Low
Carbon
Innovation
Coordination
Group

Technology Innovation Needs Assessment (TINA)

Electricity Networks & Storage (EN&S) Summary Report

August 2012

Background to Technology Innovation Needs Assessments

The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed funding and delivery bodies in the area of 'low carbon innovation'. Its core members are the Department of Energy and Climate Change (DECC), the Department of Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC), the Energy Technologies Institute (ETI), the Technology Strategy Board (TSB), the Scottish Government, Scottish Enterprise, and the Carbon Trust. The LCICG also has a number of associate members, including the Governments of Wales and Northern Ireland, Ofgem, the Crown Estate, UKTI, the Department for Transport, the Department for Communities and Local Government, the Ministry of Defence, and the Department for Environment, Food and Rural Affairs.

The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives.

This document summarises the Electricity Networks and Storage TINA analysis and draws on a much more detailed TINA analysis pack which will be published separately.

The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.

The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations. Expert input, technical analysis, and modelling support for this TINA were provided by DNV KEMA.

Key findings

Electricity networks and storage (EN&S) technologies could play an important enabling role in the future energy system, supporting the deployment of renewable electricity generation, renewable heat, electric vehicles (EVs), and other low carbon technologies. Innovation in EN&S technologies could save the UK £4-19 billion[1] in deployment costs to 2050, with significant possible additional value offered by enabling the deployment of other key technologies. Innovation can also help create UK-based business opportunities that could contribute an estimated £6-34 billion to GDP to 2050. Significant private sector investment in innovation, catalysed by public sector support to overcome barriers and market failures, can deliver the bulk of these benefits while demonstrating strong value for money.

Potential role in the UK's energy system	• By 2050, the deployment of renewable electricity generation, electric heat pumps, EVs, and micro-generation is likely to increase substantially, placing significant new demands on the UK's ageing electricity transmission and distribution networks. • Advanced EN&S technologies have the potential to meet these new stresses placed on the electricity system more cost-effectively than would be possible through traditional methods of grid reinforcement and fossil-fuel-powered system balancing capacity. Moreover, deployment of some key low carbon technologies is critically dependent on innovation in EN&S technologies. • There is significant uncertainty over the extent to which different EN&S technologies will be deployed to 2050, but our analysis suggests that high levels of uptake are possible. For indicative sub-areas within the six overarching EN&S technology areas considered for this TINA, we estimate potential UK deployment by 2050 of: – 601-2307 km of high voltage direct current (HVDC) **advanced transmission** cables; – 28-70 deployments of advanced **smart distribution** control systems; – 7-59GW of total grid-connected electricity **storage** capacity[2]; – 11-70% household penetration of energy management systems (EMS), a **home hub** technology; – 53-100% penetration of **demand response (DR)** controllers in appliances; and – 5-36 million **electric vehicle (EV)** charging controllers. • For most of these technologies, current levels of deployment are limited to a handful of demonstrations, and a very wide range of future deployment scenarios are plausible. A few key deployment uncertainties could have significant impact on the value-add from innovation: – Some **storage** technologies are likely to be deployed much more extensively than others depending on technology improvements, regulation, and commercial factors. It is not yet clear how much storage overall will be needed in the future energy system or which storage technologies will be dominant. – **EMS** could be deployed in many homes by 2050, but the market for such systems is not yet proven. Very low penetration of EMS is a plausible future outcome. – Similarly, **Vehicle-to-grid (V2G)** controllers for EV charging points could be deployed extensively, but deployment could also be negligible depending on whether a range of technical and market challenges such as concerns about battery wear are resolved.
Cutting costs by innovating	• Some of these EN&S technologies are available already, but many of them are still expensive or not yet ready for wide deployment and integration in the electricity system. Further innovation could therefore drive down the cost of deployment of these technologies by £9 billion (£4-19 billion) to 2050, divided among six technology areas:

[1] Cumulative (2010-2050) present discounted values for lowest to highest scenarios.

[2] This range reflects indicative scenarios of storage deployment used to estimate the potential value from innovation. Separate analysis from Imperial College titled 'Strategic assessment of the role and value of energy storage systems in the UK low carbon energy future' analysed the UK deployment of storage in greater detail (http://bit.ly/RUAabN). Also, for a more detailed analysis of the role that storage might play alongside other technologies (e.g. demand response and interconnection), please see DECC's recent publication on 'The Electricity System: Assessment of Future Challenges' and underpinning analytical study by Imperial College and NERA consulting titled 'Understanding the Balancing Challenge'. In this analytical study, the estimated range of storage deployed by 2050 was 1-29GW (http://www.decc.gov.uk/en/content/cms/meeting_energy/network/strategy/strategy.aspx). The storage deployment estimates in this TINA are based on high-level indicative scenarios developed by the Carbon Trust. These scenarios consider a wide range of future outcomes and are particularly sensitive to the large-scale deployment of renewables. Therefore, in some scenarios in this TINA, storage deployment is higher than estimated in the analytical study conducted by Imperial and NERA consulting.

	– **Advanced transmission (HVDC)**: Innovation in convertors and substations makes up the largest share of the potential estimated total system cost savings of £0.6 billion (£0.2-0.8 billion) to 2050. – **Smart distribution**: Innovation in advanced control systems and fault current limiters (FCLs) makes up most of the potential estimated total system cost savings of £0.2 billion (£0.2-0.3 billion) to 2050. – **Storage**: Innovation in energy storage technologies has the potential to yield estimated total system cost savings of £5 billion (£2-10 billion) to 2050. – **Home hub**: Innovation in EMS makes up most of the potential estimated total system cost savings of £2 billion (£1-5 billion) to 2050. – **DR**: Innovation in smart appliance controllers and virtual power plant (VPP) systems makes up most of the potential estimated total system cost savings of £0.3 billion (£0.3-0.4 billion) to 2050. – **EV integration**: Innovation in V2G and installation makes up most of the potential estimated total system cost savings of £1 billion (£0.2-2 billion) to 2050. • Beyond reduced deployment costs, innovation has the potential to unlock benefits by enabling the deployment of other low carbon technologies. These enabling benefits are significant across all six technology areas, with particularly high benefits in DR, EV integration, and storage, where innovation will be important to enabling the deployment of heat pumps, EVs, and renewable electricity generation. Innovation will be particularly important in the area of EV integration, where large-scale adoption of EVs will likely be possible only with some form of EV charging control to accommodate the new EV charging loads placed on the electricity network. • A key innovation challenge will be integrating the diverse range of mutually-dependent EN&S technologies into effective systems. This successful integration will be important to deployment of these technologies and will be critical to realising their full benefits.
Green growth opportunity	• As is true for the UK, global deployment of EN&S technologies could be high but is also highly uncertain. In several areas of global market value – including storage, EMS, and V2G controllers – both very low and very high deployment scenarios are plausible. • The UK has pockets of competitive strength in some EN&S technology areas and could capture a 4% share of a global market with potential cumulative gross value-added (GVA) of between £0.3-1.6 trillion up to 2050. • If the UK achieves that market share, then the EN&S industry could contribute £6-34 billion to UK GDP to 2050 after taking into account displacement effects.
The case for UK public sector intervention	• Public sector activity is critical to unlocking the biggest opportunities – although in some areas the UK may be able to rely on other countries to drive this innovation. – Market failures and barriers include uncertain demand (externality effect), infrastructure requirements (co-ordination failures), and split incentives. Co-ordination failures are a particularly potent barrier given the mutual dependency of many EN&S technologies. – In several areas – particularly storage, smart distribution, and DR – the UK could largely rely on the private sector and other countries to deliver innovation improvements. Recent international investment in storage technology innovation is particularly high, and the UK should target its support to specific innovation sub-areas to avoid duplicating other efforts.
Potential priorities to deliver the greatest benefit to the UK	• Innovation areas with the biggest benefit to the UK are: – The integration of a number of distribution-level EN&S technologies working together, including advanced distribution control systems, DR, storage, EV integration, and home hub; – EV integration technologies and installation methods, particularly for V2G controllers, that are easily usable by consumers and can be managed alongside DR, home hub, smart distribution, and distribution-level storage; – Improved storage technologies in promising select sub-areas, including thermal-to-electric storage, lithium-based batteries, sodium-based batteries, and redox flow batteries; and – EMSs that are tailored to the UK context and designed to overcome consumer acceptance challenges. • The LCICG is already delivering a number of publically-supported innovation programmes that address many of these innovation areas. • Supporting all of the UK's priority innovation areas would require tens to hundreds of millions of pounds over the next 5-10 years (leveraging 2-3 times that in private sector funding).

