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Energy storage in the UK and Korea:
Innovation, investment and co-operation

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The report considers how energy storage can play a role in the energy systems of the UK and Korea, to identify opportunities for research and industrial collaboration between the countries.

Supporting evidence, references and further detail are presented in Appendices, online at **www.lowcarbonfutures.org/energy-storage**

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1: INTRODUCTION

Energy systems are undergoing radical transformation globally. The drivers of change are varied, but there are common challenges which will require the deployment of new technologies as part of the solution. Energy storage is sitting prominently as one option which can provide greater system flexibility and deliver against the 'trilemma' of security, sustainability and economic prosperity.

It is becoming clear that for new energy technologies to be developed and deployed at scale in the timescales required will need an international effort: to improve the performance and lower costs of the technologies themselves, but also to prepare the markets and systems in which they could operate. It is with this in mind that we have been keen to explore where complementary strengths and needs exist between the UK and Korea in the area of energy storage. As a result, we hope to enable collaborative working between the respective research and industrial communities.

Given the potential role of energy storage, it is being selected by many countries and international organisations as a focus area for innovation. The UK has selected energy storage as one of the 'Eight Great Technologies' that support its science strengths and business capability, with the Government highlighting "the potential for delivering massive benefits – in terms of savings on UK energy spend, environmental benefits, economic growth and in enabling UK business to exploit these technologies internationally" (Willetts, 2013). In Korea, the Government announced a strategy in 2011 to develop energy storage systems for domestic use and hold 30% of the world market.

Elsewhere, France has also picked energy storage as one of the seven strategic goals from its Innovation 2030 Commission, and the US, Japan, Germany and Italy are all putting in place mechanisms to develop and deploy energy storage technologies. It has been the subject of a recent IEA technology roadmap, and features prominently in the EU's Horizon 2020 programme.

The opportunities for energy storage to enable a lower cost transition to a low-carbon economy are being recognised. But the timing is such that if sufficient measures are not put in place to recognise the forward value of energy storage in its many forms, traditional means of providing flexible response will be taken-up, leaving no market place for disruptive technologies in a conservative industry. This may have the impact of locking-in inefficient energy systems, making decarbonisation a more costly process.

'Energy storage', however, is a term representing a broad family of technologies which can offer a multitude of system benefits across time-scales and locations, within electricity, heat and transport sectors. Even focusing on electricity storage, as this report does, there is room for a number of different technologies to play a role. This report does not set out to provide a comprehensive assessment of the potential of energy storage – this has been done elsewhere, including by the authors (Energy Research Partnership, 2011; Centre for Low Carbon Futures, 2012).

In this report, the UK's Centre for Low Carbon Futures, and its constituent universities of Birmingham, Hull, Leeds, Sheffield and York, looks to the vital role of international collaboration for energy innovation. We have undertaken this study with Korea, and are working with Chatham House on a wider international analysis, to describe where and how energy storage should be effectively deployed to help drive the global low-carbon transition.

2: ENERGY SYSTEMS IN THE UK AND KOREA

The energy systems of both the UK and Korea need to undergo rapid transformations to meet policy objectives. The key driver for Korea has been to meet rising demand from economic growth, for the UK it has been the deployment of renewables to mitigate climate change. But to varying degrees, cost to the consumer (domestic and industrial), security of supply and reducing environmental impact are all shaping the future generation mix. Though the energy systems have very different characteristics, both require significant investment in the long and short terms.

The need for greater flexibility of the electricity system to balance supply and demand instantaneously is a common challenge. For this reason, energy storage and demand-side response, which are often integrated as part of a 'smart grid' solution, have attracted the attention of policy-makers and engineers as being cost effective ways of meeting the challenges.

COUNTRY PROFILES

The UK and Korea are similar in size of population and total energy use. Yet there are striking differences in recent history which has shaped the infrastructure, political priorities and the economy. The Korean export-driven 'economic miracle' of the last 50 years is clearly seen in the remarkable expansion of its electricity network (Figure 1); whilst the UK has become a leading service-based economy, with fuel for electricity generation shifting almost completely away from domestically produced coal (Figure 2).

The UK has a population of 63 million and GDP on a purchasing-price parity (PPP) basis of US$2.3 trillion, compared to Korea which has a population of 50 million and GDP of US$1.6 trillion, giving similar per capita PPP GDPs of $32,000 and $36,300. The Korean economy has experienced sustained rapid growth since the 1960s, but the annualised expansion of 4.1 per cent for this decade is expected to slow to 2.8 per cent in the 2020s (OECD, 2012). The UK is also likely to see a drop off in GDP growth from 3.2 per cent in the two decades to 2005, to 2.5 per cent in the early 2020s (Office for Budget Responsibility, 2013).

The smaller geographical size of Korea means it has a population density double that of the UK, with concentration in the Seoul metropolitan region in the north-west being home to half the population. Whilst the population of Korea is not expected to grow in the period to 2050, the UK could see an increase to 71 million by 2030.

The service sector dominates the UK economy, accounting for almost 80 per cent of gross value added (GVA), with the remainder accounted for almost entirely by industry. In contrast, services in the Korean economy account for 57 per cent of GVA, while industry accounts for 40 per cent – and has taken a three-percentage-point share away from services and agriculture from 2001 to 2011 (OECD, 2014). While there have been suggestions that the UK government seeks to rebalance the economy away from services, this has not yet materialised (PricewaterhouseCoopers, 2013).

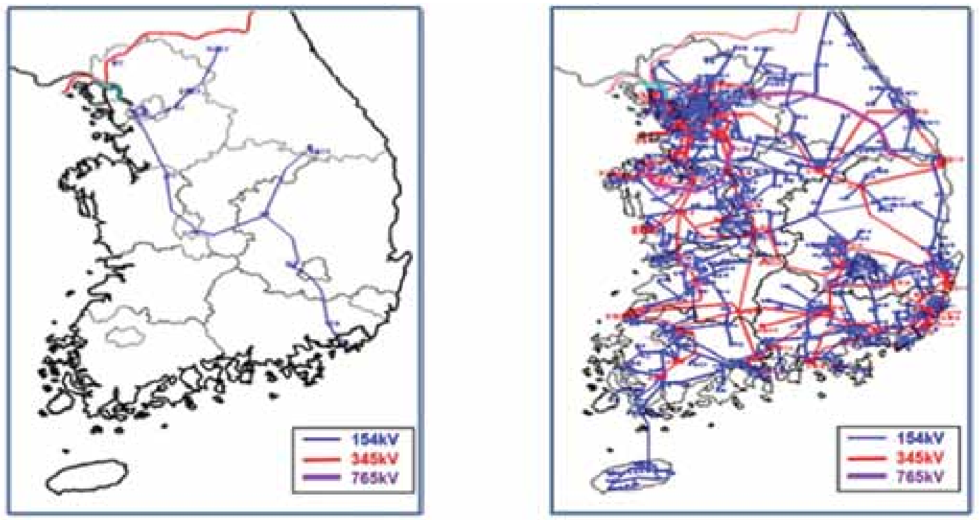

Figure 1 The power system in Korea in 1968 (left) and 2013 (right) (Source: KEPCO)

DRIVERS OF ENERGY POLICY

In 2008, the UK and Korean governments both announced legislative and policy changes expected to drive the transformation of energy provision across their economies. In the UK the Climate Change Act 2008 tightened the 2050 target for the reduction of greenhouse gases emissions to 80 per cent against a 1990 baseline. The approach of the Korean government was outlined in the National Strategy for Green Growth having broader ambitions; mitigating climate change was set among the objectives of ensuring the broad environmental sustainability of economic activity, reducing dependence on imported fossil fuels and transforming Korea into a world leader in green technologies (Presidential Commission on Green Growth, 2008).

Yet the greenhouse-gas targets set in Korea, while short-term, are stretching; as unveiled at the Copenhagen summit in 2009, carbon emissions are to be reduced in 2020 by 30 per cent against business-as-usual projections. This is the highest mitigation level recommended for developing nations by the Intergovernmental Panel on Climate Change (Presidential Commission on Green Growth, 2010). In 2010 many new legislative tools were enabled through the entry into force of the Framework Act of Low Carbon, Green Growth; this among other things requires the publication of five-yearly plans on both climate change and energy, mandated the establishment of a reporting and verification system for greenhouse gases and authorised the government to operate an emissions-trading scheme (Korean Ministry of Government Legislation, 2011).

