“Scotland: a Case Study for Liquid Air Energy Storage”

Highview Power Storage

Summary Report

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LIST OF ABBREVIATIONS

BOE	Barrels of Oil Equivalent
CAES	Compressed Air Energy Storage
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CfD	Contracts for Difference
DECC	Department for Energy and Climate Change
EMR	Electricity Market Reform
ENSG	Electricity Network Steering Group
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GVA	Gross Value Added
GW	Giga Watt
GW	Giga Watt hour
HFCSS	Hydrogen Fuel Cell Storage System
IMechE	Institution of Mechanical Engineers
LAES	Liquid Air Energy Storage
MW	Mega Watt
MWe	Mega Watt equivalent
MWh	Mega Watt hour
NaS	Sodium-Sulphur
PHES	Pumped Hydro Energy Storage
RO	Renewables Obligation
SHETL	Scottish Hydro Electricity Transmission Ltd
SPT	Scottish Power Transmission
TWh	Tera Watt hour
UK	United Kingdom

INTRODUCTION

The purpose of this report is to provide an overview of the potential for Liquid Air Energy Storage in Scotland. This technology will be primarily considered for applications within the energy industry. The focus will be on the ramifications for supply and demand of electricity, with other uses and impacts also considered.

The 2011 Census results show Scotland has a population of 5.3 million which is about 8.38% of the total UK population.[1] This gives one of the lowest population densities in Europe, with a national average of 68 people per square kilometre compared to an average density in England of approximately 400 people per square kilometre. There is also significant variation within Scotland, with densities ranging from a particularly low 9 people per square kilometre in the Highlands and islands, increasing through the denser Central Belt area to a maximum density in the City of Glasgow with 3395 people per square kilometre. [2]

With an increasingly confident national identity and significant devolved powers, debate over Scotland's political future as part of the United Kingdom is adding further uncertainty to an economy in a region suffering low or no growth in the near term. The renewable energy sector is considered by the Scottish government as a future growth industry to complement the declining oil and gas sector which has remained the dominant force in the economy over several decades.

Depending on how offshore economic activity is apportioned Scotland's 2011 GDP ranges from approximately £124 billion when considering onshore activity only, through to £150 billion with a geographic share of offshore activity.[3] The Oil and Gas industry will remain a key element of the Scottish economy in the medium to long term. Even disregarding the uncertainty over the potential for shale oil, there are considerable differences in projections for output in the near term[4] with a compounding uncertainty from hydrocarbon prices.

Scotland is recognised as having significant potential for electricity generation from renewable sources, including on and off shore wind, tidal, in-stream current generation and others. It has been estimated that 25% of the EU's offshore wind, 25% of EU tidal and 10% of EU wave resources occur in Scottish Territorial Waters.[5]

In 2011, total electricity generation in Scotland from all sources was approximately 51.2 TWh. Of this, gross consumption within Scotland was 37.9 TWh with the remaining 13.4 TWh exported.[6]

Just over half of the 13.7 TWh total energy generated by renewables came from wind power (6984 GWh, 51%). Hydroelectric (including pumped storage) contributed 5331 GWh (39%), with biofuels (862 GWh, 6%) and landfill gas (506 GWh, 4%) with relatively minor proportions. [7]

In 2008 for the UK as a whole, energy demands of 1695 TWh/y were split into heat (41.9%), transport (35.3%), and electricity (22.8%) respectively. Equivalent estimates of Scottish energy use in 2020 give an approximate split of 183.1 TWh/y into 49%, 30%, and 21% respectively.[8]

SCOTTISH ENERGY POLICY

Scotland is committed to the decarbonisation of its energy supply and the economy in general. Ambitious targets have been set for 100% of Scotland's gross electricity consumption to come from renewable electricity sources by 2020. 36% of gross consumption came from renewables in 2011, but with an interim target of 50% by 2015 there is a pressing need to build on the progress that has already been achieved. Efforts towards these targets are not restricted to generation alone, with crucial roles in demand reduction, efficiency and energy storage also identified as being vital to achieving success. From 2010's *A Low Carbon Economic Strategy for Scotland.*:

"Transforming the energy sector in Scotland will play a pivotal role in the development of a low carbon economy. The transition can provide a unique combination of benefits, including reduced greenhouse gas emissions and enhanced energy security and less volatility in the energy sector. Through timely and unprecedented levels of investment in the electricity, heat and energy efficiency sectors, the step change in activity will open up enormous opportunities for businesses across Scotland."[9]

The 100% target has received criticism from a range of sources. Concerns from within the engineering industry have been expressed over feasibility of both the target and timescale with particular reference to issues regarding balance of electricity supply, affordability and alternative back up sources.[10]

Scottish First Minister Alex Salmond outlined the Scottish Government's ambition for electricity generation and renewables in 2020:

"By then we intend to be generating twice as much electricity as Scotland needs - just over half of it from renewables, and just under half from other conventional sources. We will be exporting as much electricity as we consume. So we will continue to work with industry and governments at local, UK and European level to build on what we have achieved." [11]

While Scottish achievements of interim targets for proportion of electrical generation from renewables have been achieved, initial performance regarding Greenhouse Gas (GHG) emissions has fallen behind interim milestones.[12] The Climate Change (Scotland) Act 2009 requires a 42% reduction of GHG emissions by 2020 and 80% reduction by 2050. However, the long term trend has Scottish GHG emissions down 27.6% in 2009 from the 1990 base year.[13]

It has been predicted that in 2020 approximately half of Scotland's total energy demand will be for heat energy.[14] Efforts are being made to realise more effective use of renewable sources of heat energy. The Renewable Heat Action Plan 2009 calls for 11% of non-electrical heat demand to be provided from renewable sources by 2020.[15]

Scotland has a confirmed policy for no new nuclear capacity to be installed, but existing capacity will remain an important contributor of low carbon electricity.[16] Both nuclear plants in Scotland are scheduled to remain open until 2023. With nuclear providing about 33% of total generation in Scotland, combined fossil fuels contributed 39% of 2011's total output.

After much debate, the gas plant at Peterhead in Scotland is one of the two Carbon Capture and Storage (CCS) schemes recently approved in the UK.[17] It has been suggested that Scotland could become a world player if the CCS industry is developed. However, the economic feasibility for CCS has yet to be proven.[18]

At present, the Renewables Obligation (Scotland) Amendment Order 2011 and the Renewables Obligation (Scotland) Order 2009 are the primary legislation driving increases in renewable generation.

The UK Energy Bill proposes changes across the sector to reform the way in which measures are used to encourage greater price certainty for investment planning. This Electricity Market Reform (EMR) shifts the focus of incentives to provide price stability over a longer time frame for the purpose of giving generators and customers greater price certainty for planning and investment:[19]

"Scottish Ministers are determined that EMR must deliver for Scotland and in no way undermine Scotland's ambitions for renewables and low carbon generation."[20]

OPPORTUNITIES FOR ENERGY STORAGE IN SCOTLAND

In the Scottish Government's report *2020 Routemap for Renewable Energy in Scotland*, energy storage is identified as having a key role in achieving governmental targets. In particular, energy storage methods will be needed to address the supply-management factors that arise at generation and grid level from a significant proportion of renewable-sourced generation within the supply mix.