Chart 1 EN&S TINA summary

Area	Sub-area	Value in meeting emissions targets at low cost £bn[3]	Value in business creation £bn[4]	Key needs for public sector innovation activity/investment
Advanced transmission	Cables	0 (0 - 0.1)	0 (0 - 0.1)	Develop cost-effective superconducting cables
	Offshore platforms	0 (0 - 0)	0 (0 - 0)	Improve deep-water foundations
	Converters	0.3 (0.1 - 0.4)	1.4 (0.5 - 1.9)	Develop and trial technology for multi-terminal networks
	Installation	0 (0 - 0)	0 (0 - 0)	Develop low-cost offshore installation methods
	O&M	0.3 (0.1 - 0.3)	0.1 (0 - 0.1)	Improve weathering, remote monitoring and control
	Sub-total	**0.6 (0.2 - 0.8)**	**1.6 (0.6 - 2.2)**	
Smart distribution	Fault current limiters (FCL)	0.2 (0.2 - 0.2)	0.8 (0.8 - 1.1)	Develop cryogenic enhancement to support higher temperature operation
	Dynamic line rating (DLR)	0 (0 - 0)	0.1 (0.1 - 0.1)	Apply already-proven technology in distribution context
	Active distribution voltage control (ADVC)	0 (0 - 0)	0 (0 - 0.1)	Incrementally improve cost of components
	Advanced control systems	0.1 (0 - 0.1)	0.1 (0.1 - 0.2)	Trial and agree optimal layering and system architecture
	Sub-total	**0.2 (0.2 - 0.3)**	**1 (0.9 - 1.4)**	
Storage	Pumped hydro	**4.6 (1.9 - 10.1)**	**11.5 (3.4 - 25.7)**	Prove concept for offshore and underground projects
	Compressed air energy storage (CAES)			Develop adiabatic compression to improve efficiency
	Sodium-based batteries			Improve durability and electrolytes (including solid-state)
	Redox flow batteries			Develop low-cost membranes, real-time impurity sensing
	Lithium-based batteries			Develop solid-state conductors, improve lifetime
	Flywheels			Develop higher speed rotation (e.g. hubless design)
	Supercapacitors			Develop low wetting, high voltage electrolytes
	Thermal-to-electric			
Home hub	Home area networks (HAN)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.2)	Design simpler registration methods
	In-home displays (IHD)	0.3 (0.3 - 0.4)	0.2 (0.2 - 0.3)	Design intuitive interfaces for consumer acceptance
	Wide area networks (WAN)	0.2 (0.2 - 0.2)	0.6 (0.6 - 0.6)	Ensure designs benefit from improved telecoms costs
	Energy management systems (EMS)	1.5 (0.5 - 3.6)	1.3 (0.3 - 1.8)	Design systems to tackle consumer acceptance and UK-specific requirements
	Installation	0.1 (0.1 - 0.3)	0.1 (0 - 0.1)	Develop simple processes for more DIY installation
	Sub-total	**2.2 (1.2 - 4.7)**	**2.3 (1.2 - 2.9)**	
Demand response	Smart appliance controllers	0.1 (0.1 - 0.2)	0 (0 - 0.2)	Standardise network protocols, develop mesh-based device-to-device communication, develop control interfaces and logic to meet consumer acceptability
	Auxiliary switch controllers	0 (0 - 0)	0 (0 - 0)	
	Micro-generation controllers	0.1 (0.1 - 0.1)	0 (0 - 0)	
	Virtual power plants (VPP)	0.1 (0 - 0.1)	0 (0 - 0.1)	Trial integration of VPP systems with other technologies
	Installation	0.1 (0 - 0.1)	0 (0 - 0)	Improve automated or remote registration of devices
	Sub-total	**0.3 (0.3 - 0.4)**	**0.1 (0.1 - 0.3)**	
Electric vehicle integration	Charging controllers	0.2 (0 - 0.3)	0.1 (0 - 0.2)	Design and trial easy-to-use controllers to improve consumer acceptability, integrate and trial with other EN&S technologies
	Demand & power factor controllers	0.2 (0.1 - 0.4)	0.2 (0 - 0.3)	
	Vehicle-to-grid controllers (V2G)	0.3 (0 - 0.9)	0.2 (0 - 0.5)	Design easy-to-use controllers and integrate operation of V2G with other EN&S technologies
	Installation	0.3 (0.1 - 0.7)	0.2 (0 - 0.4)	Develop replicable low-cost installation methods
	Sub-total	**1 (0.2 - 2.3)**	**0.7 (0.1 - 1.5)**	
Total		**9.0 (3.9 - 18.7)**	**16.6 (6.4 - 33.6)**	**5-10 year investment in the hundreds of millions of GBP (programmes of material impact in individual areas in the millions to tens of millions of pounds)**

Benefit of UK public sector activity/investment[5] High Medium Low

[3] Present value 2010-2050; "Middle of the road" scenario (lowest scenario – highest scenario);
[4] 2010-2050 with displacement
[5] Also taking into account the extent of market failure and opportunity to rely on another country but without considering costs of the innovation support
Source: Expert interviews, Carbon Trust analysis

Electricity networks and storage (EN&S) technologies have an important role to play in the UK energy system

By 2050, the deployment of renewable electricity generation, electric heat pumps, electric vehicles (EVs), and micro-generation is likely to increase substantially, placing significant new demands on the UK's electricity transmission and distribution networks. Advanced EN&S technologies have the potential to meet the new stresses placed on the electricity system more cost-effectively than would be possible through traditional methods of grid reinforcement and fossil-fuel-powered generation capacity (e.g. spinning reserve). Moreover, deployment of some key low carbon technologies is critically dependent on innovation in EN&S technologies.

This TINA considers six EN&S technology areas

The EN&S area, often called "smartgrids", spans a wide range of technologies with complex functions and interdependencies. To focus the scope of this TINA, we filtered a range possible technologies to identify those most likely to realise significant value from public sector innovation support. The filtered list of technologies falls into six linked technology areas.

Advanced transmission

We have considered advanced transmission as high-voltage direct current (HVDC) technology for long-distance transmission of power. While also applicable onshore, HVDC technology is particularly well-suited to long-distance subsea applications, including connection of offshore wind farms, offshore interconnection within the UK, and interconnection with the power grids of other countries.

We have considered innovation needs in a few sub-areas of advanced transmission, specifically: cables, offshore platforms, and substation equipment including convertors.

While all EN&S technologies have some degree of interdependence, advanced transmission is probably the most independent of those we have considered.

Smart distribution

Smart distribution technologies are technologies that could help distribution networks to manage the strains placed on them through increased penetration of EVs, heat pumps, and micro-generation.

We have considered innovation needs in:

- Fault current limiters (FCLs), which could help to protect distribution network infrastructure from surges in current due to electrical faults in EVs, heat pumps, or micro-generation;
- Dynamic line rating (DLR), which actively monitors the status of transmission or distribution lines to enable maximum utilisation of those lines;
- Active distribution voltage control (ADVC), which actively corrects sags or spikes in voltage within distribution networks; and
- Advanced control systems, which are systems for the monitoring and control of distribution networks.

Smart distribution technologies are highly interlinked with other technologies in this TINA. Advanced control systems in particular form the critical IT backbone for remote control of EV charging, coordination of demand response (DR), utilisation of distribution-level energy storage, and communication of energy data through the home hub.

Storage

Energy storage technologies include a range of physical, electrochemical, and thermal approaches to storing energy for later conversion into electricity. Such storage can be used to help balance the strains placed on the electricity network from greater penetration of EVs, heat pumps, and renewables.