There have been general improvements in the emission intensity of the Korean economy over time, with a partial decoupling of greenhouse-gas production growth from GDP growth since the Asian financial crisis (OECD, 2012b, p. 90). However, absolute emissions have increased by almost one-third since 2000. A shift away from fossil fuels would likely reduce energy-import dependence, which today stands at 96 per cent of primary consumption (Korea Energy Economics Institute, 2012).

The UK, in contrast, has reduced emissions between 1990 and 2010, thanks largely due to fuel switching in power generation, a decline in manufacturing and the global economic slow-down. The UK Department of Energy and Climate Change (DECC) reports that 14 per cent of the reductions were from the power sector (DECC, 2014a).

Whilst not legislated for, of critical political importance in the UK as they are in Korea, are the other points of the energy trilemma: reliability of supplies, and costs. Energy dependency has grown to 43 per cent in 2012 from 2004, when the UK became a net energy importer for the first time since the development of North Sea oil and gas (DECC, 2013b). And as coal-fired and nuclear power stations close down, policies which do not take into account the imperatives to 'keep the lights on' will get short shrift from voters. At the same time, with rising household bills, policies which add to the burden in the short term are not popular, even if the longer term impact is to deliver a more efficient and sustainable system.

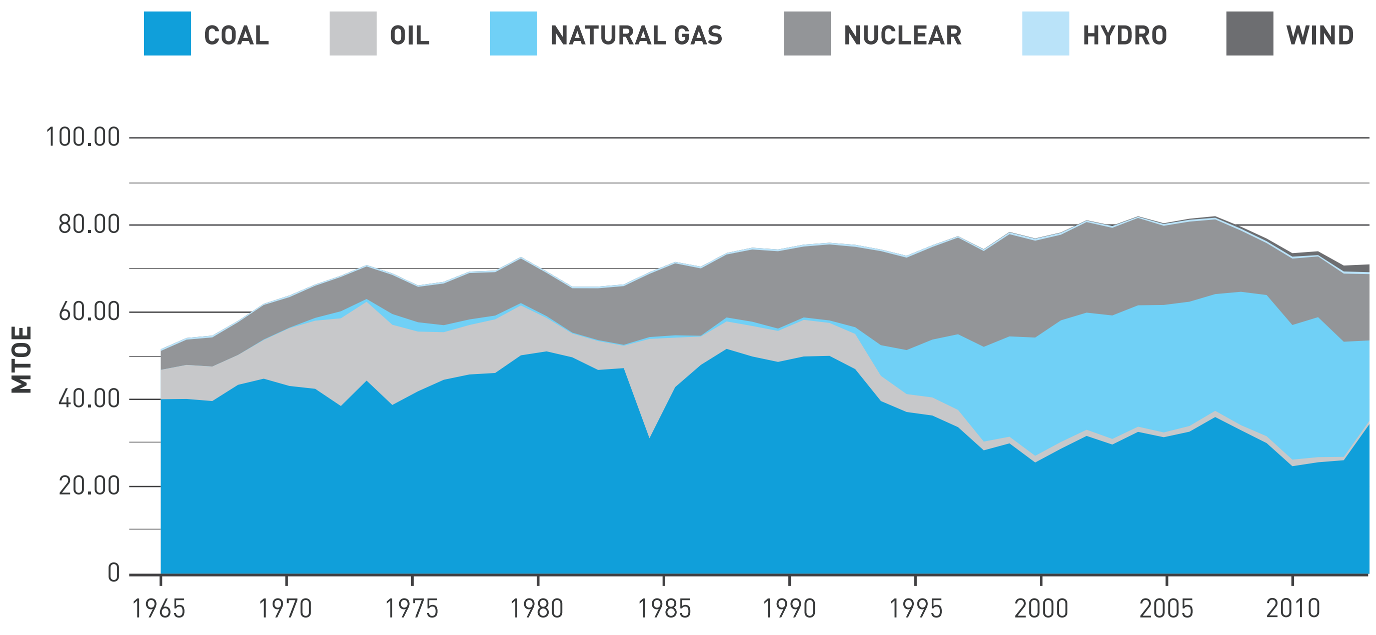

Figure 2: Fuel for electricity generation in the UK (Source: DUKES, DECC)

THE ELECTRICITY SECTOR

The differing foci of the two economies have important consequences for energy demand. In the UK overall electricity consumption is largely unchanged today from 1990, having peaked in the mid-2000s and fallen with similar timing to the economic downturn.

In contrast, Korean energy demand continues to grow strongly, with electricity consumption having increased five-fold in 30 years. This has been driven, but not proportionally coupled, to economic output (Yoo, 2005); between 1990 and 2000 the growth in primary energy consumption outstripped growth in the economy, although from 2000 to 2012, that trend was reversed. These outcomes are even more pronounced for the electricity sector, with 19 per cent of the final energy demand now met by electricity, similar to that of the UK (Korea Energy Economics Institute, 2012).

The electricity systems of both Korea and Great Britain[1] require the transmission of large amounts of electricity. In Korea much of the generation capacity is sited on the southern and eastern coasts, necessitating large south-to-north power flows. The Korean Electric Power Corporation (KEPCO), in which the government holds a majority stake, owns all Korean transmission and distribution assets and has a 95 per cent market share in generation. As an alternative to privatisation, competition between business units of KEPCO has been promoted (International Energy Agency, 2012), with electricity bought and sold on the Korea Power Exchange. Electricity retail prices are regulated by the government and fail to cover the costs of delivery.

In Great Britain the power flows have traditionally been north to south (National Grid, 2013) coming from coal-fired power stations in the north of England, but this is increasingly replaced by wind in Scotland. The transmission system comprises three connected parts: two in Scotland, and one covering England and Wales. The owner of the latter, National Grid, acts as system operator for the whole network. Whilst the Korean electricity system operates effectively as a nationalised industry, the UK has one of the most liberalised energy markets in the world with retail and generation prices determined through a competitive market.

At the end of 2012, the Korean electricity system had a total capacity of 81.8 GW, with electricity generation in the preceding year of 510 TWh (Korea Electric Power Corporation, 2013). There are two annual peaks in electricity demand: in summer from air conditioning load, and in winter for heating (Figure 3). There have been efforts to reduce peak demand, including contracting with businesses to spread holiday periods, which has led to a 2.5 GW peak reduction (Ministry of Knowledge Economy, 2013). The total system capacity of the UK is around 96 GW, with an annual gross generation of 364 TWh (DECC, 2013a).

Pumped hydro storage (PHS) is the dominant bulk electricity storage technology in both countries, with 4.7GW capacity in Korea and 2.7GW in the UK. The last scheme to be commissioned in the UK was in 1983, whilst in Korea the proportion of PHS capacity has increased as new generation has been added over the last 20 years (Figure 4).

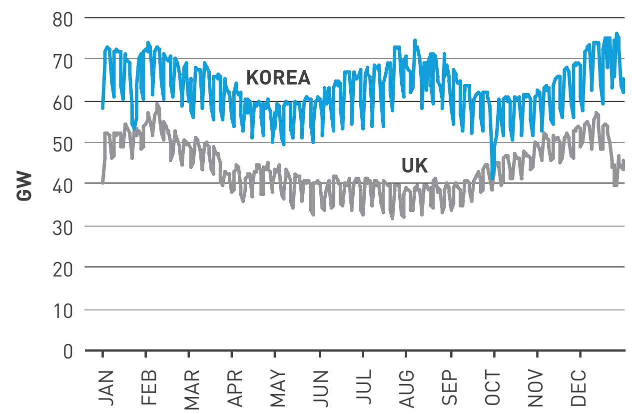

Figure 3: Peak daily demand for 2012 in Korea (red, source: EPSIS) and UK (blue, source: ELEXON).

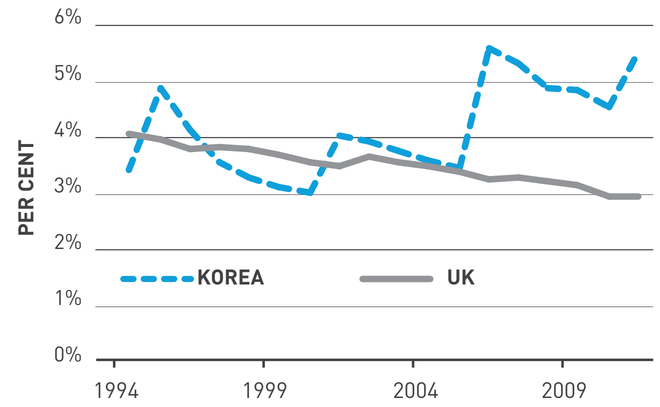

Figure 4 Proportion of total electricity generation capacity from pumped-hydro storage in Korea and the UK (source: US Energy Information Administration)

[1] In the UK, there are two distinct electricity systems: Great Britain and Northern Ireland. The latter is part of the Irish All-Island electricity system formed with the Republic of Ireland in 2007. The focus in this section is on the Great Britain system, as it accounts for the vast majority of the electricity production and consumption.