"To achieve our target of meeting the equivalent of 100% of Scotland's electricity demand from renewables by 2020 we will need to increase the deployment of energy storage systems alongside interconnection and demand-side response. Energy storage can help to overcome many of the challenges associated with accommodating high levels of intermittent generation from renewable sources onto the grid, and can allow us to harness our renewable resources more efficiently. In addition, small-scale decentralised energy storage offers a number of potential benefits, such as avoiding or deferring the need for grid upgrades."[21]

With interim targets set for 2015, and 100% net renewable generation by 2020, the immediate need for a significant expansion of Scotland's energy storage capacity has been highlighted by the Scottish Government, related UK government departments, institutions and industry. Sufficient storage capacity could improve the economic feasibility of intermittent generators such as onshore wind. It needs to be developed to suit Scotland's distributed and intermittent sources of supply and dispersed and variable-density demand.

The aging distribution network built to connect large centralised and predictable generation with demand is not optimised to a scenario of dispersed generation, providing variable and unpredictable output into a market with growing and diversifying demand. Major upgrading work has been identified to achieve reliability of supply to customers from a market increasingly based on wind or other intermittent sources.[22]

With over one third of Scottish electricity generation already coming from renewable sources, this proportion is set to increase substantially over the next decade. Provisional DECC figures from 2012 indicate a further 12 GW of capacity in planning (7.7 GW), consented (2.6 GW) or under construction (1.7 GW) in addition to the 5.7 GW installed capacity in operation.[23]

In their 2012 report *Our Electricity Transmission Network: A Vision for 2020,* the UK's Electricity Network Steering Group (ENSG) plans for a scenario 'Gone Green 2011' that meets the current 2020 targets for both the UK and Scotland.[24] This scenario includes an expansion from 0.9 GW to 7.2 GW of generation in the north of Scotland, and from 1.4 GW to 3.9 GW across central and southern Scotland.

But this is only one half of the balancing equation. Ideally, the ability to balance supply would also come with the means to influence demand in a controlled fashion. Having a mechanism to balance both sides of the equation would make operating the grid a more predictable process. Greater predictability could have a positive impact on forecasting and the economics of the market.

Along with other measures such as demand management and upgrades to the network infrastructure, efficient use of Scotland's renewable generation will be a key part of the desired decarbonising of the Scottish energy economy and achievement of energy targets.

Just as there are different uses of electricity so are there different applications that could be considered for energy storage. These applications could arise from a number of motivations, whether singly or in combination, including:

- Making better use of electricity being generated by intermittent or variable sources;
- Reducing or offsetting demand for electricity from the market by using electricity of a lower price;
- Creating a more diversified income stream;
- Lowering the carbon intensity of generated electricity;
- Providing security of electricity supply for specific activities vulnerable to supply interruption;
- Providing security of electricity supply independent of fuel availability;
- Providing price security against volatility in fossil fuel prices or availability.

The specific motivation behind considering energy storage will identify the characteristics most likely to be important for that use.

Operating within the competitive market, and supplying electricity into that market means the final form of the Energy Bill and Electricity Market Reform will directly affect the energy storage sector.

The EMR proposes a Capacity Market to help balance supply and demand for a market featuring increasing amounts of intermittent capacity. The specifics of this market are still being developed, but concerns have been raised that early proposals will favour established solutions only and not encourage the use of alternatives. [25] The Scottish Government supports non-generating technologies such as energy storage as an equivalent to generation and is working towards the final legislation enabling this.[26]

There is considerable uncertainty resulting from Scotland's political relationships with the UK and the EU. Other uncertainty arises from future price volatility in the fossil fuel markets as both the main source of wealth for Scotland and the determinant of reference prices to assess alternatives, particularly when justifying the case for investment and or permissions. The impact of shale oil is also unknown.

Financial uncertainty or risks are also increased with unknown technological solutions. Something commonly understood, with established experience available in financial feasibility, manufacture, commercial and technical operation has less risk and has favourable considerations to be adopted over an equivalent but newer alternative.

Any planned uptake on a major scale would benefit from some prior engagement with potential customers, local government and the general public to include them in the debate about energy storage and the role it could play in the low carbon economy.

As well as the need for energy storage, Scotland has existing industry and technical expertise in the oil and gas sector which could play a role in developing and expanding this new industry. The signs of government support with legislation and supportive financial frameworks will need to continue and are necessary in developing an energy storage industry in Scotland.

ENERGY STORAGE OPTIONS

There are demonstrable advantages from implementing appropriate energy storage on a sufficient scale in Scotland. Even discounting the ambitious political targets set for 2015 and 2020 - something that could prove extremely controversial for the Scottish leadership should they be missed, there are clear economic and technical cases for storage capacity to be created.

This section is based on the three reports, included in the Appendices: 2012's *Pathways for Energy Storage in the UK* for its inclusion of LAES within the comparisons, the equally recent *Report Summarizing the Current Status, Role and Costs of Energy Storage Technologies* for it's inclusion of LAES as a sub category of CAES, and 2010's *Energy Storage and Management Study* for its specifically Scottish analysis.

The Scottish Government's *Energy Storage and Management Study* and subsequent independent studies identify that different technologies being considered are best suited to different applications and that there is no one technology available or yet under development that could optimally satisfy all applications. The three reports assess similar groupings of constraints of energy storage technologies, namely: [27]

- Environmental or geographic constraints;
- Incentive or market structures limitations;
- Technological characteristics, maturity, necessary skills and research development;
- Infrastructure requirements.

Across the reports the rankings or characteristics for each of the storage technologies varies to a degree, based on differing assessment models or changes in the technological status due to recent advancements. However, all three reports identify Pumped Hydro Energy Storage and Compressed Air Energy Storage as the two available technologies with the best characteristics for centralised storage. Taking a composite across the reports gives additional options for distributed storage. Identified for consideration are certain kinds of advanced battery, Hydrogen Fuel Cell systems and Liquid Air Energy Storage.

Of the technologies available now, Pumped Hydro Energy Storage (PHES) is the most mature but has limited options for expansion that would be likely to go ahead for financial reasons or be easily accepted by the public. PHES capacity in Scotland has two large new projects under consideration but the economic case for either has yet to be decided. Should they go ahead, it is unlikely they will be operational by 2020.

The necessary geological formations for Compressed Air Energy Storage (CAES) to be potentially viable do not exist in Scotland. As a less proven bulk storage solution it is unlikely to contribute significantly without considerable advances in the technical process and subsequent economic feasibility. Advances in compressor technology may remove the need for fossil fuel use and improve the equation, but the lack of natural storage formations is a severe limitation.

Hydrogen Fuel Cell Storage Systems (HFCSS) have great potential in theory, particularly when considered for its transport potential. However, inefficiency, safety and relatively short lifetimes are considerable technical obstacles that are yet to be overcome. Major advancements will need to be achieved before the economic factors become realistic for uptake on any meaningful scale. Should these be achieved, HFCSS could play a significant role.

In many ways, the increasingly distributed nature of Scottish electricity generation from variable renewable sources could suit a more distributed, network level storage capacity. Distributable alternatives at present each suffer from one or more weaknesses that may eventually be addressed at a technical level and much work is being undertaken by the proponents of each option. But, as with bulk storage, achieving commercial feasibility will be the likely determinant of success.

The Scottish government, industrial and academic parties such as the Institute of Mechanical Engineers recognise a need for energy storage to be available on a sufficient scale, as soon as possible, and in an economically effective manner.