We have considered pumped hydroelectric storage, compressed air energy storage (CAES), sodium-based batteries, redox flow batteries, lithium-based batteries, flywheels, supercapacitors, and thermal-to-electric storage. Some other storage technologes exist that were not included in the scope of this analysis. We consider the role of hydrogen as an energy storage medium in a separate TINA. Hydrocarbons produced via the Fischer Tropsch method and ammonia are other possible storage mediums that we do not consider here.

Particularly when installed at the distribution level, energy storage is tightly linked with other EN&S technology areas as a potential source of DR, a key integrated component of EVs, and dependent on advanced control systems for effective dispatching.

Home hub

Home hub includes the networked infrastructure on the customer side of the energy meter that enables the control of energy use and data.

Specifically, we have considered:

- Home area networks (HAN), which serve as the hub of energy information flow in a home or business;
- In-home displays (IHD), which display energy data to the end consumer;
- Wide area networks (WAN), which allow for the communication of data to outside networks; and
- Energy management systems (EMS), which automate control of some elements of energy consumption.

The home hub is a key node that enables effective coordination of DR, EV charging, and end user-level storage.

Demand response (DR)

DR includes control systems for the active turning up or down of energy demand from appliances, micro-generation, and other energy-consuming equipment. We have considered:

- Smart appliance controllers, which are integrated into appliances to control their operation;
- Auxiliary switch controllers, which are DR controllers fixed to existing appliances or equipment without integrated controls;
- Micro-generation controllers, which control the use of micro-generation; and
- Virtual power plant systems (VPP), which work alongside advanced distribution control systems to coordinate a number of DR, storage, and micro-generation resources so that they can be used much like a single dispatchable power plant.

DR relies heavily on home hubs and advanced distribution control systems to work. In addition, EVs and storage can also be integrated as sources of DR.

Electric vehicle (EV) integration

EV integration includes controllers to coordinate the charging of electric vehicles, thereby reducing potential strains on the system from many EVs being charged at once.

We have considered charging controllers, demand and power factor controllers, and vehicle-to-grid (V2G) controllers. Collectively, these controllers allow for the timing and intensity of EV charging to be controlled remotely and for vehicle batteries to be used as grid-connected sources of energy storage.

EV integration is enabled by home hub and advanced distribution control systems, and EV controllers allow EVs to be sources of DR and energy storage. The role of EVs as sources of energy storage through V2G controllers has a potentially major impact on the need for dedicated grid-connected energy storage. Even under moderate assumptions about the level of EV penetration, the collective storage capacity of EV batteries in the UK could greatly exceed the total capacity of grid-connected storage we have estimated in our deployment scenarios. To be deployed extensively, V2G technology must first overcome important technical challenges, particularly related to the battery life impacts of repeated cycling. However, if V2G does achieve significant penetration, the need for dedicated grid-connected storage technologies could be lower than estimated due to this substitution effect.

Future deployment of EN&S technologies is uncertain, but could be high

There is significant uncertainty over the extent to which different EN&S technologies will be deployed to 2050, but our analysis suggests that high levels of uptake are possible.

Four scenarios for deployment of EN&S technologies

To evaluate the potential value of innovation in reducing the cost of deployment of EN&S technologies, we have considered four indicative deployment scenarios covering the 2010-2050 period. These long-term scenarios are intended to capture a wide range of possible futures for the UK energy system and are not intended to establish a definitive forecast. Although innovation will play an important role in ensuring EN&S technologies are deployed, the levels of deployment also depend on key exogenous factors, especially the deployment of heat pumps, EVs, renewable generation, and overall electricity demand.

- **Low electrification**: This scenario is characterised by relatively **much lower electricity demand**. Electric vehicles and heat pumps are not taken up in great numbers, while biofuels, fuel cell vehicles, and other forms of road transport are taken up. Renewables deployment is relatively low, with nuclear and CCS generation deployed significantly.
- **Middle of the road**: This scenario is a **moderate balance**, with no notable extremes. End user electricity demand is moderate, driven by growth from significant deployment of heat pumps and electric vehicles, but tempered by uptake of efficiency measures. There is simultaneous major deployment of renewables, CCS, and nuclear to meet growing demand. We have used this as our central case throughout this TINA summary.
- **High electricity demand**: This scenario is characterised by **high electricity demand growth**. Electricity demand grows strongly due to high electric vehicle and heat pump penetration and low efficiency improvements. Renewables, CCS, and nuclear all increase to meet this growth in demand.
- **Two-thirds wind**: This scenario is characterised by **high renewables deployment**. In this scenario, wind generation makes up around two-thirds of all electricity generated in 2050 (423 TWh), with nuclear and CCS much less deployed than in other scenarios. Electricity demand is moderate, with high electric vehicle uptake and high heat pump penetration moderated by efficiency improvements.

These scenarios are based on customised Energy System Modelling Environment (ESME) modelling and establish the backdrop for different future energy system needs, including long-term emissions targets, that EN&S technologies could help to meet.[6]

[6] These scenarios aim to capture a wide range of feasible deployment scenarios, and are neither forecasts for the UK nor targets for policy makers. By trying to capture the full range of uncertainty over the mid to long term to inform innovation policy, these indicative deployment levels were not precisely aligned with UK government short and mid-term targets. DECC has recently published an assessment of the future electricity system titled 'The Electricity System: Assessment of Future Challenges' that uses different scenarios based on 2050 carbon targets (http://www.decc.gov.uk/en/content/cms/meeting_energy/network/strategy/strategy.aspx)

While the ESME modelling directly informs some key drivers of EN&S technology deployment – EV deployment is directly linked to EV charging control deployment – most drivers for EN&S technology deployment are more indirectly linked. In part, this is due to some ESME limitations, which does not model the energy system with sufficiently fine time resolution to reflect the full value of many EN&S technologies. We have therefore relied extensively on expert judgement and consultation rather than the ESME model itself to estimate the parameters that link modelling outputs to EN&S technology deployment. Recent analysis carried out by Imperial College for DECC has assessed the value and deployment of storage technologies in greater detail. This analysis is now available on the DECC website.[7]

EN&S technology deployment estimates

The deployment of EN&S technologies under the four scenarios varies greatly, but high levels of penetration are possible. Chart 2 shows the deployment estimates for the "middle of the road" scenario and for the minimum and maximum deployment in each technology area, summarised here for some key technology sub-areas:

- 1663 km (601-2307) of high voltage direct current (HVDC) **advanced transmission** cables;
- 42 deployments (28-70) of advanced **smart distribution** control systems;
- 27 GW (7-59) of electricity **storage** capacity;
- 28% (11-70%) household penetration of EMS, a **home hub technology**;
- 70% (53-100%) penetration of **DR** controllers in appliances; and
- 19 million (5-36) **EV** charging controllers.

Key uncertainties

For most of these technologies, current levels of deployment are limited to a handful of demonstrations, and a very wide range of future deployment scenarios are plausible. Moreover, some technology areas – particularly storage, DR, and EV integration – will compete to provide some of the same services to the electricity system, further complicating any analysis of future deployment. A few key deployment uncertainties could have significant impact on the value from innovation:

- Some **storage** technologies are likely to be deployed much more extensively than others depending on technology improvements (including cost reductions), regulation, and commercial factors. It is not yet clear how much storage capacity overall will be needed in the future energy system or which storage technologies will be dominant. For the purposes of estimating value from innovation, we have estimated the magnitude of different types of system needs for storage. We then mapped specific technologies' abilities to meet those different needs, considering the technical maturity and cost of each storage technology when estimating their future shares of deployment. However, we expect that actual future deployment will heavily favour a subset of dominant technologies, and we do not know with certainty which those will be. Published research commissioned by the Carbon Trust and conducted by the Energy Futures Lab at Imperial College suggests that the value of energy storage in the UK energy system could be high, particularly after 2030. However, the analysis also shows that the value and penetration of energy storage technologies will depend significantly on the level of variable renewable generation capacity and on the penetration of competing technologies, particularly demand response.[8] These conclusions are supported by Imperial College's modelling for DECC of the wider electricity system.[9]
- **EMS** could be deployed in many homes by 2050, but the market for such systems is not yet proven. Very low penetration of EMS is a plausible future outcome.
- Similarly, **V2G** controllers for EV charging points could be deployed extensively, but deployment could also be negligible depending on whether a range of technical and market challenges are resolved. In particular, it is not clear that the V2G application is a cost-effective use of EV batteries' limited useful cycle lifetimes. Moreover, V2G deployment will be dependent on the deployment of distribution control systems that can actively manage the charging and discharging of a large number of small batteries through the low voltage network. If these challenges are not addressed, V2G adoption could be very low.