FUTURE PROSPECTS

UK The overarching framework in the UK is set by the Climate Change Act 2008, which puts the 2050 emission-reduction target into legislation, with five-year carbon budgets set in advance, reducing the impact of economic fluctuations and providing greater clarity to investors. These targets are greatly challenging over the short term: a 50 per cent emissions reduction is required during the period 2023–27 compared to 1990 levels (HM Government, 2011). The UK is also party to EU-wide objectives, requiring that the UK sources 15 per cent of its primary energy from renewables, implying that approximately 30 per cent of electricity come from renewable supplies (HM Government, 2009).

Many scenarios exist for the development of the UK power sector, typically covering the period to 2030, with some extending to 2050. Although there are differences in the generation mix between long-term scenarios, there is a focus primarily on three technologies: nuclear, CCS and wind power (ERP, 2010). Another common theme is that in most scenarios for the UK, electricity demand declines in the short term, but increases out to 2020 and beyond as heating and transportation are electrified.

The 'Gone Green' scenario from the system operator, National Grid, presented in Fig 5(a) shows how generation capacity could evolve over the next 15 years to meet the Government's emission targets. In the early 2020s, fifty per-cent of instantaneous power could come from variable renewable generation, compared to the near absence of renewables at the turn of the century. Finding engineering solutions and business models which can adapt to a new system in such a short space of time, and enable the transition to take place efficiently, is a challenge that should not be underestimated.

KOREA Korea has put in place several policies designed to restrain energy growth, increase demand for low-carbon electricity and drive economy-wide decarbonisation. The First National Energy Master Plan aims to reduce the energy intensity of the economy by 46 per cent against business as usual. A renewable portfolio standard (OECD, 2012b) was introduced in 2012 to replace a renewables feed-in tariff, representing a shift towards a more market-based policy design. There are also plans for an emissions-trading scheme to start in 2015 (GLOBE, 2014). Korea is expected to release a new national renewable energy plan in 2014.

The Korean Ministry of Knowledge Economy (now the Ministry of Trade, Industry and Energy) has built two detailed energy system scenarios, which form the basis of their projections (Ministry of Knowledge Economy, 2013).

Under the baseline projection electricity consumption increases broadly in line with the long-term average, reaching 771 TWh in 2027 from an estimated 485 TWh in 2013. Under this scenario, peak demand increases in proportion to electricity consumption, with the summer peak rising at a higher rate than the winter peak to reach 127 GW in 2027. To restrain this growth the government intends to implement a number of measures: the electricity price is to be brought in line with costs by 2014; efficiency improvements; and smart grid development by 2020, incorporating 2 GW of electricity storage. Together, these measures are expected to reduce below business-as-usual levels electricity consumption by 15 per cent to 655 TWh and peak demand by 13 per cent to 111 GW. In this outlook, total capacity grows from 81.8 GW today to 158 GW in 2027. Renewables are projected to account for 13 per cent of installed capacity in 2020 and 20 per cent in 2027. Over the period, pumped storage capacity remains at 4.7 GW.

The three-phase programme to develop the smart grid begins with the demonstration test bed on Jeju island, followed by a national roll out. System-wide, it is thought that the full roll out of smart meters by 2020 will result in a 10 per cent peak power reduction by 2030 (Korea Smart Grid Institute, 2010).

The '2050 Calculator' developed by the UK Department of Energy and Climate Change, which allows users (including policy-makers and the public) to explore their options to reduce greenhouse gas emissions and help tackle climate change, has been developed for a number of international cases, including Korea. However, this is yet to be used extensively by Korean policy makers, so the results are not presented here.

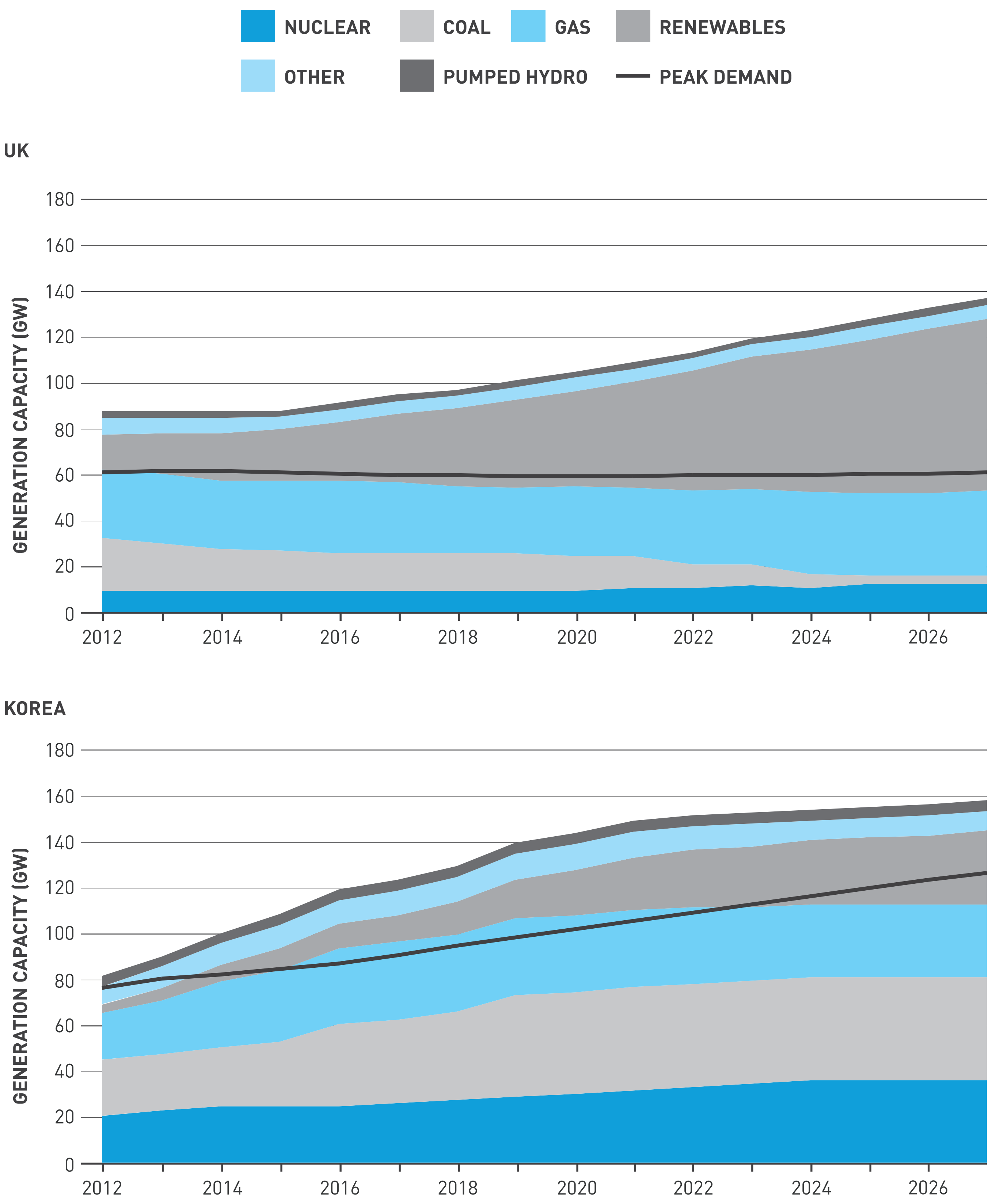

Figure 5: Projected electricity generation capacity in (a) the UK (top, source: National Grid); (b) Korea from 2012 to 2027 (bottom, source: Ministry of Knowledge Economy)

3: ENERGY STORAGE TECHNOLOGIES

There are many different types of energy storage, each type with its own defining set of characteristics, advantages and disadvantages which render that particular technology suitable for some applications and scales but not for others. This Chapter identifies the energy storage technologies which may be suitable for application within the UK and Korea energy networks, assessing both the urgency of the need and the state of development of the prospective technologies.