LIQUID AIR ENERGY STORAGE IN SCOTLAND

Having considered the merits and difficulties associated with other energy storage methods, this section considers the attributes of Liquid Air Energy Storage (LAES) for use in Scotland. LAES is considered one of the more promising options currently available within both *Pathways for Energy Storage in the UK* and *Report Summarizing the Current Status, Role and Costs of Energy Storage Technologies* (as a sub category of CAES).

One of the most important issues is that storage be implemented on a large enough scale to make a contribution and on a short enough time scale that the benefits are demonstrated as early as possible. Because there is existing knowledge of the operation of cryogenic gases both within industry and from a regulators perspective, the risks of delay associated with newer alternatives such as hydrogen or advanced batteries would be reduced.

Although LAES is yet to be adopted on a commercial level, LAES technology is based on well established and well understood equipment and processes. While the application of the components for the combined LAES system may be new, the individual elements are mature and well understood. A potential LAES supply chain is well established in Scotland. The oil and gas supply chain provides a major source of expertise and manufacturing capacity for many of the components required for the liquefaction, storage and generation processes.

LAES is not constrained by economic factors based on optimal geology. This should enable LAES to be considered for a wider range of contexts than other options such as PHES or CAES within Scotland. While the storage capacity of an individual LAES facility is likely to be smaller than PHES facilities such as Ben Cruachan, the characteristics of LAES make a more distributed network of storage at the 100MW scale a more likely scenario. This provides significant advantages in combination with an equally distributed network of generation, and positively relates to dispersed renewable applications such as onshore wind farms or at landfall for offshore generation.

For a distribution system with increasingly diversified sources of supply providing varying levels of output at unpredictable times, a distributed LAES network could provide operational benefits for operation of the Scottish network. Some of the £5.7 billion investment indicated for upgrading the network may be mitigated or delayed by reducing the peak power flows of exported electricity from high generation areas such as the north of Scotland.

LAES could ease the operation of the transmission system by providing a controllable demand for otherwise surplus electricity and providing a source of stored supply for times of high demand or when other generation is insufficient. Suitably sized LAES could provide security of electricity supply for specific activities vulnerable to supply interruption and to avoid general interruptions to supply caused by weather or maintenance. This is particularly relevant for isolated Scottish communities and islands.

The modular and scaleable nature of LAES would allow it to be designed for the needs of different applications. The liquefaction and generation processes do not need to be undertaken at the same site if the commercial infrastructure is developed to distribute the liquefied gas from producer to customer's storage. The potential to develop smaller and more diversified storage capacity close to points of generation or consumption suggests LAES could be considered as a part of any new generation capacity. It could also be considered as an addition to an existing facility.

LAES has the potential to create commercial value to a variety of organisations including generators of underutilised electricity, consumers of electricity, and generators of untapped heat energy. The elements LAES requires are available within the Scottish context:

- Availability of electricity otherwise of low demand and therefore 'low value' is important;
- An increasing demand for electricity domestically and exported to England;
- Availability of waste heat from other processes;
- Uses of cold for other processes.

The processes in LAES could establish symbiotic relationships between the availability of underutilised electricity with otherwise wasted heat energy from thermal generation or from certain manufacturing processes. This will need to be considered alongside other priorities for heat to make better use of renewable sources and for district heating schemes where feasible.

The *Energy Storage and Management* Study calculated that decentralized energy storage would require more support to get established as an industry due to less certain revenue streams and availability of finance. It recommended that legislation should be developed to provide stability and help develop technology and industry within the energy sector.[28]

The potential to establish an LAES industry within Scotland could take advantage of this fortunate set of circumstances to develop a new industry that is complementary to the renewables sector as the oil and gas sector matures.

Models for Liquid Air in Scotland

Within the Scottish Government's *Energy Storage and Management Study,* two scenarios were presented for the percentage of gross consumption coming from renewables by 2015 and 2020. At 52% and 53% of gross consumption coming from renewables, Scenarios 1 and 2 just exceed the 50% interim set for 2015 and for the purposes of this estimation can be considered a match. Table 1 presents the data from the report.

Subsequent to the study, the 2020 targets were raised by the Scottish Government. Scenario 1 is 24% below and Scenario 2 20% above the actual 100% target, as indicated in Table 2. A basic calculation can be made using these scenarios and averaging them to achieve an unscientific equivalent to the 100% target. This conversion is not intended as a proper model of the relationship between generation and capacity across the variety of generation sources. Table 3 shows the averaged scenario.

Quoted within the study was a report for the Portuguese government proposing a desirable ratio of 1 MW pumped hydro storage capacity to 3.5 MW of wind generation capacity, based on Portugal's typical wind profile.[29] A ratio of 3.5 MW of intermittent capacity to 1 MW of general storage capacity is proposed here as a proxy for more detailed calculations based on the performance of LAES.

The categories of generation used considered for equivalent storage capacity are: Onshore wind; Offshore wind; Wave; Tidal. [30] Combining these gives subtotals for capacity and generation from intermittent sources for both Scenario 1 and 2. Tidal is predictable as a source and its contribution could be anticipated. However, this contribution may fall at a time of low demand so it has been included.

This estimates a need for 1570 MW of storage in 2015 and 3086 MW in 2020. Using a non-specific 100 MW LAES facility would indicate 16 or 17 installations in 2015 and 31 or 32 by

2020, shown in Table 4. Installations may need to be distributed to the source of generation (such as by wind farm or at connection landfall from offshore turbines). Of course, installations of different sizes could be accommodated for a closer match.

The report *Our Electricity Transmission Network: A Vision for 2020* details network upgrades within Scotland and connecting Scotland with England and Wales. In their 'Gone Green 2011' model which matches Scotland's 2020 renewables target, major expansion of renewable generation takes place. In northern Scotland, combined renewable capacity increases from 0.9 GW to 7.2 GW, with central and southern Scotland combined growing from 1.4 GW to 4.7 GW.[31] Using the same methodology, 21 or 22 indicative LAES facilities would need to be sited in the north with 14 across the centre and south.

Conclusion

Scotland as an economy is transitioning towards a lower carbon future. More efficient use of existing and proposed renewable energy is part of the response alongside demand management and efficiency. There is a need for storage solution now, on sufficient scale and at an economically attractive price. The performance characteristics of Liquid Air Energy Storage make it ideal as a distributed complement to established Pumped Hydro Energy Storage. Liquid Air Energy Storage uses well proven processes and equipment and could be used to add considerable value in expanding Scotland's unique energy potential.