[7] For a full electricity system analysis please see DECC, 2012 'The Electricity System: Assessment of Future Challenges' and Imperial's supporting analysis setting out the balancing challenge and possible savings from deployment a range of flexibility options including storage.
(http://www.decc.gov.uk/en/content/cms/meeting_energy/network/strategy/strategy.aspx).

[8] Strbac et al, 'Strategic assessment of the role and value of energy storage systems in the UK low carbon energy future', http://bit.ly/RUAabN.

[9] Imperial College and NERA Consulting, 2012, 'Understanding the Balancing Challenge', (http://www.decc.gov.uk/en/content/cms/meeting_energy/network/strategy/strategy.aspx).

Cutting costs by innovating

Current costs

Some of the EN&S technologies in this TINA are available already, but many of them are still expensive or not yet ready for wide deployment and integration in the electricity system. The diversity of the EN&S technologies we have considered makes it impossible to summarise current unit costs across all technology areas in one metric. The scope of this TINA ranges from smart appliance controllers costing around £25 per appliance to offshore HVDC platforms costing over £100 million.

Therefore, we have estimated current costs for each of the individual technology sub-areas as summarised in Chart 3. Where relevant, we have shown the total or average costs in a technology area. For example:

- The total estimated installed costs for the full set of home hub technologies are around £765 per home.
- The total costs of a full set of controllers installed at one EV charging point are around £870.
- The average cost of the storage technologies considered is around £1975 per kW.

Across all technology areas, there will be significant differences in costs depending on the specific application, often down to the individual installation. This is particularly true for large, customised EN&S systems. The costs shown in the table should therefore be interpreted as average unit costs. Moreover, while these average unit costs are presented as single point estimates, we recognise that there are differing views on current cost levels for different technologies. In developing these cost assumptions, we have considered a range of sources to develop an average central estimate.

Chart 2 EN&S technology deployment scenarios

Area	Sub-area	Units	2020 deployment		2050 deployment	
Advanced transmission	Cables	km	468 (165 - 652)		1663 (601 - 2307)	
	Offshore platforms	Platforms	2 (1 - 3)		9 (3 - 12)	
	Converters	Converters	20 (7 - 27)		70 (25 - 97)	
Smart distribution	FCL	Units	296 (296 - 406)		1183 (1182 - 1625)	
	DLR		440 (391 - 538)		2054 (1826 - 2510)	
	ADVC		130 (125 - 192)		2845 (1505 - 5116)	
	Advanced control systems		12 (8 - 20)		42 (28 - 70)	
Storage		GW or GWh	**GW**	**GWh**	**GW**	**GWh**
	Pumped hydro		4.3 (3.1 - 6.6)	21 (15 - 33)	8.2 (3.3 - 17.3)	41 (16 - 87)
	CAES		1.8 (0.2 - 3.8)	9 (1 - 19)	7.1 (0.7 - 15.3)	35 (4 - 76)
	Sodium-based batteries		0.5 (0.1 - 1.1)	2 (1 - 6)	1.9 (0.5 - 4.6)	9 (3 - 23)
	Redox flow batteries		0.3 (0.1 - 0.9)	2 (1 - 4)	1.4 (0.4 - 3.5)	7 (2 - 18)
	Lithium-based batteries		0.4 (0.3 - 0.9)	0 (0 - 3)	1.7 (1.2 - 3.6)	2 (2 - 10)
	Flywheels		0.1 (0.1 - 0.1)	0 (0 - 0)	0.5 (0.3 - 0.6)	0 (0 - 0)
	Supercapacitors		0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
	Thermal-to-electric storage		1.7 (0.2 - 3.6)	8 (1 - 18)	6.7 (0.8 - 14.3)	34 (4 - 72)
	Total		**9.1 (4.1 - 17.1)**	**43 (19 - 83)**	**27.4 (7.2 - 59.2)**	**128 (31 - 286)**
Home hub	HAN	% of homes	100% (100% - 100%)		100% (100% - 100%)	
	IHD		24% (21% -30%)		45% (30% - 80%)	
	WAN		100% (100% - 100%)		100% (100% - 100%)	
	EMS		4% (2% - 10%)		28% (11% - 70%)	
Demand response	Smart appliance controllers	% of homes	10% (8% - 15%)		7% (53% - 100%)	
	Auxiliary switch controllers		1% (1% - 2%)		8% (7% - 10%)	
	Micro-generation controllers		1% (1% - 1%)		4% (4% - 5%)	
	VPP	VPP systems	0 (0 - 0)		96 (64 - 128)	
Electric vehicle integration	Charging controllers	Million charging points	3 (1 - 5)		19 (5 - 36)	
	Demand & power factor controllers		1 (0 - 3)		18 (5 - 35)	
	V2G controllers		0 (0 - 0)		5 (0 - 14)	

Chart 3 EN&S technology current estimated unit costs

Area	Sub-area	Variants (if applicable)	Units	Costs per unit (£)[10]	
Advanced transmission				**Equipment**	**Installation**
	Cables		km	0.8m	0.1m
	Offshore platforms		Platform	35m	89m
	Converters		MW	0.18m	
	O&M	Cables and convertors	Capex/yr	1.5%	
		Platforms	Platform/yr	1.1m	
Smart distribution	FCL	11kV	Unit	0.8m	
		33kV		2m	
	DLR			120k	
	ADVC			60k	
	Advanced control systems	Central systems		17m	
		132kV sub-systems		19m	
Storage				**£/kWh[11]**	**£/kW**
	Pumped hydro	Traditional onshore reservoir	kWh or kW	150	1500
		Offshore 'energy islands'		200	2000
	CAES	Underground/geological		150	1500
		Aboveground		200	2000
	Sodium-based batteries			250	1250
	Redox flow batteries			400	2000
	Lithium-based batteries			1000	5000
	Flywheels			4000	1000
	Supercapacitors			6000	1500
	Thermal-to-electric storage			200	2000
	Average			**1255**	**1975**
Home hub				**Equipment**	**Installation**
	HAN		Home	20	5
	IHD			70	5
	WAN			60	5
	EMS			500	100
	Sub-total			**650**	**115**
Demand response				**Equipment**	**Installation**
	Smart appliance controllers		Controller	20	5
	Auxiliary switch controllers			70	50
	Micro-generation controllers			250	100
	VPP		VPP system	4m	
Electric vehicle integration				**Equipment**	**Installation**
	Charging controllers		Charging point	70	50
	Demand & power factor controllers			100	50
	V2G controllers			500	100
	Sub-total			**670**	**200**

[10] Cost refers to total installed costs per unit unless equipment and installation costs are noted separately.

[11] The most relevant cost metric for each storage technology is in black text, and the less relevant metric is in a lighter shade.