SCALE OF ENERGY STORAGE TECHNOLOGIES

Within the energy systems of both the UK and Korea (indeed within any energy system) there are essentially three main ways in which storage can find opportunities:

1. Providing short-term response and reserve in order to help the grid operator balance the system near to real-time.
2. Removing the need for system and transmission upgrades by increasing the load factors of existing transmission/distribution capability
3. Engaging in arbitrage directly with the electricity market, but low cost electricity and selling it back at a higher price.

Acting in these roles there are many applications for energy storage devices ranging across the energy network; from generation and system level applications, to transmission and distribution applications, to end-user applications (Table 1).

With this wide range of energy storage applications, ranging over capacity scales from kWh – GWh, power scales from kW – GW and timescales from milliseconds (ms) – months, it is to be anticipated that a variety of energy storage options will be necessary to meet the system needs.

	STORAGE APPLICATION	DESCRIPTION
GENERATION AND SYSTEM LEVEL	WHOLESALE ENERGY SERVICES	Large centralised energy storage systems providing ancillary services and energy management
	RENEWABLES INTEGRATION	Large centralised/decentralised energy storage systems allowing for time-shifting of renewable generation to match demand
TRANSMISSION NETWORK	STORAGE FOR TRANSMISSION & DISTRIBUTION NETWORK SUPPORT	Storage systems that provide support or defer the need for transmission/distribution upgrades. Can be either stationary or portable
	DISTRIBUTED ENERGY STORAGE	Energy storage embedded in the distribution network providing reliability to customers, easing transmission constraints and providing energy management on a smaller scale
DISTRIBUTION NETWORK	POWER QUALITY FOR COMMERCIAL AND INDUSTRIAL USES	Providing high quality power for specialised applications and processes
	BACKUP AND RELIABILITY FOR COMMERCIAL AND INDUSTRIAL USES	Backup power for specialised applications and processes
END USERS	DOMESTIC ENERGY STORAGE	Small-scale energy storage systems providing backup, reliability, and time-shifting.

Table 1 generalised applications for energy storage in energy networks

ASSESSING THE VALUE OF ENERGY STORAGE

Energy storage operates to meet balancing needs over timescales from seconds to days, on networks from within a domestic consumer to that of the transmission grid. The modelling of such a system is inherently complex and system-dependent. As energy storage technologies can be deployed in a number of different application areas, and can in principle meet more than one 'system need' when deployed, assessing their value against other options becomes an incredibly complicated problem. Further, how the energy mix will evolve is not known, which adds considerable uncertainty to future values.

There has been some recent work in the UK which has tackled this issue, using a model to optimise investment and short-term operation decisions for the entire European system on an hourly basis, also taking account of long-term system adequacy and security requirements (Strbac, 2012). The method uses alternative balancing technologies with the objective of reducing the short and long-term cost of system balancing.

Specific £/kW values were attributed to storage, but in general terms Strbac found that in UK scenarios with high renewables:

- the value of storage increases markedly towards 2030 and further towards 2050;
- a few hours of storage are sufficient to reduce peak demand and capture significant value;
- storage has a consistently high value across a wide range of cases that include interconnection and flexible generation;
- the deployment of bulk storage occurs at lower levels than distributed storage.

The values tended to be higher than previous studies suggest. However, the 'split benefits' of storage were seen to pose significant challenges for policy makers to develop appropriate market mechanisms to ensure that the investors in storage are adequately rewarded for delivering these diverse sources of value.

The analysis suggested some of the key storage technology characteristics that are required:

- Low cost solutions are needed as energy requirements increase, decoupling power & energy.
- There is significant value for fast storage, but a limited market.
- Frequent cycling is most valued for distributed storage, with 6 hours capacity.
- Efficiency of the energy storage technology is not as important at low levels of deployment as the overall costs, scaleability, and lifetime.

OVERVIEW OF ELECTRICITY STORAGE TECHNOLOGIES

As we have seen, energy storage technologies are available over a range of scales. Different scales are suitable for different applications, with very large scale technology options more suitable for centralised storage facilities providing energy management, or for the storage of large amounts of renewable energy. Smaller scale facilities can be used in distribution networks, providing support for districts of the distribution network or even for individual houses. However the technologies on the different scales can often be effectively used for the same purpose provided the storage efficiency and self-discharge characteristics are similar, i.e. a large scale centralised storage option could be used for energy management or a large amount of domestic scale storage devices could provide energy management for many individual properties. A summary of the main electricity storage technologies, which we concentrate on is this report, is presented in Table 2.

TYPE	- POWER - CAPACITY - DURATION	EFFICIENCY (%)	LIFESPAN	CYCLABILITY	COMMENTS
PUMPED HYDRO (PHS)	- 50 MW – 3 GW - 0.5 – 20 GWh - Hours - days	75-85	→50 years	High	97% of existing energy storage globally, but requires favourable landscape
COMPRESSED AIR (CAES)	- 50 – 300 MW - 0.5 – 2.5GWh - Hours – days	n/a	20-40 years	High	Two commercial plants operating. Requires suitable geology for large-scale underground CAES.
PB-A BATTERY	- Up to 20 MW - Up to 40 MWh - Seconds – days	75-90	Up to 20 years	500-2000 cycles	Commercially mature re-chargeable batteries, used as DC auxiliary, and suitable for power quality, UPS and spinning reserve applications
NI BASED BATTERY	- Up to 50MW - - Up to 20 MWh - Seconds-days	72-78	Up to 20 years	1500-3000	Ni-Cd batteries usually have slightly higher energy density than lead-acid types, can tolerate a deep state of discharge, and require less maintenance.
LI-ION BATTERY	- Up to 50MW - Seconds - hours	75-90	5-15 years	3000	Dominant battery in small portable applications due to high energy density, light-weight and high efficiencies; but high cost and limited lifetime
NA-S BATTERY	- Up to 10MW - Up to 50MWh - Secs - hours	75-89	5-15 years	3000 cycles	316 MW installed globally. Due to the temperature requirements these type of cells become more economical with bigger size.
METAL-AIR BATTERY	- Power/ capacity to be proven - Seconds - days	50	-	100 - 300	At R&D stage, but potential increase in energy density over conventional batteries, currently have poor efficiency and cycling capability
VRB FLOW BATTERY	- Up to 3MW - Up to 6MWh - hours - months	65-85	25+ years	10000+	Flow batteries can release energy continuously at a high rate of discharge. Three main different electrolytes that form the basis of existing designs currently in demonstration or in large-scale project development. Electrolytes are stored in external tanks, decoupling power and energy.
ZN-BR FLOW BATTERY	- Up to 500kW - Up to 3MWh - hours - months	65-75	20 years	3000	
PSB FLOW BATTERY	- Up to 15MW - Up to 120MWh - hours - months	60-75	5-30+ years	3000	
H2 STORAGE & FUEL CELLS	- 0-50 MW - 100's MWh - hours - months	35 35-45 20-85	5-20 years	High	High energy density and portability also makes it an attractive prospect for vehicle propulsion. Can also be used to supplement natural gas.
FLYWHEELS	- Up to 20MW - Up to 5MWh - msecs - mins	85-95	20 years	High	Commercially deployed in US for grid frequency regulation. Long lifetimes but huge self –discharge.
SUPER-CAPACITORS	- Up to 300 kW - Up to 1 kWh - Secs - mins	95 75-98	20 years	High	Lower energy density, but higher power density than batteries, often combined in hybrid systems.
SUPERCONDUCTING MAGNETIC ENERGY STORAGE	- Up to 40 MW - Up to 20 MWh - msecs - mins	→95	20+ years	Very High	Very quick response time, suitable for maintaining power quality. Very expensive and must be kept at very low temperatures.
CRYOGENIC ENERGY STORAGE (CES)	- 10 - 100sMW - 10s - 100sMWh - mins - hours	Expect → 60	20-40 years	High	In demonstration phase in UK. 'Liquid air' used as storage medium also has other transport / refrigeration applications

Table 2: Characteristics of electricity storage technologies.

UK/KOREA ENERGY STORAGE EXPERTISE

Both the UK and Korea have significant areas of energy storage expertise and there is research across all the different energy storage technologies. However the main bulk of the research and development in each country is focussed on a few energy storage technologies.

In the UK there is expertise in several aspects around energy storage. In 2010 the Research Councils Review of Energy noted internationally leading position in lithium energy storage and hydrogen / fuel cells (RCUK, 2010). There are also recognised strengths in thermal energy storage (including sensible heat energy storage, phase-change materials and thermo-chemical thermal energy storage) as well as research interest in flow batteries and CAES. The UK is now leading research in several new storage technologies like cryogenic energy storage (CES) and pump-thermal energy storage (PTES), with much of this work being undertaken in partnership with technology developers.

