sector with expert advice, finance and accreditation.
- By stimulating demand for low carbon products and services.

We cut future carbon emissions

- By developing new low carbon technologies through project funding and management, investment and collaboration.
- By identifying market barriers and practical ways to overcome them.

www.carbontrust.co.uk

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ACT ON CO_2 is the Government's initiative to help individuals understand and reduce their carbon footprint. Visit http://actonco2.direct.gov.uk for more information.

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