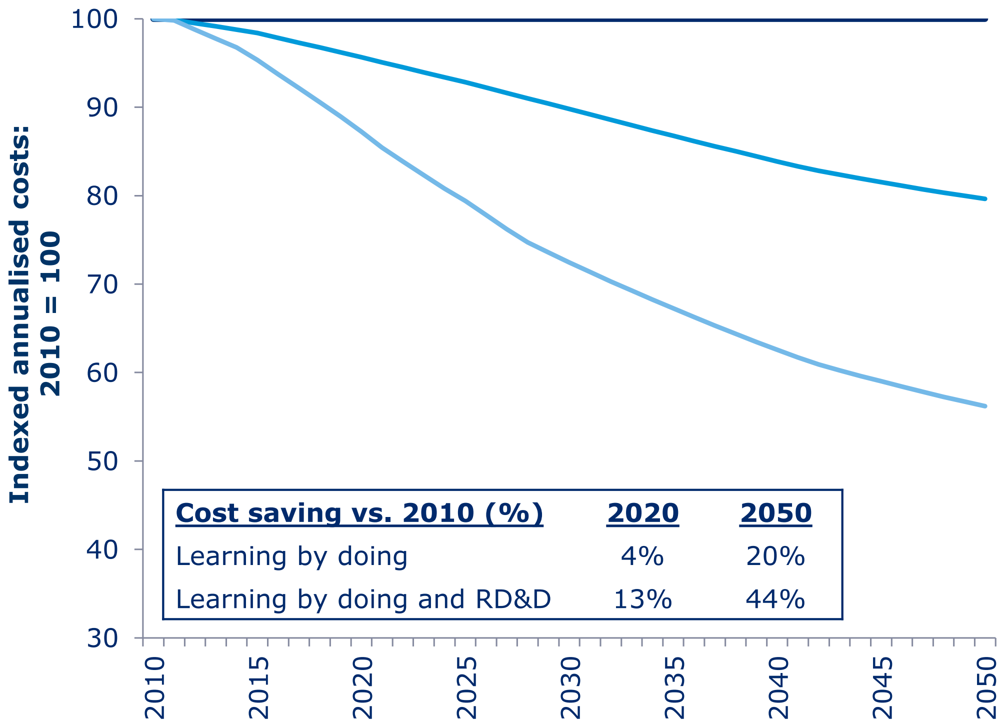
Source: Expert interviews, Carbon Trust analysis

Cost savings through economies of scale and innovation

Many of the EN&S technologies considered in this TINA are relatively nascent, with only a limited number of deployments globally to date. Further innovation is needed to bring down the costs of these technologies and to make them ready for wide deployment.

Innovation opportunities in EN&S technologies could bring down costs significantly. Over the next 10 years, innovation could lower costs by around 13%, with further savings after 2020 capable of lowering costs by around 44% by 2050 compared with 2010 costs (see Chart 4). While some of this innovation potential could be realised through "learning-by-doing", we expect that over half the cost reduction potential to 2050 would be driven by RD&D.

Chart 4 Potential impact of innovation on annualised unit costs of EN&S technologies †



† The index of annualised unit costs is based on the weighted average unit costs of the EN&S technologies considered, weighted by their total present value deployment costs from 2010-2050 in the "middle of the road" scenario.

Source: Expert interviews, Carbon Trust analysis

We have estimated the potential for innovation to reduce the costs of each EN&S technology considered. These estimates are based on a bottom-up assessment of highest potential cost and performance improvements identified and potentially commercialisable by 2020 and 2050. The share of that innovation potential that can be realised by learning-by-doing is based on the stage of development for each technology area, with a greater share of the potential realisable through learning-by-doing for later stage technologies.

Chart 5 shows the estimated total innovation potential for each technology area and sub-area across all EN&S technologies. There is significant potential for cost reduction across all areas, with 44% cost reductions possible overall by 2050 and with the possibility of greater cost reductions in home hub (68%) and EV integration (53%) technologies.

Chart 5 Estimated cost savings from innovation by technology sub-area

Area	Sub-area	Total learning-by-doing and RD&D			
		2020		2050	
Advanced transmission	Cables	5%		20%	
	Offshore platforms	20%		65%	
	Converters	5%		25%	
	Installation	5%		20%	
	O&M	10%		45%	
	Sub-total	**9%**		**35%**	
Smart distribution	FCL: 11kV	10%		40%	
	FCL: 33kV	10%		25%	
	DLR	10%		10%	
	ADVC	5%		30%	
	Advanced control systems	15%		25%	
	Sub-total	**10%**		**28%**	
Storage	Pumped hydro	-		20%	
	CAES	10%		30%	
	Sodium-based batteries	20%		40%	
	Redox flow batteries	20%		40%	
	Lithium-based batteries	20%		50%	
	Flywheels	15%		30%	
	Supercapacitors	5%		25%	
	Thermal-to-electric storage	20%		50%	
	Sub-total	**15%**		**39%**	
Home hub	HAN	10%		50%	
	IHD	20%		50%	
	WAN	10%		50%	
	EMS	20%		80%	
	Installation	10%		35%	
	Sub-total	**21%**		**68%**	
Demand response		**Equipment**	**Installation**	**Equipment**	**Installation**
	Smart appliance controllers	15%	5%	30%	10%
	Auxiliary switch controllers	10%	5%	50%	10%
	Micro-generation controllers	15%	10%	80%	30%
	VPP	5%		40%	
	Sub-total	**13%**		**38%**	
Electric vehicle integration	Charging controllers	5%		55%	
	Demand & power factor controllers	0%		45%	
	V2G controllers	0%		55%	
	Installation	5%		50%	
	Sub-total	**<1%**		**53%**	
Total†		**13%**		**44%**	

† The index of annualised unit costs is based on the weighted average unit costs of the EN&S technologies considered, weighted by their total present value deployment costs from 2010-2050 in the "middle of the road" scenario.

Source: Expert interviews, Carbon Trust analysis

Value in meeting emissions and energy security targets at lowest cost

Based on our estimates of potential cost improvements and our scenarios for deployment (taking into account emissions and energy security constraints), we calculate the potential savings in energy system costs through innovation.

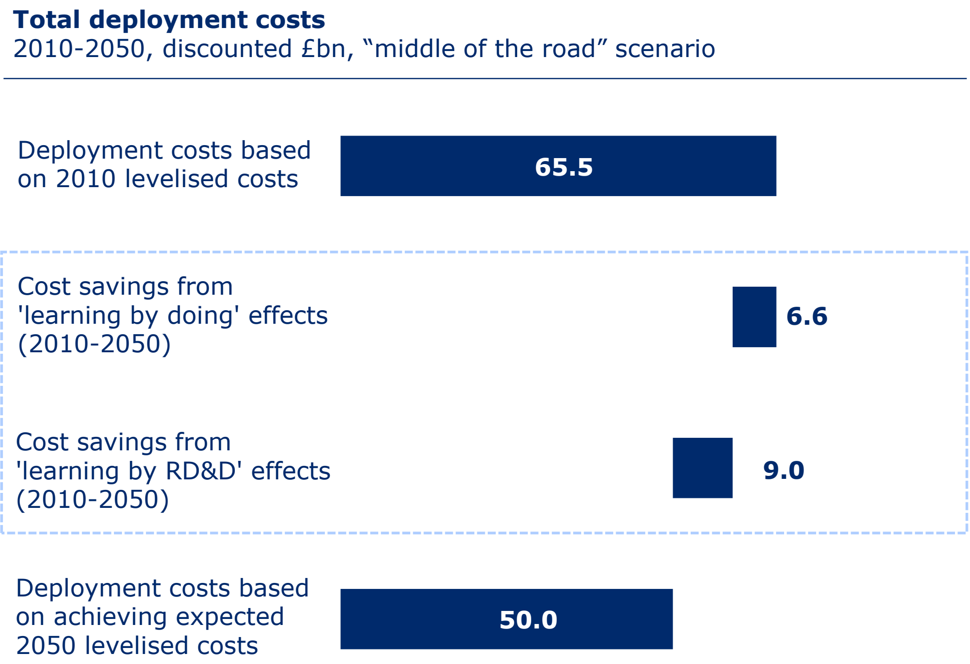
In our "middle of the road" scenario, the identified innovation opportunities lead to a saving of £15.6 billion in deployment costs over 2010-2050. As shown in the chart below, around 42%, £6.6 billion, is from learning-by-doing improvements. The remaining 58%, £9.0 billion, is saved from learning-by-research improvements. These savings estimates use an 'inflexible deployment' counterfactual, which is most appropriate if we believe the feasibility of substitute technologies is low and/or deployment incentives are inflexible to changes in the relative cost-effectiveness of different technologies. This is a high cost saving estimate that does not reflect the possibility that alternative technologies, such as traditional grid reinforcement, could be deployed if innovation does not successfully bring down the costs of advanced EN&S technologies. TINA analysis for other technology families has shown that accounting for such system flexibility can reduce the estimated value of innovation significantly, sometimes by 50% or more.