Korea is a world leader in the development, production and manufacturing of electrochemical batteries. There is a large amount of research and development in Li-ion/metal-air/Li-S/NaS batteries as well as flow batteries and super-capacitors. There is also major research in thermal energy storage, with a large-scale CAES demonstration activity being planned.

NAME	TECHNOLOGY	*CAPACITY (KW)*	*ENERGY (KWH)*	*DURATION (MIN)*	STATUS
KOREA					
KIER VANADIUM REDOX BATTERY PROJECT; JUJU ISLAND	- Vanadium–redox-flow battery	100	200	120	Operational
POSCO SECONDARY BATTERY RESEARCH ACTIVITY; INCHEON	- Sodium–nickel-chloride battery	198	139	42	Operational
GAMACO PROJECT; GURI-SI, GYEONGGI	- Lithium-ion battery	250	500	120	Operational
2013 SMART GRID PROJECT; CHUNCHEON-SI, GANGWON	- Lithium-ion battery	500	1500	180	Operational
JEJU SMART RENEWABLE; JEJU-SI, JEJU	- Lithium-ion battery	800	200	15	Operational
GIHEUNG SAMSUNG SDI PROJECT; YONGIN-SI, GYEONGGI	- Lithium-ion battery	1000	1000	60	Operational
GAPADO ISLAND, JEJU SMART GRID PROJECT	- Lithium-ion battery	1000	1000	60	Operational
RENEWABLE & OFF-GRID INTEGRATION; GASADO-RI, JEJU	- Lithium-ion battery	1250	3333	160	Operational
FREQUENCY REGULATION ESS; YEOSU-SI, JEOLLANAM	- Lithium-ion battery	4000	2000	30	Operational
CHO'CHEON SUBSTATION PROJECT; JEJU-SI, JEJU	- Lithium-ion battery	4000	8000	120	Under Construction
INNOVATIVE COMPOSITE HUB AND RIM; ANSAN-SI, GYEONGGI	- Flywheel	100	50	30	Contracted
UNITED KINGDOM					
ABB & UK POWER NETWORKS ENERGY STORAGE INSTALLATION; HEMSBY, NORFOLK	- Lithium-ion battery	200	200	60	Operational
WPD FALCON PROJECT, GE DURATHON; MILTON KEYNES	- Sodium–nickel-chloride battery	250	500	120	Operational
HIGHVIEW PILOT PLANT; SLOUGH, BERKSHIRE	- Liquid-air storage	350	2450	420	Operational
ORKNEY STORAGE PARK PROJECT; KIRKWALL, ORKNEY	- Lithium-ion battery	2000	500	15	Operational
NORTHERN ISLES NEW ENERGY SOLUTION; LERWICK, SHETLANDS	- Valve-regulated lead-acid battery	1000	3000	180	Under Construction
GIGHA WIND FARM BATTERY PROJECT; GIGHA, SCOTLAND	- Vanadium–redox -flow battery	100	1200	720	Announced
ISENTROPIC DEMONSTRATION PROJECT; TOTON, NOTTINGHAMSHIRE	- Heat thermal storage	1400	5600	240	Announced
UNIVERSITY OF SHEFFIELD RESEARCH DEMONSTRATOR; WOLVERHAMPTON	- Lithium-ion titanate battery	2000	1000	30	Announced
SMARTER NETWORK STORAGE; LEIGHTON BUZZARD, BEDFORDSHIRE	- Lithium-ion battery	6000	10000	100	Announced

Table 3: Energy Storage demonstration activities > 100kW in UK and Korea (Source: US DOE Global Energy Storage Database)

IDENTIFYING SUITABLE ENERGY STORAGE TECHNOLOGIES

Table 4 shows a matrix of application area against the storage technologies in terms of performance characteristics.

APPLICATION DESCRIPTION	SCALE OF STORAGE	TECHNOLOGY OPTIONS *(RED INDICATES FUTURE POTENTIAL)*
Domestic scale energy storage for domestic peak shaving	2-5 kW 4-10 kWh 2-8 hours	• Li-ion/lead-acid batteries • †TES
District scale energy storage for peak shaving and deferring distribution network capacity increases	50-500 kW 200 kWh – 2 MWh 2 – 8 hour	• Li-ion/Pb-acid/NaS batteries, Hydrogen, flow batteries • †TES with heat network • CES, SMES
District scale energy storage for balancing microgrids and renewables integration	200 kW – 1 MW 1-10 MWh 6 – 12 hours	• NaS/Pb-acid batteries, Hydrogen, flow batteries • †TES with heat network • CES, SMES
District scale seasonal energy storage	200 kW – 1 MW 100's MWh months	• Thermal energy storage – underground hot water/rock storage • PCM's, hydrogen
Large scale storage for renewables integration	10 – 200 MW 100 MWh – 2 GWh 12 – 48 hours	• PHS, CAES, Hydrogen, flow batteries • PTES, CES, A-CAES
Energy storage for spinning reserve	5-500 MW 10 MWh – 1GWh 24 hours – weeks	• PHS, CAES, flow batteries • PTES, CES
Centralised large scale grid storage for wind integration	1-10 GW several GWh days – weeks	• PHS • PTES, CES, hydrogen

Table 4: Matrix of energy system need against potential technologies.

†TES can be used but only absorbs off-peak demand and displaces peak heating/cooling demand – i.e. cannot reduce peak electrical demand unless for heating/cooling

4: MARKETS, AND THE INVESTMENT CASE FOR ENERGY STORAGE

The assessment of the potential of energy storage is usually based on analysis of the increasing variability of supply due to intermittent renewables in the system such as solar and wind power, as well as changes in patterns of demand due to potential electrification of heat and transport loads (Strbac et al., 2012, Grünewald et al., 2011, Edmunds et al., 2014). These studies typically assess the economics of storage based on assumptions of optimal dispatch of generation technologies under particular scenarios of penetration of renewable energy in the system. Typically, as the share of intermittent renewable energy increases, the economic potential for storage also increases, since storage can help balance the effects of variability in a number of ways, and can help to reduce overall system costs of integrating variable generation.

However, an economic potential for a technology is not the same as a viable business case. Investment decisions in real markets deviate from purely economic expectations for many reasons, in particular because they are exposed to a number of risks which are often not included in economic models. Whilst investment risks come in many forms, investment risk literature (e.g. (IEA, 2007, Blyth and Bunn, 2011)) groups them into three broad categories: techno-economic, market/systems, and policy/regulatory.

Although there is considerable overlap and interaction between these different categories, they represent types of risk that are in general managed differently, and towards which investors typically have different attitudes. Here we provide a brief overview of some of the key issues that arise under these different risk categories when considering storage technology development from an investment perspective.

TECHNO-ECONOMIC RISKS

(UKERC, 2014) identifies techno-economic risks as relating to attributes of individual technologies that have a direct impact on their technical and economic performance. The extent to which these risks are well-characterised depends largely on the maturity of the technology concerned. Technologies being considered for commercial investment will usually have a track-record from which investors can learn so that they can assess the risks and apply appropriate risk adjustments to their normal investment appraisals. This applies to some storage technologies such as pumped hydro and mature battery technologies.

Another category of risk is involved when the technologies concerned have not reached full maturity. These are wide-ranging in nature, and include existence of appropriate innovation networks, political and regulatory support, social acceptability, as well as institutional, market and supply-chain structures to support scale-up and deployment.

These types of technical risk depend strongly on the level of maturity of a technology. Some types of investor will aim to engage at an early stage of development whilst risks (and potential returns) are relatively high, whilst others prefer to wait before investing in bulk applications for technologies to become mature and proven. Sometimes during the technology development pathway there may be a lack of potential investors, leading to a potential 'valley of death' in the financing chain, which occurs when technical risks are still high, but the level of required investment rises steeply at the point where initial large-scale demonstration trials are required.

In practice, the development chain is considerably more complex than the linear pathway this model suggests. Innovation relies on a more complex 'ecosystem' in which multiple public and private funding agencies, research organisations and commercial applications provide a rich set of relationships and exchange of ideas, information and skills (Chart 1).

From the point of view of potential investors, managing technical risk in immature technologies cannot simply therefore be a case of assessing previous performance track record. Companies will typically need to engage in multiple relationships within this kind of ecosystem, and will typically do so for reasons of long-run strategic positioning within their market sector.