CALCULATIONS

Table 1. Calculation of storage capacity and LAES, ESMS Scenarios 1 and 2, 2015[32]

	Scottish Generation Capacity (MW)		**Scottish Generation Output (TWh)**		**Storage Capacity @ 1:3.5 of Renewable Capacity (MW)**		**Number of 100 MW LAES facilities**	
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**
	2015	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**
CCGT	1,524	1,524	8.4	8.1	435	435	-	-
Pumped Storage	740	740	1.1	1.3	211	211	-	-
Biomass	150	150	1.1	1.1	43	43	-	-
CHP	313	313	2.0	2.0	89	89	-	-
Coal	2,304	2,304	6.3	6.9	658	658	-	-
Hydro	1,361	1,361	2.7	3.1	389	389	-	-
OCGT	55	55	0.0	0.0	16	16	-	-
Other (inc Landfill gas)	49	49	0.4	0.4	14	14	-	-
Offshore Wind	500	500	1.8	1.8	143	143	2	2
Onshore Wind	5,000	5,000	13.4	13.4	1,429	1,429	15	15
Nuclear	1,200	1,200	8.5	8.5	343	343	-	-
Tidal	0	0	0.0	0.0	0	0	0	0
Wave	0	0	0.0	0.0	0	0	0	0
Subtotal Wind, Tidal and Wave	5,500	5,500	15.2	15.2	**1,571**	**1,571**	**16-17**	**16-17**
Total Renewables	7,011	7,011	19.2	19.6				
Total	13,196	13,196	45.8	46.6				
Total Renewables as % of Total	53.1%	53.1%	-	-				
Gross Consumption	-	-	36.9	37				
Renewables as % of Scottish Gross Consumption	-	-	**52%**	**53%**				

Table 2. Calculation of storage capacity and LAES, ESMS Scenarios 1 and 2, 2020[33]

	Scottish Generation Capacity (MW)		**Scottish Generation Output (TWh)**		**Storage Capacity @ 1:3.5 of Renewable Capacity (MW)**		**Number of 100 MW LAES facilities**	
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**
	2020	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**
CCGT	1,524	1,524	6.9	6.3	435	435	-	-
Pumped Storage	1040	1040	1.6	1.7	297	297	-	-
Biomass	300	400	2.2	3.0	86	114	-	-
CHP	368	368	2.9	2.9	105	105	-	-
Coal	2,304	2,304	5.3	5.3	658	658	-	-
Hydro	1,407	1,407	3.0	3.0	402	402	-	-
OCGT	55	55	0.0	0.0	16	16	-	-
Other (inc Landfill gas)	49	49	0.4	0.4	14	14	-	-
Offshore Wind	1500	6400	5.4	22.6	429	1,829	5	19
Onshore Wind	6,500	6,000	17.1	15.7	1,857	1,714	19	18
Nuclear	1,200	1,200	7.8	7.8	343	343	-	-
Tidal	200	300	0.5	0.7	57	86	1	1
Wave	300	400	0.7	0.9	86	114	1	2
Subtotal Wind, Tidal and Wave	8,500	13,100	23.7	39.9	**2,429**	**3,743**	**25-26**	**38-40**
Total Renewables	10,207	14,907	29.1	46.1				
Total	16,747	21,447	53.7	70.3				
Total Renewables as % of Total	60.9%	69.5%	-	-				
Gross Consumption	-	-	38.1	38.3				
Renewables as % of Scottish Gross Consumption	-	-	**76%**	**120%**				

Table 3. Calculation of storage capacity and LAES, ESMS Scenarios Average, 2020[34]

	Scottish Generation Capacity (MW)	**Scottish Generation Output (TWh)**	**Storage Capacity @ 1:3.5 of Renewable Capacity (MW)**	**Number of 100 MW LAES facilities**
	Average	**Average**	**Average**	**Average**
	2020	**2020**	**2020**	**2020**
CCGT	1,524	6.60	435	-
Pumped Storage	1,040	1.65	297	-
Biomass	350	2.60	100	-
CHP	368	2.90	105	-
Coal	2,304	5.30	658	-
Hydro	1,407	3.00	402	-
OCGT	55	0.00	16	-
Other (inc Landfill gas)	49	0.40	14	-
Offshore Wind	3,950	14.00	1,129	12
Onshore Wind	6,250	16.40	1,786	18
Nuclear	1,200	7.80	343	-
Tidal	250	0.60	71	1
Wave	350	0.80	100	1
Subtotal Wind, Tidal and Wave	10,800	31.8	**3,085.7**	**31-32**
Total Renewables	12,557	37.8		
Total	19,097	62.05		
Total Renewables as % of Total	65.8%	-		
Gross Consumption	-	38.2		
Renewables as % of Scottish Gross Consumption	-	**101%**		

Table 4. Gone Green 2011 distributed LAES capacity by 2020[35]

	Northern Scotland, SHETL			Central and Southern Scotland, SPT		
	Capacity (MW)	**Storage @ 1:3.5 (MW)**	**Number of 100 MW LAES**	**Capacity (MW)**	**Storage @ 1:3.5 (MW)**	**Number of 100 MW LAES**
Onshore Wind	4400	1257	13	3700	1057	11
Offshore Wind	2200	629	7	1000	286	3
Marine	600	171	2		0	0
	7200	2057	**21-22**	4700	1343	**14**

[1] UK Government, Office for National Statistics. (2013) *2011 Census, Population Estimates by five-year age bands, and Household Estimates, for Local Authorities in the United Kingdom*. Available at: http://www.ons.gov.uk/ons/rel/census/2011-census/population-estimates-by-five-year-age-bands--and-household-estimates--for-local-authorities-in-the-united-kingdom/index.html (Accessed 21st March 2013).

[2] National Records of Scotland. (2012) *Scotland's Census 2011, Statistical Bulletin 1A*. Available at: http://www.scotlandscenssus.gov.uk/en/censusresults/rel1asb.html#8 (Accessed 21st March 2013).

[3] Scottish Government. (2013) *Key Economy Statistics - Gross Domestic Product*. Available at: http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Q/pno/0 (Accessed 21st March 2013).

"Activities on the continental shelf are not classified as occurring in any particular nation or region of the UK, but are counted as being extra-regio in official statistics. Figures are provided to illustrate the impact of attributing a share of extra-regio activity to Scotland."

[4] Scottish Government. (2013) *Oil and Gas Bulletin, March 2013*. [Online] Available at: http://www.scotland.gov.uk/Topics/Statistics/Browse/Business/Energy/OilGas (Accessed 1st March 2013), p. 3.

"The latest forecasts by Oil and Gas UK suggest that production could reach 2 million BOE a day by 2017. This would represent a 30% increase on current production levels. Analysis published by Professor Alex Kemp in November 2012 also projected that production could rise in the years to 2017 under a number of different scenarios.

In contrast, the Office for Budget Responsibility (OBR) forecast that production will decline by 4% between 2012-13 and 2017-18. The analysis by DECC upon which the OBR forecasts are based notes that they incorporate "very significant negative contingencies to the aggregate figures"."

[5] Scottish Government. (2012) *Electricity Generation Policy Statement 2012*. [Online] Available at: http://www.scotland.gov.uk/Resource/0038/00389294.pdf (Accessed 1st March 2013), p. 11.

[6] Scottish Government. (2013) *Energy Statistics Database*. Available from: http://www.scotland.gov.uk/Topics/Statistics/Browse/Business/Energy/Database (Accessed 1st March 2013), from Sheet 'Electricity generation, consumption and export'.

[7] Scottish Government. (2013) *Energy Statistics Database*. Available from: http://www.scotland.gov.uk/Topics/Statistics/Browse/Business/Energy/Database (Accessed 1st March 2013), from Sheet 'Renewable electricity - DECC' data.

[8] Institution of Mechanical Engineers, (IMechE). (2011) *Scottish Energy 2020?* [Online] Available at: http://www.imeche.org/Libraries/2011_Press_Releases/IMechE_Scottish_Energy_Report.sflb.ashx (Accessed 2nd February 2013), Table 1 p 10.

[9] Scottish Government. (2010) *A Low Carbon Economic Strategy for Scotland*. [Online] Available at: http://www.scotland.gov.uk/Publications/2010/11/15085756/12 (Accessed 1st March 2013), p. 43.