The total cost-saving value of innovation is highly dependent on the level of technology deployment. And because there are significant differences in our deployment estimates between the highest and lowest scenarios, there is a great deal of variation between our estimates of the value from innovation across these scenarios. As shown in Chart 8, the value of RD&D-led innovation ranges from £3.9 billion in the "low electrification" scenario to £18.7 billion in the "two-thirds wind" scenario, compared with £9.0 billion in the "middle of the road" scenario (see Chart 8).

The savings opportunity can be further broken down by each technology area, as shown in Chart 7. The greatest cost savings are from storage, EV integration, and home hub technologies.

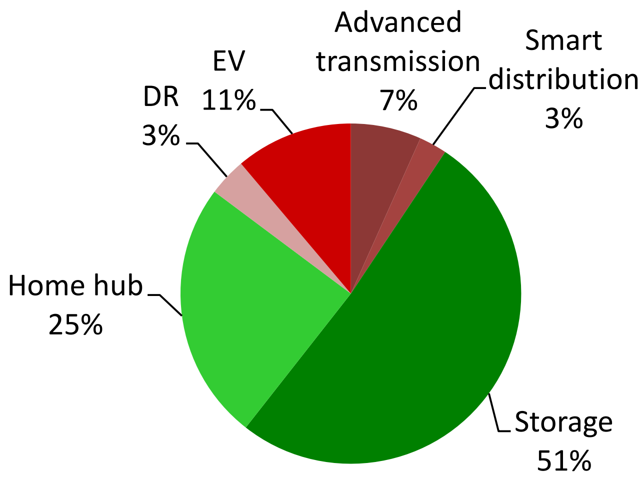
While we have estimated the innovation benefits for the whole of the UK, the geographical spread of benefits from the deployment of EN&S technologies will not be homogeneous throughout the country. Particularly for technologies deployed within the distribution network, EN&S technologies will be deployed to manage local challenges and constraints.

Chart 6 Value of innovation in meeting emissions and energy security targets at lowest costs (2010-2050)



Cumulative cost of EN&S technologies installed between 2010 and 2050 discounted to 2010 using the social discount rate
Source: Expert interviews; Carbon Trust analysis

Chart 7 Cost savings from 2010 to 2020 by sub-area ("middle of the road" deployment scenario)



Source: Expert interviews (including input from ETI and Kema), Carbon Trust analysis

Beyond reduced deployment costs, innovation has the potential to unlock significant benefits by enabling the deployment of other low carbon technologies. Chart 8 assesses the significance of innovation in each EN&S technology area to realising enabling benefits. This enabling value from innovation is a function of:

- **The underlying value of the enabled benefits**. For example, successful deployment of renewable electricity generation is critical to meeting emissions targets at lowest costs. The benefits from enabling renewable electricity generation are high.
- **The importance of the enabling technology to the deployment of the enabled technology**. For example, EV charging control could help enable the deployment of renewable electricity generation, but other technologies may have a more critical role. The role of EV charging control to realising these enabled benefits are moderate.
- **The importance of innovation to realising enabled benefits**. For example, innovation in EV charging control will be essential to realise the enabling benefits that such controls could provide to the deployment of renewables electricity generation.

The combination of these qualitative factors gives a rough guide to the value of innovation to enabling other low carbon technologies in the energy system.

The enabling benefits due to innovation are significant across all six technology areas, with particularly high enabling benefits from innovation in DR, EV integration, storage, and smart distribution where innovation will be important to enabling the deployment of heat pumps, electric vehicles, and renewable electricity generation. Innovation will be particularly important in the area of EV integration, where large-scale adoption of EVs will likely be possible only with some form of EV charging control to accommodate the new EV charging loads placed on the electricity network. A key innovation challenge will be integrating the diverse range of mutually-dependent EN&S technologies into effective systems. This successful integration will be important to deployment of these technologies and will be critical to realising their full enabling benefits.

Chart 8 Value of innovation to meeting emissions targets and enabling deployment of other technologies

Area	Sub-area	Value from meeting emissions targets at lowest cost	Enabling value from innovation (sub-area)	Enabling value from innovation (area)	Rationale for enabling value
Advanced transmission	Cables	0 (0 - 0.1)	Low-medium	Low-medium	The most important sources of enabling value are for renewable electricity generation (particularly offshore wind) and interconnection. However, there are viable substitute technologies (e.g. HVAC) and current HVDC technology that could deliver most enabling benefits.
	Offshore platforms	0 (0 - 0)	Low-medium		
	Converters	0.3 (0.1 - 0.4)	Low		
	Installation	0 (0 - 0)	Low-medium		
	O&M	0.3 (0.1 - 0.3)	Low		
	Sub-total	**0.6 (0.2 - 0.8)**			
Smart distribution	FCL	0.2 (0.2 - 0.2)	Medium	Medium-high	EVs and heat pumps are the most important sources of enabling value, where the enabled benefits are high, smart distribution technologies are key enablers, and some innovation will be important to realising the enabled benefits.
	DLR	0 (0 - 0)	Low		
	ADVC	0 (0 - 0)	Medium-high		
	Advanced control systems	0.1 (0 - 0.1)	High		
	Sub-total	**0.2 (0.2 - 0.3)**			
Storage	Pumped hydro	0.2 (0 - 0.5)	Medium	Medium-high	Storage is important to enabling deployment of renewables, EVs, heat pumps, and better network utilisation. The enabled benefits of these technologies are high, and innovation in storage is important to realising those benefits.
	CAES	0.3 (0 - 0.8)	Medium		
	Sodium-based batteries	0.4 (0.1 - 1.1)	Medium-high		
	Redox flow batteries	0.3 (0.1 - 0.8)	Medium-high		
	Lithium-based batteries	2 (1.4 - 4.3)	Medium-high		
	Flywheels	0 (0 - 0)	Medium-high		
	Supercapacitors	0 (0 - 0)	Medium-high		
	Thermal-to-electric storage	1.3 (0.2 - 2.7)	Medium		
	Sub-total	**4.6 (1.9 - 10.1)**			
Home hub	HAN	0.1 (0.1 - 0.1)	Low	Low-medium	Home hub technologies are important to the deployment of renewables, EVs, and energy efficiency. However, current technologies are able to deliver most of these enabling benefits.
	IHD	0.3 (0.3 - 0.4)	Medium		
	WAN	0.2 (0.2 - 0.2)	Low		
	EMS	1.5 (0.5 - 3.6)	Medium		
	Installation	0.1 (0.1 - 0.3)	-		
	Sub-total	**2.2 (1.2 - 4.7)**			
Demand response	Smart appliance controllers	0.1 (0.1 - 0.2)	Medium-High	Medium-high	DR is important to the deployment of renewables, EVs, and heat pumps, and innovation in DR is important to the realisation of enabling benefits.
	Auxiliary switch controllers	0 (0 - 0)	Medium		
	Micro-generation controllers	0.1 (0.1 - 0.1)	Medium		
	VPP	0.1 (0 - 0.1)	High		
	Installation	0.1 (0 - 0.1)	-		
	Sub-total	**0.3 (0.3 - 0.4)**			
Electric vehicle integration	Charging controllers	0.2 (0 - 0.3)	Medium-high	Medium-high	EVs themselves are very important to meeting emissions targets at lowest cost, and innovation in EV integration technologies is critical to EV deployment. EV integration technologies also have significant enabling benefits for heat pumps and renewables.
	Demand & power factor controllers	0.2 (0.1 - 0.4)	Medium-high		
	V2G controllers	0.3 (0 - 0.9)	High		
	Installation	0.3 (0.1 - 0.7)	-		
	Sub-total	**1 (0.2 - 2.3)**			
Total		**9.0 (3.9 - 18.7)**			

Source: Expert interviews, Carbon Trust analysis

Green growth opportunity

A large global market for EN&S technologies

While global deployment projections are highly uncertain, EN&S technologies could be deployed extensively by 2050. To assess the economic opportunity for the UK from participating in this global market, we have considered a range of possible 2050 scenarios for future deployment.