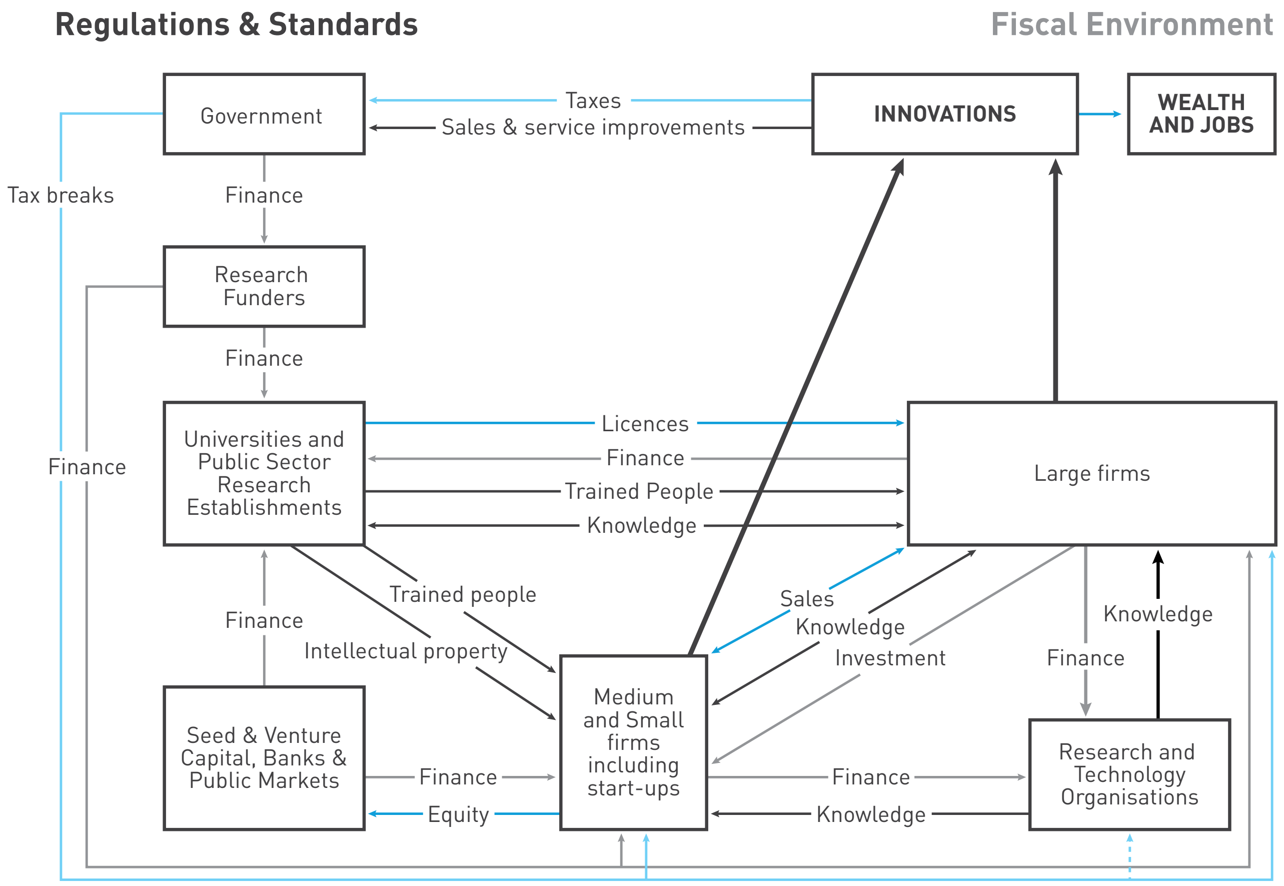

Chart 1: The Innovation Ecosystem. Source: (House of Commons, 2013) (attributed to Prof. Georghiou)

MARKET/SYSTEMS RISK

The expected financial performance of technologies in the electricity supply sector depends strongly on the characteristics of market prices. For many mature generation technologies, market price risk can represent the most significant risk factor facing investors (Blyth and Bunn, 2011). From a market risk exposure perspective energy storage technologies share many of the same characteristics as other generation technologies; they also have some important differences, notably:

- The economic case for bulk storage technologies relies primarily on the ability to arbitrage price differences between different time periods, so that economic value is more strongly tied to the characteristics of price volatility than for most types of power generation.
- Whilst energy storage technologies in general benefit commercially from high price volatility, most generation technologies are the opposite. This means that storage technologies could provide a useful risk hedging role in a company's generation portfolio.
- Many energy storage technologies can provide very rapid response / ramp rates, and so are suitable for providing multiple services over different timeframes. The business case will therefore depend on companies being able to access returns across multiple markets or payment mechanisms, which introduces risk exposure to market design.

Energy storage can be located at various points in the electricity grid. Market design will affect whether or not companies are able extract the full system value for the services they provide.

Because market prices are determined by the mix of technologies in the system, these market price risks will change as the electricity system evolves towards a lower-carbon generation mix, and will depend on evolution of the technical characteristics of the system such as demand load factors, the level of interconnection etc. Storage technologies are therefore also exposed to what we might call 'system risks' associated with uncertainty over the direction and timing of these systemic changes.

Another important element of market risk is the way in which fundamental risk factors (such as technology mix, demand fluctuations, wind speed variation etc.) feed through into actual price variation. This is determined by market design characteristics. In practice, the exposure of storage technologies to market risk therefore requires careful assessment of the particular market design arrangements with a particular country-specific context – for example whether markets are tariff-based, whether they include energy only, capacity mechanisms, arrangements for balancing market, and so on.

POLICY/REGULATORY RISKS

Policy and regulation have a strong influence on the economics of storage technologies throughout the commercialisation process. The economic case for storage is therefore connected to policy decisions at various levels: R&D budgets; specific support measures such as targeted feed-in tariffs, supplier obligations or other subsidies for commercialisation; the market frameworks (e.g. energy markets, capacity markets, short-term operating reserve balancing mechanisms, carbon pricing); and the policy underpinning the transition towards greater renewable energy for which storage is expected to play its role.

Since policy decisions can be changed, these various types of support underpinning the economics of storage are therefore subject to policy risk. Policy risk typically comprise situations where decisions are taken at a political level but are not followed through at an executive level, or where changes are made to established support mechanisms.

The existence of policy risk will in general terms lead companies to apply an additional risk premium to their project appraisal. This increases the returns required to justify proceeding with any particular investment. These risks may be lower on an individual project basis in countries where governments provide guarantees that technology support prices such as feed-in tariffs will not be changed for pre-existing assets (i.e. grandfathering). In countries where such guarantees are not in place, policy risk will be considerably higher, and companies will tend to apply substantial discounts to any such supports that are offered.

POLICY IMPLICATIONS AND BUSINESS MODELS

Investments in storage technologies are subject to a range of risks as described above, many of which are influenced either directly or indirectly by policy and regulatory decisions. Drawing on literature related to other technologies in the energy supply sector, we can predict that from an investor's perspective, these risks will be perceived as higher for technologies that are more capital intensive (i.e. high capital cost, low operating cost), where policy decisions have a significant bearing on the financial outcome of the investment, and where the period of policy stability is short. Such perceived risks will incur a risk premium, which will tend to reduce the rate at which technologies will penetrate the market.

Policy risks can in general be reduced by ensuring that support at the level of individual projects is grandfathered (i.e. subsidy levels are not changed retrospectively for pre-existing assets), and by aiming to achieve reasonably long periods of policy stability. The latter however is hard to achieve in a period when the electricity system is rapidly changing, and subsidy regimes and market arrangements may therefore be in flux. It may be inevitable that some degree of policy risk will be factored into companies' investment appraisals, raising the implied costs (compared to purely economic analyses that do not factor in the effects of risk). Policy-makers may therefore need to factor in such risk premiums when considering the necessary levels of support required to achieve expected levels of technology penetration in the market.

The translation of policy risk into investment behaviour will however depend on the type of investor being considered. Private investors will respond differently to policy risk than state-controlled utilities. The situation in the UK and Korea provide interesting comparisons in this regard.