[10] Professional Engineering (2011) *Green energy target is a 'nonsense'.* Available at: http://profeng.com/news/green-energy-target-is-a-nonsense (Accessed 1st March 2013).

"Peter Hughes, chief executive of Scottish Engineering… said that energy supply needed to be balanced and affordable, with adequate back-up load for when renewable sources are not operating. He said that a more realistic target would be 50% by 2020, and claimed that the proposed figure had been made for political gain.

"There will always have to be some back-up load. There is going to have to be a big injection of cash to drive this forward. If you get something towards 40% or 50% renewables that's much more realistic."

He went on: "We need a balanced, sustainable, affordable, secure energy supply. We need a dose of realism in relation to the prediction of 100% by 2020 – that's only nine years away."

[11] Scottish Government. (2011) *Renewables revolution aims for 100%.* [Online] Available at: http://www.scotland.gov.uk/News/Releases/2011/05/18093247 (Accessed 1st March 2013).

[12] Financial Times. (2013) *Watchdog praises Scotland's green record.* [Online] Available at: http://www.ft.com/cms/s/0/00ca370a-8a76-11e2-9da4-00144feabdc0.html#axzz2NJOMHujz (Accessed 12th March 2013).

[13] Scottish Government. (2011) *Scottish Greenhouse Gas Emissions 2009* Available at: http://www.scotland.gov.uk/Publications/2011/09/05094939/3 (Accessed 21st March 2013).

"The [Climate Change (Scotland) Act 2009] creates a statutory framework for greenhouse gas emissions reductions in Scotland by setting an interim target of at least a 42 per cent reduction for 2020, and at least 80 per cent reduction target for 2050. These reductions are based on a 1990 baseline (1995 for the F-Gases). It also requires the Scottish Ministers to set annual targets, in secondary legislation, for Scottish emissions from 2010-2050.

The long term target (2050) now equates to the target in the Climate Change (Scotland) Act 2009.

The Scottish Government has also set a short term target to reduce emissions by 2011 compared with a 2006 baseline."

[14] Institution of Mechanical Engineers, (IMechE). (2011) *Scottish Energy 2020?* [Online] Available at: http://www.imeche.org/Libraries/2011_Press_Releases/IMechE_Scottish_Energy_Report.sflb.ashx (Accessed 2nd February 2013), Table 1 p 10.

[15] Scottish Government. (2011) *Renewable Heat Action Plan, Update December 2011*. Available at: http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/Heat/RHUpdate11 (Accessed 1st March 2013).

"Scotland currently has a target to source 11% of heat demand from renewable sources by 2020. Energy Saving Trust updated our renewable heat database earlier this year and reported that we are making good progress, with 2.8% of heat demand currently being met by renewables."

[16] Scottish Government. (2013) *Energy: frequently asked questions*. Available at: http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Facts/faqs (Accessed 1st March 2013).

"Scottish Ministers have made it clear that they are supportive of possible life extension of existing nuclear power stations in the short term to help security of supply. They are however, committed to the policy of no new nuclear power stations in Scotland."

[17] BBC. (2013) *Carbon capture: Peterhead and Drax preferred bidders in £1bn contest.* Available at http://www.bbc.co.uk/news/uk-scotland-tayside-central-21865798 (Accessed 21st March 2013).

"The UK government selected the gas-fired power station at Peterhead in Aberdeenshire and the coal-fired power station at Drax in North Yorkshire.

At Peterhead, Shell and SSE are behind the plans.

Greenhouse gas would be transported to the Shell-operated Goldeneye gas field in the North Sea using, as far as possible, existing pipeline infrastructure."

[18] Wood McKenzie. (2009) *The Scottish Government - Scotland's Generation Advantage*. Available at: http://www.scotland.gov.uk/Publications/2009/12/10134807/0 (Accessed 21st March 2013), p. 20.

[19] Scottish Government. (2012) *2020 Renewable Routemap for Scotland - Update 30th October 2012.* [Online] Available at: http://www.scotland.gov.uk/Publications/2011/08/04110353/0 (Accessed 1st March 2013), p. 12 and 13.

"2.20 The Renewables Obligation (RO) remains the key incentive for the build of new, large scale renewable electricity generating capacity across Scotland. While its future beyond 2017 depends very much on the outcome of the current electricity market reform proposals (see below), changes emerging from a recent review of technology bands and related consultations are due to take effect from April 2013.

"2.23 The [Electricity Market Reform] proposals represent a significant change, with the RO being replaced by a new support mechanism – a Contract for Difference (CfD) – providing long term price certainty for low carbon generation. … [C]hanges to the support mechanism for renewables must be at least as effective as the current framework and the reforms must build on our strengths and successes."

[20] Scottish Government. (2012) *Electricity Generation Policy Statement 2012.* [Online] Available at: http://www.scotland.gov.uk/Resource/0038/00389294.pdf (Accessed 1st March 2013), p. 29.

[21] Scottish Government. (2011) *2020 Renewable Routemap for Scotland.* [Online] Available at: http://www.scotland.gov.uk/Publications/2011/08/04110353/5#emergingtechnologies (Accessed 1st March 2013), p. 107.

[22] Institution of Mechanical Engineers, (IMechE). (2011) *Scottish Energy 2020?* [Online] Available at: http://www.imeche.org/Libraries/2011_Press_Releases/IMechE_Scottish_Energy_Report.sflb.ashx (Accessed 2nd February 2013), p. 4.

"The UK National Grid was built to connect large centralised electricity generating plant to industrial and domestic customers. However the situation has now changed significantly and the grid is increasingly required to integrate remote power generators using local renewable sources. Furthermore, much of the Grid asset is reaching the end of its design life and requires updating. A multi-billion pound investment is needed in order to tackle both of these issues and make this infrastructure fit for purpose in the new energy regime. Further, in the case of heat energy, there is no significant, available delivery network in Scotland and little thought appears, as yet, to have been given to this issue."

[23] Scottish Government. (2013) *Energy in Scotland. A Compendium of Scottish Energy Statistics and Information, January 2013.* [Online] Available at: http://www.scotland.gov.uk/Topics/Statistics/Browse/Business/Energy (Accessed 1st March 2013), p. 27 Figure 4.5.

[24] Electricity Network Steering Group. (2012) *Our Electricity Transmission Network: A Vision for 2020.* Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48275/4264-ensg-summary.pdf (Accessed 31st March 2013), pp 4-5.

"This scenario, developed by NGET, and updated annually in consultation with stakeholders, represents a potential generation and demand background which meets the UK targets of 15% of energy demand being provided by renewable sources and a 34% reduction in Green House Gas emissions by 2020. It would also meet the Scottish and Welsh Governments' 2020 renewable energy targets i.e. the equivalent of 100% of Scotland's electricity demand should be met from renewables and 7 TWh per annum of Welsh electricity production by 2020. It takes an holistic approach to the meeting of the targets i.e. assumes that heat and transport will also contribute towards meeting the targets."

[25] Low Carbon Futures. 2012) *Pathways for energy storage in the UK.* Available at: http://www.lowcarbonfutures.org/sites/default/files/Pathways_for_Energy_Storage_UK.pdf (Accessed on 1st March 2013), p. 30.

[26] Scottish Government. (2012) *2020 Renewable Routemap for Scotland -Update 2012.* [Online] Available at: http://www.scotland.gov.uk/Topics/Business-Industry/Energy/UpdateRenewableRoutemap (Accessed 1st March 2013), p. 27.