Across the lowest to highest scenario, the global market turnover for EN&S technologies by 2050 could grow to £114 billion (£48 – £226 billion, undiscounted). This represents potential cumulative, discounted gross value-added (GVA) between 2010 and 2050 of £0.8 trillion (£0.3 – £1.6 trillion).

The UK could be a player in some market niches

Overall, the UK is likely to capture only a moderate share of the global EN&S market. However, there are a handful of niches where the UK could be an important market player. In particular, the UK could achieve significant market shares in some smart distribution, storage, and home hub technology sub-areas. Market shares will vary by each sub-area, but overall the UK could expect to achieve a global market share of around 4% in the global EN&S technology market.

£6 – 34bn net contribution to the UK economy

If the UK successfully competes in a global market to achieve the market share above, then EN&S technologies could add a cumulative GVA contribution[12] to the UK economy of £33 billion (£13 – 67) from 2010 to 2050.

It may be appropriate to apply an additional displacement effect since part of the value created in the export market will be due to a shift of resources and thus partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat 50%. Including this displacement factor, EN&S technologies would still make a net contribution of £17 billion (£6 – 34) in cumulative GVA from 2010 to 2050.

The case for UK public sector intervention

Public sector activity is required to unlock all of this opportunity – both the reduction in the costs to the energy system from learning-by-research, and the net contribution to UK GDP from new business creation.

[12] Discounted at 3.5% to 2040, and 3.0% between 2041 and 2050, in line with HM Treasury guidelines

Market failures and barriers impeding innovation

A number of overall market failures and barriers inhibit innovation in EN&S technologies, especially related to uncertain demand (externality effect), infrastructure conditions (co-ordination failures), and split incentives:

- Smart distribution, EV integration, DR, and home hub technologies are particularly held back by co-ordination failures. These technologies are mutually reinforcing and dependent, making it difficult for individual players to push forward.
- Uncertain demand affects all EN&S technology areas, but particularly those where markets are highly nascent such as storage, DR, and EV integration technologies.

These and other market failures and barriers are further detailed in Chart 9 below.

In many areas, the UK can rely on the private sector and other countries to drive innovation

In several technology areas – particularly storage, smart distribution, and DR – the UK could largely rely on the private sector and other countries to deliver innovation improvements. In addition, most EN&S technologies are globally tradable, and UK firms could participate in the global market even in the absence of significant UK activity. In the area of storage, for example, the USA and Germany are both investing hundreds of millions of US dollars over the next few years in storage technology development and demonstration. So while there is significant potential value from innovation in storage, the UK can largely rely on others to deliver that innovation in many technology sub-areas, including CAES and lithium-based batteries. Most UK public sector support for storage innovation should therefore focus on sub-areas that are promising but not as strongly supported by other countries or the private sector. Such sub-areas include thermal-to-electric storage, redox flow batteries, and novel pumped hydro storage.

There are a number of other technology sub-areas where the UK may not be able to rely on others. For example, EMS will require some UK-specific innovation and adaptation, making it impossible to entirely rely on other countries. In advanced transmission, expected rapid growth in offshore wind in the UK could create unique UK needs for the development of substations and convertors for HVDC multi-terminal networks. In EV integration, due to a lower demand response opportunity from controllable loads such as air conditioning, the UK is likely to have greater need than other countries for sophisticated EV charging control and V2G technologies. Across many technology sub-areas, installation is not globally tradable and will therefore require home-grown UK innovation to realise cost improvements.

Chart 9 Market failures and barriers in EN&S innovation areas

Area	What market failures and barriers exist?	Assessment
Advanced transmission	▪ **Policy dependent demand** for offshore and other renewables, and associated HVDC connections (owing to negative externalities, current costs, and high apparent consumer hurdle rates) creates uncertainty. ▪ Since transmission infrastructure serves multiple users and suppliers, and hence requires government co-ordination or guidance; specific issues include: ▪ **Lack of clarity** on long-run plans for offshore electricity grid ▪ **Complexity of coordination** and development mechanisms, especially in integrating across energy suppliers, offshore (or long-distance) transmission and onshore (or shorter-distance) transmission	Critical failures
	▪ An additional possible weakness is the UK regulatory framework that requires radial offshore connections that could be described as **dis-incentivising interest in DC multi terminal configurations**	Significant failures
Smart distribution	▪ Moreover, the **scale of investment** required to integrate telecommunications in new equipment is a barrier to DNOs investment ▪ No current national coordination or roll out plan or developed roadmap for these technologies also creates **demand uncertainty**	Critical failures
	▪ **High coordination required** for full "smart grid" infrastructure makes it difficult for individual players (e.g. DNOs) to push forward in absence of central coordination ▪ Broader energy **infrastructure plans are uncertain**, including the extent of the role of renewables, energy efficiency improvements, electric vehicles, and deployment of heat pumps	Significant failures
Storage	▪ All parties – including regulators, network operators, and technology providers – are **unsure of the value and the extent of the role storage will play in the future energy system**, creating a barrier to innovation and deployment ▪ The value of some of the services that storage can provide, such as voltage support or T&D investment deferral, **cannot be easily captured under existing market arrangements** ▪ **Lack of clarity about infrastructure planning**, particularly development of infrastructure that could substitute for storage technologies, does not give parties sufficient confidence to invest in R&D or deployment	Critical failures
Home hub	▪ **Policy dependent demand** for demand side management (owing to negative externality, current costs, and high consumer investment hurdle rate) creates uncertainty ▪ **Regulation doesn't allow sufficiently dynamic tariffs** to incentivise peak demand reductions, reducing a major underlying source of value for home hub – optimal regulation complicated by fairness issues, windfalls for inherently off-peak users, and potential switching to gas	Critical failures
	▪ Most elements of infrastructure serve multiple users and suppliers, and hence require government co-ordination or guidance – any lack of certainty in government roadmap and commitment inhibits market development, specific issues include: ▪ Any setbacks or a cancellation of smart meter roll out would introduce a significant market failure for home hub technologies ▪ Any infrastructure failures related to demand response roll out will also affect home hub, whose benefits are greater in combination with demand response	Significant failures
	▪ **Lack of common standards** results in confusion, difficulty ensuring benefits from both home-level management and network-level demand response, and hence fewer products from suppliers	Important failure
Demand response	▪ **Regulation doesn't allow sufficiently dynamic tariffs** (e.g. metering requirements for Ancillary Services) to incentivise peak demand reductions, reducing a major underlying incentive for DR ▪ **Policy dependent demand** for demand side management and micro generation (owing to negative externality, current costs, and high consumer investment hurdle rate) creates uncertainty ▪ **High level of coordination (and transaction costs) required** for an integrated national DR system makes it hard for individual players in the market to drive demand ▪ Most elements of infrastructure are serve multiple users and suppliers, and hence require government co-ordination or guidance	Critical failures
Electric vehicle integration	▪ **Policy dependent demand** for EVs (owing to negative externalities and current cost disadvantage) creates uncertainty ▪ Market rules (e.g. metering requirements for Ancillary Services) **prevent rollout of cost reflective tariffs to customers** ▪ High level of **coordination (and transaction costs) required** for consolidated EV integration makes it hard for individual players in the market to drive demand ▪ Most elements of infrastructure serve multiple users and suppliers, and hence require government co-ordination or guidance	Critical failures
	▪ **Lack of common standards** results in confusion and very few products from suppliers ▪ **Regulated industry (owing to monopoly power)** means that some current incentives do not equally reward load management strategies as alternatives to network augmentation ▪ **Regulated utilities require government guidance** appropriate connection agreements, incentives for customers to participate in demand response and distributed "generation", the lack of which limits likely uptake and thus supplier product offerings	Significant failure

Source: Expert interviews, Carbon Trust analysis

Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas of innovation with the biggest relative benefit to the UK and where there are not existing or planned initiatives (both in the UK and abroad). The LCICG has identified and prioritised these innovation areas.

Innovation areas with the biggest relative benefit from UK public sector activity/investment

The LCICG has identified the areas of innovation with the highest relative benefit from UK public sector activity/investment. These are: EV integration; storage technologies including thermal-to-electric storage, lithium-based batteries, and redox flow batteries; and overcoming co-ordination challenges for integrated EV, DR, smart distribution, and storage solutions (see Chart 10).