Recent analysis for Korea (Shcherbakova et al., 2014) suggests that energy storage with NaS or Li-ion batteries would not be cost effective as a method of bulk price arbitrage in Korea's current electricity system, under typical standard discount rate applied to public projects of 5.5%. Nevertheless, implementation of such solutions can be considered either for reasons of demonstrating potential value in the longer-term should Korea's own supply situation change, or for strategic reasons to provide a demonstration of battery performance in support of Korea's battery supply industries. State ownership or control of utilities allows such experiments to be carried out, without necessarily needing to explicitly value the potential spill-over benefits to the wider economy through defined subsidy arrangements. Indeed, strategic links through the state between power companies, and key technology providers (storage, generation plant manufacturers etc.) is likely to provide a significant stabilisation process in terms of perception of policy support. This is likely to reduce policy risk in the Korean case relative to the UK case, even if it means that investments are not always made with a sharp focus on achieving short-term commercial value.

In the UK by contrast, whilst companies may still invest in marginally economic projects for strategic reasons, the link between the investment decision and the underlying business case is more explicit. Policy-makers in this context therefore have to give careful consideration to the economic incentives they send if they want to influence the uptake of different types of technology. This clearly applies in the case of explicit incentives for particular projects (e.g. the £13.2m support through Ofgem's Low Carbon Network Fund for the 6MW / 10MWh 'Smarter Network Storage' demonstration project[1]).

Perhaps more importantly in the long-run policy determines the market design arrangements through which storage technologies will ultimately gain their income. This requires the development of suitable potential business models for energy storage in a competitive market. The diverse nature of storage technologies (the range of different technologies involved; the different scales of investment; the ability to provide different types of service over different timescales; the potential for applications at both upstream and downstream ends of the transmission and distribution system) means that these models may be quite diverse.

Given the fact that the market as a whole is in a state of flux and evolving quite rapidly, development of new business models is a learning process, involving a wide number of actors across policy-makers, power generation companies, distribution and transmission network operators, equipment suppliers and the wider research community. Policy-makers therefore need to strike a fine balance between being responsive to such developments, whilst aiming for stability in the wider policy framework.

[1] For a review of lessons learned to date on the project, see: www.ukpowernetworks.co.uk/internet/en/community/documents/SNS1.2_SDRC_9.1_Design_and_Planning_Considerations_Report_v2.0.pdf

5: STAKEHOLDER ANALYSIS

A series of structured interviews was undertaken to get a range of perspectives from key stakeholders in the UK and Korea on the need for energy storage and the potential opportunities and barriers to its deployment. The stakeholders comprised twelve representatives from each country drawn from government, regulators, research institutes, technology developers, consulting engineers, electricity companies, academics and RD&D funders. Interviews were completed between February and April 2014, either by telephone or in person.

Each interview was preceded by a brief explanation of the purpose of the overall project and the definition of energy system flexibility, which was described as its ability to cope with events that may cause imbalance between supply and demand while maintaining system reliability in a cost-effective manner. The stakeholders were then asked a series of questions, often with multiple choice answers, and were also given the opportunity to provide more detailed reasoning to explain their selections.

The following sections highlight a selection of the key issues raised, comparing the responses from UK and Korean stakeholders. These responses highlight that while the two countries face some similar challenges to their electricity system, the most important barriers often differ and that the role for government in facilitating energy storage is also seen differently.

THE NEED FOR FLEXIBILITY

In both the UK and Korea, stakeholders were almost unanimous in the view that greater system flexibility would be needed in the period to 2030 if current energy policy goals were maintained. The impact of variable renewables was clearly the most important in both countries, but the timescale in which this need would be evident showed how the Korean electricity system is under stress to meet peak demand in the short-term. This contrasts with the UK, where the perceived need is seen to coincide with the growth in offshore renewables and electric vehicles in the early 2020s.

TECHNOLOGICAL RESPONSES TO FLEXIBILITY

In considering how this need for flexibility could be met, Korean responses were very strong in identifying energy storage and demand-side response (DSR), whereas UK responses were more evenly spread, including the role for interconnection and back-up fossil-fuel (Figure 7). The last two options are less attractive to the Korean system due to its geography (though establishing transmission links to Japan were cited by some) and desire to reduce dependency on imported fuels. It was also telling that Korean stakeholders saw storage and DSR as consistent with the Government's plans for the roll-out of smart grids, and so should naturally play a significant role.

The UK response finding an important role for all options including back-up fossil-fuel raises questions whether a market could support significant quantities of each technology to make them commercially viable. It may equally signal some uncertainty as to how flexibility will be, or could be, provided.

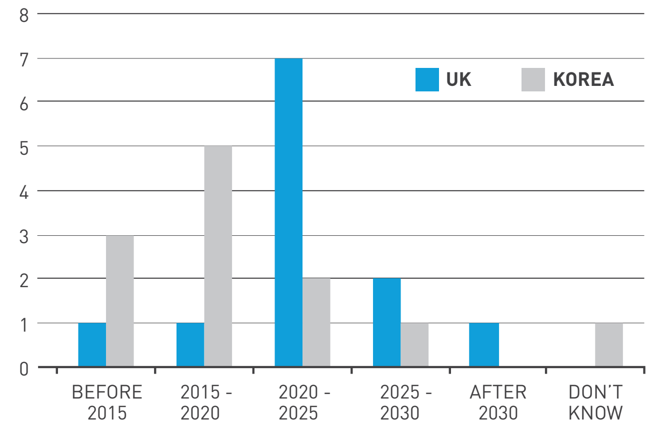

Figure 6: When do you think that the current energy system will prove to be insufficiently flexible?

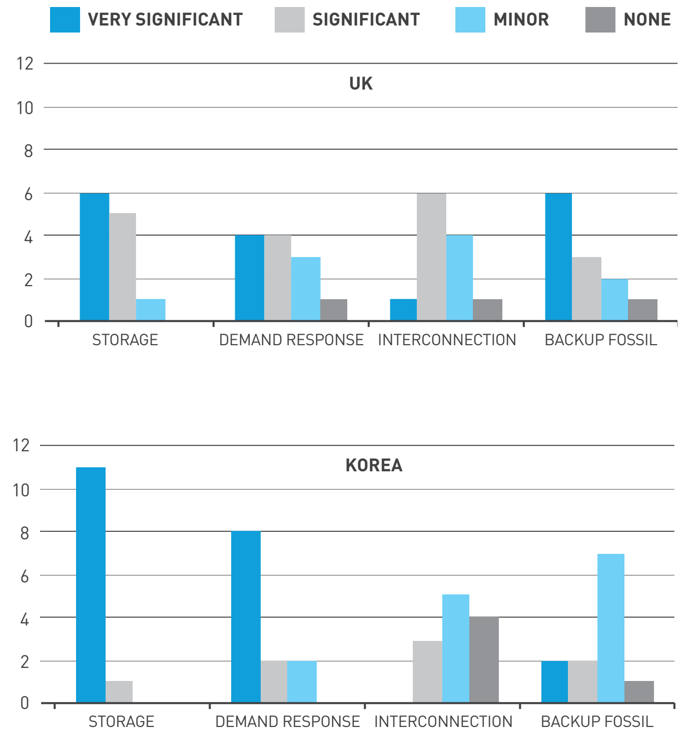

Figure 7 What role would you expect the following options to play by 2030 in providing flexibility to the energy system?

CHARACTERISTICS OF SUITABLE ENERGY STORAGE TECHNOLOGIES

Energy storage which could respond over timescales between seconds and hours was seen to be the most likely requirement in UK and Korea. However, there was felt to be a greater need for storage over seconds – minutes in Korea compared to the UK. This could in part be due to the storage technology which can meet this need being available now, from various electrochemical batteries, and being the focus of energy storage manufacturing in Korea.

ADDRESSING UNCERTAINTIES IN DEPLOYMENT

Current technology cost and performance were important barriers to increased deployment of energy storage for almost all stakeholders (Figure 8). A striking difference between the countries was how the uncertainty in future value was not seen as a barrier in Korea. This may emanate from the more strongly planned approach by Government described in Chapter 2 (though it may be questioned whether the plans are actually implemented).

The regulatory and market framework was also seen to be an important barrier in the UK. A number of respondents highlighted uncertainty in the market and regulatory structure as a problem, rather than necessarily any need for further reform. For Korea, the regulations concerning how and where energy storage could be connected was found to be a challenge to deployment.