"4.5 Under the Electricity Market Reform proposals, DECC has committed to non-generation technologies and approaches, including storage capacity, playing a fair and equivalent role to generation in a Capacity Market. This represents an opportunity to exploit the cost-effective potential of storage to contribute to security of supply. We are working with the UK Government on the development of policy in this area."

[27] Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013), Table 5.1.1 p. 54.

[28] Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013), p. 87.

[29] Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013), p. 30.

"Portugal has a number of similarities with Scotland featuring a strong drive to renewable energy (potentially 45% in 2010, mainly from hydro then wind) and increasing interconnection to its neighbour of 3GW by 2014 (in this case Spain). Portugal has the second highest planned capacity figure of pumped hydro with plans to upgrade or build new sites totalling 2000MW. In 2010 Portugal is expected to have 45% renewable with hydro followed by wind the main contributors. Wind production in Portugal is poorly correlated with peak demand, the windiest periods occurring at night time and early morning (Deane et al 2010). A Portuguese government programme 'The National Programme of High Hydroelectric Potential Dams' reported that the ideal relationship between pumping capacity and wind power was 1 MW pumped storage to 3.5MW of wind power. Energie de Portugal (EDP) who are building 4 new plants state that increasing wind penetration and interconnection to Spain is adding value to pumped hydro through energy storage and ancillary services."

[30] Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013).

[31] Electricity Network Steering Group. (2012) *Our Electricity Transmission Network: A Vision for 2020.* Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48275/4264-ensg-summary.pdf (Accessed 31st March 2013), p 15.

[32] Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013).

Scenario 1 values from Table 2.3.1 p. 18, Table 2.3.4 p. 22.

Scenario 2 values from Table 2.4.1 p. 24, Table 2.4.2 p. 25.

Rounding accuracy has been retained from the originals.

[33] ibid

[34] ibid

[35] ibid

APPENDIX 1. PATHWAYS FOR ENERGY STORAGE IN THE UK

Table 5. Storage technology comparison, Pathways for Energy Storage in the UK[36]

TECHNOLOGY		TYPICAL RATED CAPACITY (MW)	NOMINAL DURATION	CYCLE EFFICIENCY (%)	ENERGY COST ($/ KWH)	POWER CAPACITY COST ($/ KW)	TYPICAL LIFE (YEARS)	TECHNOLOGY MATURITY	USUAL/ ANTICIPATED SCALE
PUMPED HYDROELECTRIC STORAGE		100-5000	1-24+ hrs	70-87	5-100	600-2000	30-60	Mature & Commercial	Large grid
COMPRESSED AIR ENERGY STORAGE		50-300	1-24+ hrs	70-89	2-120	400-1150	20-40	Commercial	Large grid
CRYOGEN-BASED ENERGY STORAGE		10-200	1-12+ hrs	40-90+	260-530	900-2000	20-40+	Early commercial	Grid/EV/ Commercial UPS
FLYWHEEL		0.4-20	1 - 15 mins	80-95	1000-14000	250-25000	15-20	Demo/ Early commercial	Small grid/House/EV
HYDROGEN STORAGE AND FUEL CELL		0-50	Seconds-24+ hrs	20-85	6-725	1500-10000+	5-20	Demo	Grid/House/EV/ Commercial UPS
BATTERIES	**Flow**	0.03-3	Seconds - 10h	65-85	150-1000	600-2500	5-30+ (200-12000 cycles)	Research/ Early demo	Grid/House/EV/ Commercial UPS
	Lithium	1-100	0.15-1 hrs	75-90	600-3800	400-1600	5-15 (4000-100,000 cycles)	Demo	Grid/House/EV/ Commercial UPS
	Metal-Air	0.01-50	Seconds-5 hrs	~75	10-340	100-1700	(100-10000 cycles)	Research/ Early demo	Grid/House/EV/ Commercial UPS
	Sodium-Sulphur	0.05-34	Seconds-8hrs	75-90	300-500	350-3000	5-15 (2500-4500 cycles)	Commercial	Grid/House/EV/ Commercial UPS
	Nickel	0-40	Seconds-hrs	60-90	800-1500	400-2400	10-20 (1500-3000 cycles)	Early commercial	Grid/House/EV/ Commercial UPS
	Lead-Acid	0-40	Seconds-10hrs	63-90	200-400	50-600	5-20 (200-1000 cycles)	Mature & Commercial	Grid/House/EV/ Commercial UPS
SUPERCONDUCTING MAGNETIC ENERGY STORAGE		0.1-10	Milliseconds-seconds	90-97+	1000-10000	200-350	20-30	Early commercial	Small grid/ Commercial UPS
SUPERCAPACITOR		0-10	Milliseconds-1 hr	<75-98	300-20000	25-510	8-20+ (25000-1 million cycles)	Early demo	Small grid/ House/EV

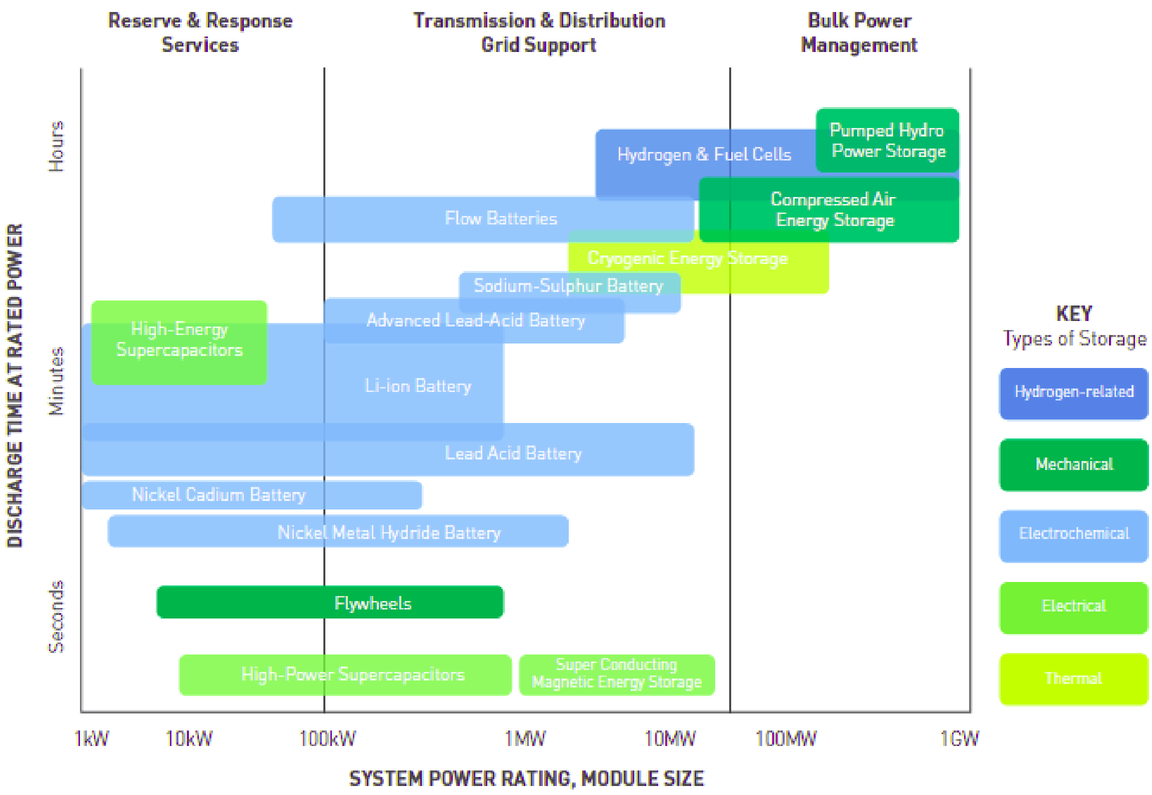

Figure 1. Suitability for grid application, Pathways for Energy Storage in the UK[37]

[36] Low Carbon Futures. 2012) *Pathways for energy storage in the UK*. Available at: http://www.lowcarbonfutures.org/sites/default/files/Pathways_for_Energy_Storage_UK.pdf (Accessed on 1st March 2013), Table 3.1 p. 21.