These have been prioritised by identifying those areas that best meet the following criteria:

- value in meeting emissions targets at lowest cost
- value from enabling other low carbon technologies
- value in business creation
- extent of market failure
- opportunity to rely on another country

Chart 10 Benefit of UK public sector activity/investment by sub-area and technology type

Area	Value in meeting emissions targets at low cost £bn‡	Enabling value from innovation	Value in business creation £bn†	Extent of market failure/ barriers	Opportunity to rely on someone else	Benefit of UK public sector activity/investment (without considering costs)
Advanced transmission	0.6 (0.2 - 0.8)	Low-medium	1.6 (0.6 - 2.2)	Critical failures	Yes, partly: offshore wind could create unique UK needs for substations in multi-terminal networks	Low: Overall value to meeting targets is low, and the UK could mostly rely on others to deliver innovation
Smart distribution	0.2 (0.2 - 0.3)	Medium-high	1.0 (0.9 - 1.4)	Critical failures	Yes, partly: implementation will require some UK-specific innovation	Medium: Despite low value in meeting targets, smart distribution technologies, particularly advanced control systems, are a critical lynchpin to realising value from storage, EVs, and demand response
Storage	4.6 (1.9 - 10.1)	Medium-high	11.5 (3.4 - 25.7)	Critical failures	Yes, partly: thermal-to-electric may require UK support to realise global commercial benefits	High: Storage has high value in meeting targets, high enabling value, high green growth potential, and critical failures, all of which support the case for public sector activity. However, there is a high opportunity to rely on others—the UK should be very targeted in its support to avoid duplicating other efforts.
Home hub	2.2 (1.2 - 4.7)	Low-medium	2.3 (1.2 - 2.9)	Critical failures	Yes, partly: EMS will require UK-specific adaptation	Medium: EMS in particular will be valuable area for support
Demand response	0.3 (0.3 - 0.4)	Medium-high	0.1 (0.1 - 0.3)	Critical failures	Yes, partly: implementation will require some UK-specific innovation	Medium: Enabling value is significant, and co-ordination challenges make a case for public support
Electric vehicle integration	1.0 (0.2 - 2.3)	Medium-high	0.7 (0.1 - 1.5)	Critical failures	No: the UK is likely to have greater/ sooner need	Medium: Value is medium and the UK cannot likely rely on others for innovation
Total	**9.0 (3.9 - 18.7)**	**Medium-high**	**16.6 (6.4 - 33.6)**	**Critical failures**		**Medium-high relative to other technology families**

Benefit of UK public sector activity/investment	
	High
	Medium
	Low

‡RD&D effects, net of learning-by-doing
†After displacement effects
Source: Expert interviews, Carbon Trust analysis

Existing innovation support

The UK is supporting many of the areas highlighted in this report through regulatory reform, funds for demonstration of near-to-market EN&S technologies, and earlier-stage RD&D investment. The LCICG membership, including Ofgem, are key stakeholders and supporters of EN&S technology innovation and deployment and are already playing a central role in the advancement of these technologies.

Ofgem

The Low Carbon Networks Fund (LCNF) was set up in 2010 by Ofgem to provide up to £500 million in support over five years to trial new technologies through projects sponsored by the UK's distribution network operators (DNOs). In the two years since its inception, the LCNF has committed over £100 million to a range of projects that demonstrate storage, EV charging, demand response, distributed generation, and advanced monitoring and control technologies. The scope and large scale of this fund makes it a global leader in the development of EN&S technologies and provides an important platform for UK network companies and their suppliers. From 2013, Network Innovation Competitions (NICs), Network Innovation Allowances (NIAs), and an Innovation Rollout Mechanism (IRM) will provide further funding, and Ofgem's new "RIIO" regulatory framework will also provide new incentives for innovation for network operators.

Engineering and Physical Sciences Research Council (EPSRC)

The EPSRC is providing grant funding to a range of EN&S projects, including projects funded through its Energy Networks Grand Challenge and Energy Storage Grand Challenge.

Energy Technologies Institute (ETI)

The ETI has funded a number of projects and companies through its Energy Storage and Distribution Programme. These include projects related to fault current limiters, advanced management of power flows, energy storage, and offshore electricity networks. ETI's Smart Systems and Heat programme, launched in 2012, seeks to demonstrate a first-of-its-kind Smart Energy System in the UK. The programme will provide £100 million over five years, focused mainly on demand management and reduction.

Technology Strategy Board (TSB)

The TSB recently accepted proposals for its new Smart Power Distribution and Demand programme, which will provide £2.4 million for feasibility studies related to automated power distribution and demand management. TSB has also led the Smart Grid Special Interest Group (SESIG) to map and coordinate research in this area.

Department for Energy and Climate Change (DECC)

DECC has led, jointly with Ofgem, the Smart Grid Forum to identify priorities for innovation in EN&S technologies and their deployment.

Potential priorities for public sector innovation support

In the sections above, we identified the key innovation needs and the market barriers hindering these innovations. This analysis points to a number of priorities for public sector innovation support:

- There is a cross-cutting need for **co-ordination and integration of different EN&S technologies**, particularly advanced distribution control systems, DR, EV integration, and storage. As previously discussed, these EN&S technologies are mutually dependent and reinforcing, and **large-scale trials** of several technologies at once are needed to test and develop functioning solutions.
- Innovation in **EV integration** technologies and installation methods has high potential value to the UK, and the UK is likely to have a greater and sooner need for these technologies compared to other countries. A key challenge will be developing control systems that are sophisticated enough to deliver the benefits of dynamic charging and V2G control and are also acceptable to consumers.
- Innovation in **selected storage technologies** in a handful of sub-areas is likely to be important. **Thermal-to-electric storage, redox flow batteries, and novel pumped hydro** in particular represent unique UK strengths and a potential source of considerable value from innovation.
- Innovation in **EMS** will be important to tailoring solutions that are applicable in the specific UK context and acceptable by end consumers.

Chart 11 Potential EN&S innovation priorities and support

Area	Potential innovation priorities	Indicative scale of public funding†	Current activities/investments	Future potential activities
Cross-cutting	**Integrated EN&S solutions** incorporating advanced distribution control systems, DR, EV integration, storage, and home hub technologies	High tens to low hundreds of millions of pounds	• Ofgem's LCNF and future NIC and NIA funds • TSB Smart Power Distribution and Demand programme	Conduct comprehensive large-scale trials to test how various EN&S systems can work together to deliver benefits
Advanced transmission	**Power electronics for multi-point offshore HVDC networks**	Millions of pounds	• None	Demonstration of multi-point networks in offshore environment
Smart distribution	**Advanced control system architectures**	Millions of pounds	• Ofgem's LCNF and future NIC and NIA funds • ETI Energy Storage and Distribution Programme, particularly on management of power flows • TSB Smart Power Distribution and Demand programme	Trials of control architectures and layering approaches
Storage	**Thermal-to-electric storage, redox flow batteries, and novel pumped hydro storage**	Tens of millions of pounds	• ETI Energy Storage and Distribution Programme • EPSRC Energy Storage Grand Challenge	Large-scale trials and demonstration of these select storage technologies
	Improved lithium-based and sodium-based batteries	Millions of pounds	• None	Focused research on key technical challenges, improving durability, lifetime, and cost
Home hub	**Development and design of EMS systems**	Millions of pounds	• None	Competitions for UK-tailored EMS designs, with a focus on customer acceptability
Demand response	As a part of cross-cutting trials, **demonstration of DR controls and VPP systems**	Millions of pounds	• Ofgem's LCNF and future NIC and NIA funds • TSB Smart Power Distribution and Demand programme	Large-scale demonstration alongside other EN&S technologies (see cross-cutting innovation priorities above)
Electric vehicle integration	**Effective and usable EV control systems**	Tens of millions of pounds	• Ofgem's LCNF and future NIC and NIA funds	Development and trials of EV control systems, both alongside other EN&S technologies (see cross-cutting innovation priorities above) and for specific improvement of effectiveness and customer acceptance

†Provides an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need.
Source: Expert interviews, Carbon Trust analysis

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