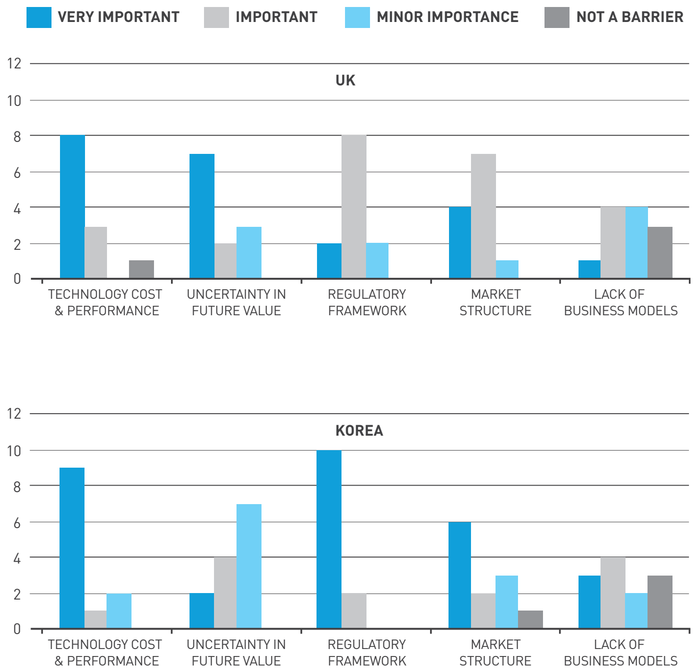

Figure 8 How important are each of the following barriers to the deployment of energy storage over the next 5-10 years?

THE ROLE FOR GOVERNMENT

Stakeholders in the UK responded that Government should be supporting energy storage innovation particularly in the demonstration and regulatory stages – signifying a need to pull energy storage through the 'valley of death' by de-risking the technology and showing a potential revenue stream.

The high importance of Governments in providing support for energy storage development and/or deployment was found in both countries, but more so in Korea, where the value of having targets for deployment were also seen to be higher (Figure 9).

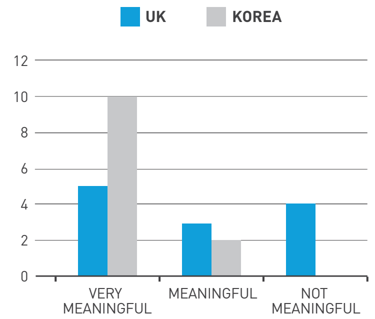

Figure 9 How meaningful would it be to have a deployment target for energy storage?

6: CONCLUSIONS AND RECOMMENDATIONS

THE ROLE OF ENERGY STORAGE IN THE UK AND KOREA

We have seen from the analysis and stakeholder interviews that energy storage could be an important component for delivering more flexible energy systems in the UK and Korea as they undergo rapid transformations. The nature and timing of the transformations is somewhat different, as will be the role that energy storage could play.

In the UK, a growth in electricity generation from variable renewables over the next ten years will drive the need for a more flexible energy system.

FOR THE UK, THE POTENTIAL FOR ENERGY STORAGE IS EXPECTED TO EMERGE MOST STRONGLY:

- **IN THE NEAR TERM, FOR A LIMITED AMOUNT OF SHORT TIMESCALE STORAGE FOR GRID SUPPORT.**
- **OVER THE NEXT TEN - FIFTEEN YEARS, WITH INCREASING AMOUNTS OF DISTRIBUTED STORAGE, AGGREGATED TO ALLOW THE CAPTURE OF EXCESS RENEWABLES AND RE-SUPPLY WHEN IT IS NEEDED.**

In Korea, the system is under pressure from increasing demand, as generation fails to meet the peak. Whilst this could normally be mitigated by building new plant this is less than straightforward: nuclear power has declined in popularity after Fukushima, and cases of bad practice in Korean power stations; the desire to reduce dependency on imported fossil fuel limits appetite to build more thermal generation; and a weak grid between the main centres of generation and population, make transmission of new power sources difficult.

FOR KOREA, WE CAN SEE A POTENTIAL ROLE FOR ENERGY STORAGE:

- **IN THE NEAR TERM, FOR LOCAL STORAGE TO PEAK-SHAVE AND AVOID DISRUPTION FROM BLACK-OUTS WHEN DEMAND OUTSTRIPS SUPPLY NATIONALLY.**
- **IN THE 2020S, IF RENEWABLES TARGETS ARE MET, TO INTEGRATE VARIABLE RENEWABLES, THOUGH THE MOST VALUABLE STORAGE CHARACTERISTICS ARE YET TO BE ASSESSED.**

In both the UK and Korea, energy storage will compete against existing generation technologies when providing power at peak times, so there will need to be technical innovation which reduces costs, and a development of market mechanisms through which value of flexibility can be captured.

OPPORTUNITIES FOR COLLABORATIVE WORKING

In Korea, more local 'smart grids' are seen as key to managing electricity use, and so the perceived need is for smaller-scale batteries. This aligns with a strong industrial strategy supporting a number of Korean battery manufacturers (such as Samsung, LG), for whom the impetus has come from the move to provide batteries for electric vehicles. Strong basic research in the UK on Li-based battery technologies and smart grids makes this a good area for collaboration with Korea.

Given that the UK is leading Korea in the move to a more renewable-based energy system, the issues being confronted by the system operator, network operators, regulators and policy-makers for providing additional flexibility could be applied to Korea. Our discussions with Korean stakeholders have led us to understand that UK expertise in market design and energy system modelling would be highly valued.

RECOMMENDATION: A JOINT CALL BETWEEN FUNDING AGENCIES IN UK AND KOREA ON BATTERY TECHNOLOGIES, AND SYSTEM INTEGRATION.

RECOMMENDATION: INCREASED COLLABORATION BETWEEN ELECTRICITY SECTOR STAKEHOLDERS TO ALLOW AN EXCHANGE OF BEST PRACTICE BETWEEN THE COUNTRIES. SUCH COLLABORATION MAY TAKE PLACE ON A BI-LATERAL BASIS, OR THROUGH INTERNATIONAL FORA, SUCH AS THE IEA.

The UK comparative advantage in developing larger-scale storage technologies, which are especially suited to capturing excess renewable generation, is not yet felt in Korea.

The evolving energy system and market structure, and a strategy to capture the global market, makes Korea a particularly challenging environment for the British energy storage industry to enter at the moment. However, over the medium term, if Korea expands its renewable generation portfolio to the extent that is planned, and energy storage technologies being developed in the UK mature, they will be well-placed to provide the elements of a more flexible energy system.

ONGOING CLOSE COOPERATION AND DISCUSSION BETWEEN THE UK AND KOREA IN THE DEVELOPMENT OF ENERGY SYSTEMS WILL HELP TO ENSURE THAT OPPORTUNITIES ARE NOT MISSED AS THEY ARISE IN THE FUTURE.

LESSONS TO BE LEARNT

The UK has put a lot of effort into energy systems analysis through long-term scenario planning and energy systems modelling. Our engagement with Korean stakeholders has brought out the desire for greater debate on possible options. Whilst DECC's 2050 Calculator has been translated to a Korean system, it has very low visibility from our experience.

RECOMMENDATION: INTERNATIONAL WORK ON THE 2050 CALCULATOR CAN BE OF GREAT VALUE, BUT HIGH-LEVEL AND WIDESPREAD ENGAGEMENT IS NEEDED AT THE OUTSET FOR IT TO BE MORE THAN AN ACADEMIC EXERCISE.

The wide range of options that come from scenarios and models in the UK have led to a lack of vision from successive Governments, which has stifled investment. The Korean 'Plans' may not be appropriate to the UK context, but they show how certainty of future direction (to an extent) can encourage innovation by reducing risks. Having chosen energy storage as one of its 'Eight Great Technologies' to benefit from early stage innovation support, this should be backed-up with mechanisms to pull the technology through.

RECOMMENDATION: THE UK GOVERNMENT SHOULD PROVIDE GREATER CERTAINTY FOR THE ROLE OF ENERGY STORAGE IN THE ENERGY SYSTEM, WHICH WILL ENCOURAGE INVESTMENT IN THE TECHNOLOGIES FROM INDUSTRY AND ALLOW THE UK TO TAKE A POSITION AS A LEADING INNOVATOR.

WITH THE TRANSFORMATION OF THE ENERGY SYSTEM, NEW BUSINESS MODELS ARE LIKELY TO EMERGE, AND NON-TRADITIONAL PLAYERS WILL ENTER THE ENERGY MARKETS IF THE INCUMBENTS FAIL TO INNOVATE. THIS IS BEGINNING TO BE FELT IN THE UK. COMPETITION CAN DRIVE UP EFFICIENCIES IN ENERGY AS IN OTHER SECTORS, SO REGULATORY FRAMEWORKS NEED TO BE CAREFULLY CONSTRUCTED.

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