[37] Low Carbon Futures. 2012) *Pathways for energy storage in the UK*. Available at: http://www.lowcarbonfutures.org/sites/default/files/Pathways_for_Energy_Storage_UK.pdf (Accessed on 1st March 2013), Figure 3.1 p. 22.

APPENDIX 2. STORE PROJECT

Store Project. (2012) *D2.1 Report summarizing the current Status, Role and Costs of Energy Storage Technologies.* [Online] Available at: http://www.store-project.eu/documents/results/en_GB/report-summarizing-the-current-status-role-and-costs-of-energy-storage-technologies (Accessed 31st March 2013).

Page 17: "Liquid air energy storage (LAES) systems employ proven cryogenic processes that use liquid air as the energy storage instead of compressed air… The round-trip efficiency of the LAES system is projected to be between ~ 50 % and 70 %. However, only one pilot plant exists today. (Highview Power Storage, 2012)."

Table 6. Properties of energy storage types, Store project[38]

Technology	Typical Capacity	Response time	Discharge time	Efficiency	Life time	Development stage	Application[12]
Pumped hydro energy storage (PHES)	5 MW – 2 GW	1 min (if standing still) 10 sec (if spinning)	4 - 100 h	55-85%	50+ years	Mature	Primary[13] / secondary / tertiary control, energy arbitrage
Compressed air energy systems (CAES)	25 MW – 2.5 GW	15 min from cold start	2 - 24 h	40-70%	15-40 years	Mature / premature (AA-CAES)	Tertiary control, energy arbitrage
Batteries	1 kW – 50 MW		1 min – 3 h	65-75%	2-10 years	Premature / mature	Uninterruptible power supply, RES-E fluctuation reduction, primary / secondary control
Flywheels	5 kW – 20 MW		4 sec - 15 min	90-95%	~20 years	Mature	Primary control, power quality
Hydrogen Fuel Cell Storage System (HFCSS)	1 kW – 10 GW	Depends on fuel cell	0.01 sec-days	20-40%	5-10 years	Prototype	RES-E fluctuation reduction, tertiary reserve
Super magnetic energy storage (SMES)	10 kW – 1 MW		5 sec – 5 min	95%	~30 years	Premature	Uninterruptible power supply, power quality
Supercapacitors	< 150 kW		1 sec – 1 min	85-95%	~10 years	Premature	Uninterruptible power supply, power quality

Pages 27-28: "From the assessment [above]… it can be clearly seen that PHES and CAES systems have major advantages concerning their capacities and discharge times in comparison to the other technologies. While batteries, flywheels, SMES and supercapacitors can only be deployed for short time periods up to a few hours, PHES and CAES have longer discharge times of up to a day. Therefore it is clear that PHES and CAES systems are the only mature large scale energy storage systems available at present.

"Hydrogen Fuel Cell Storage Systems (HFCSS) are an exception here; HFCSS also have the theoretical potential for longer discharge times and capacities, both depending on the amount of hydrogen stored. Since HFCSS are currently only available as prototypes or under research, the properties of HFCSS will have to be verified in the future. Besides that, HFCSS suffer from low overall efficiencies of about 40 %, which is the result of a maximum efficiency of 70 % for electrolysis combined with an efficiency of ~60 % for power generation."

[38] Store Project. (2012) *D2.1 Report summarizing the current Status, Role and Costs of Energy Storage Technologies*. [Online] Available at: http://www.store-project.eu/documents/results/en_GB/report-summarizing-the-current-status-role-and-costs-of-energy-storage-technologies (Accessed 31st March 2013), Table 1, p. 27.

APPENDIX 3. ENERGY STORAGE AND MANAGEMENT STUDY

Scottish Government. (2010) *Energy Storage and Management Study, October 2010.* [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013)

Since this study was undertaken, LAES has been further developed and the commercial demonstration plant has been operating, although this is still a technology yet to be commercially adopted.[39]

The green group are considered energy storage technologies, with the pink group considered as power quality measures.

The greatest weighting within the analysis was placed on the technology's ability to store significant amounts of energy.[40]

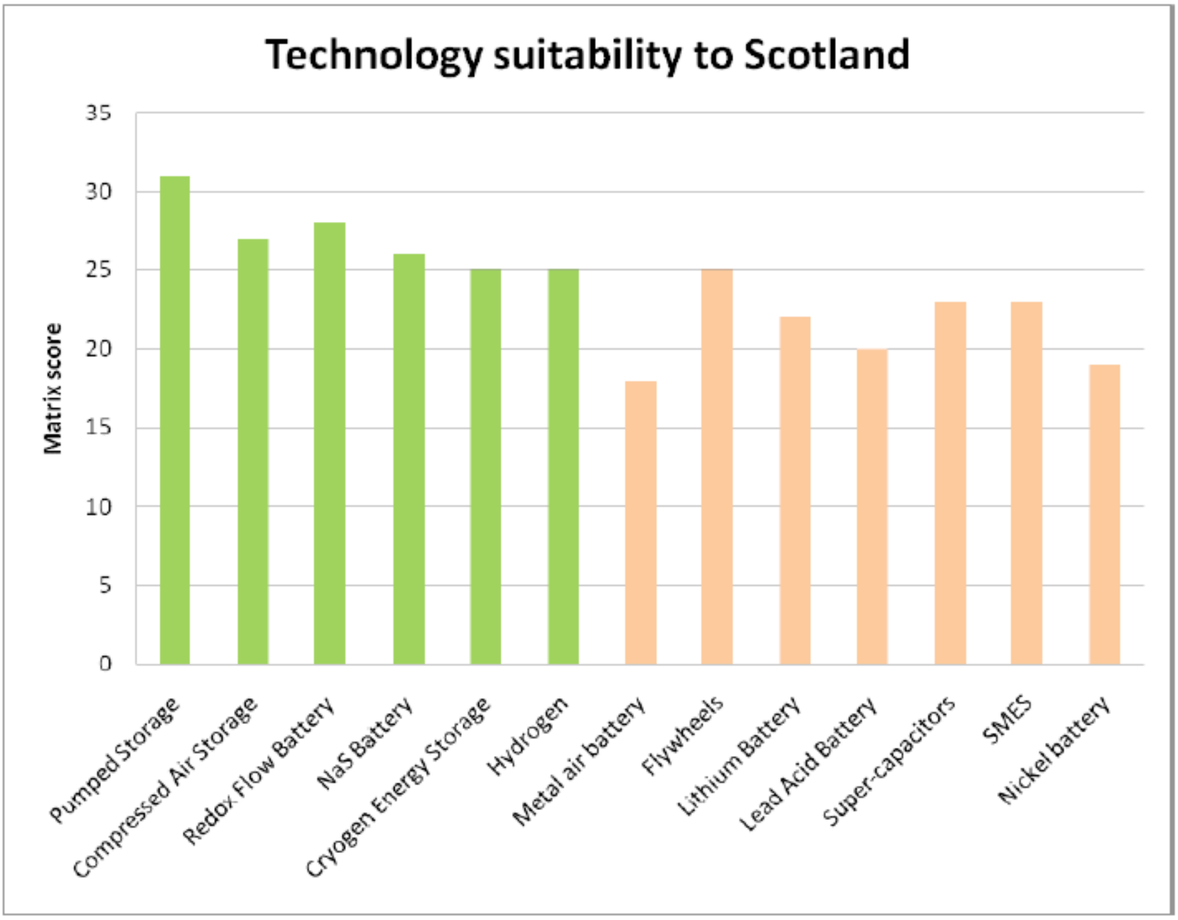

Figure 2. Graph of energy storage technology suitability to Scotland (page 73)

Table 7. Characteristics of energy storage technology for Scotland (from Appendix 1)

	5 = Good 0 = Poor	£/kW Capacity	Efficiency of recovery	Storage Capacity	Technical Maturity	Scottish Infrastructure	CO_2 Emissions	Public Acceptability	Environmental Impacts	Future potential advances	**OVERALL SCORE**	Remote/ Rural Use	Energy Management	Power Quality
Energy Storage technologies	Pumped Storage	1	2	10	5	5	2	3	1	2	31	Centralised storage	✔✔✔	✔✔
	Compressed Air Storage	2	2	8	3	2	1	4	3	2	27	Back-up electricity generation	✔✔✔	✖
	Redox Flow Battery	0	3	4	2	2	4	5	4	4	28	Decentralised/ potentially centralised	✔✔✔	✔✔
	NaS Battery	0	3	6	3	2	2	5	2	3	26	Decentralised	✔✔✔	✔✔
	Cryogen Energy Storage	3	0	6	0	2	2	4	4	4	25	Decentralised	✔✔✔	✔
	Hydrogen	0	0	6	1	3	3	4	4	4	25	Decentralised/ potentially centralised	✔✔✔	✔
	Metal air battery	4	0	2	5	4	0	1	1	1	18	Decentralised	✖	✔✔
Power Quality technologies	Flywheels	2	3	2	2	1	3	5	4	3	25	Decentralised	✖	✔✔✔
	Lithium Battery	0	5	2	2	1	3	4	2	3	22	Decentralised	✖	✔
	Lead Acid Battery	3	3	2	5	4	1	1	0	1	20	Decentralised	✔	✔✔✔
	Super-capacitors	2	4	0	2	2	3	5	3	2	23	Decentralised	✖	✔✔✔
	SMES	3	5	4	1	1	2	1	1	5	23	Centralised at a large scale	✖	✔✔✔
	Nickel battery	2	3	4	3	1	2	3	0	1	19	Decentralised	✔	✔✔

SCENARIOS

Page 16: "Our analysis indicates that Scottish electricity demand growth will be muted over the period to 2015, a reflection of the large fall in electricity demand anticipated during 2009 due to the global economic downturn. Although demand growth begins to recover in 2010, it takes until around 2015 for electricity demand to recover to pre recession levels.

"The drivers behind electricity demand growth have been identified by a number of commentators – with increased electrification in transport together with a move towards greater electric space and water heating part of a package to steer the UK towards a low carbon economy (CCC, 2009)."

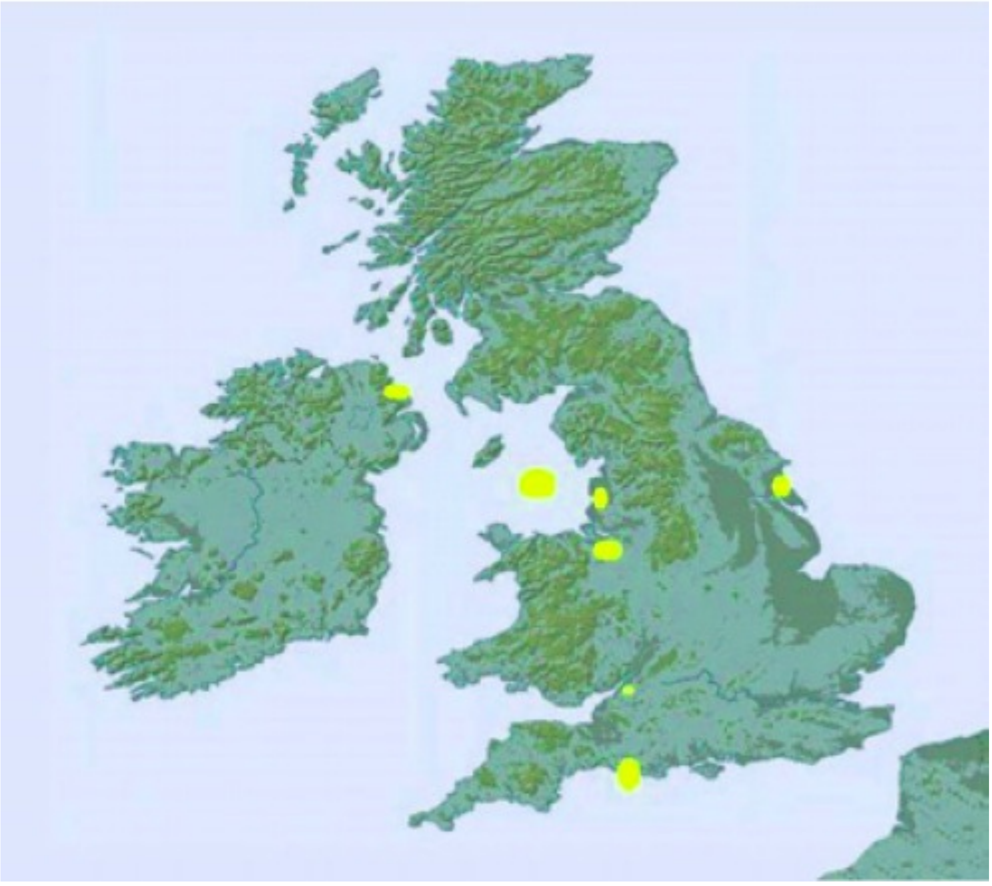

Figure 3. Suitable geology for salt cavern development in the UK and Ireland (from Appendix 2 Figure A2.2.)

Appendix 2: "In Scotland there are no salt mines to use as physical air compression caverns. The potential would be for using disused mines, of which there are many, for this purpose, but the geological soundness of this idea is unclear.

"In figure A2.2 [shown] the salt caverns available in the UK can be seen. As CAES is best designed when nearby a gas turbine power plant, the opportunities for this in Scotland are nil."

[39] Highview Power Storage. (2012) *Highview: Route to Market*. Available at: http://www.highview-power.com/wordpress/?page_id=6 (Accessed 2nd February 2013).

[40] Scottish Government. (2010) *Energy Storage and Management Study, October 2010*. [Online] Available at: http://www.scotland.gov.uk/Publications/2010/10/28091356/0 (Accessed 1st March 2013), p. 73.