scottish renewables

ENERGY STORAGE
THE BASICS

Whitelee Wind Farm

INTRODUCTION

Our demand for energy varies constantly throughout the days, weeks and months, and our energy system needs to be flexible and deliver electricity and heat at the right times.

Fossil fuels have been used from the industrial revolution to the present day to help meet this demand, to drive our industry and businesses, and to ensure our homes are comfortable places to live. Fossil fuels are effective at doing this as they are natural stores of energy, and can be quickly burned to generate power. Using these resources to generate our energy, however, is not only unsustainable in the long term, but is one of the main sources of carbon dioxide and other climate change-causing greenhouse gases.

The need to move away from fossil fuel generation to renewable sources is clear, and in Scotland we are one of the world leaders. Our renewables sector provides more of our electricity than any other source - more than coal, gas and even nuclear. We are also increasingly looking to renewables to generate heat and to fuel our road, rail, sea and air transport.

However, the transition to low-carbon and renewable generation isn't straightforward. Renewable generation is variable, depending on the weather, while nuclear is inflexible. This means we need both innovative and long-standing storage technologies to provide greater flexibility and to maximise our use of renewable generation by storing it at times of low demand and making sure it is available when we need it most.

Ultimately, storage used in conjunction with renewables can help to tackle climate change, decrease our reliance on fossil fuels and maintain our energy security.

This paper highlights some of the energy storage technologies available today at various scales and stages of development, outlining the characteristics and relative strengths of each while providing real-life examples of where they are being used today.

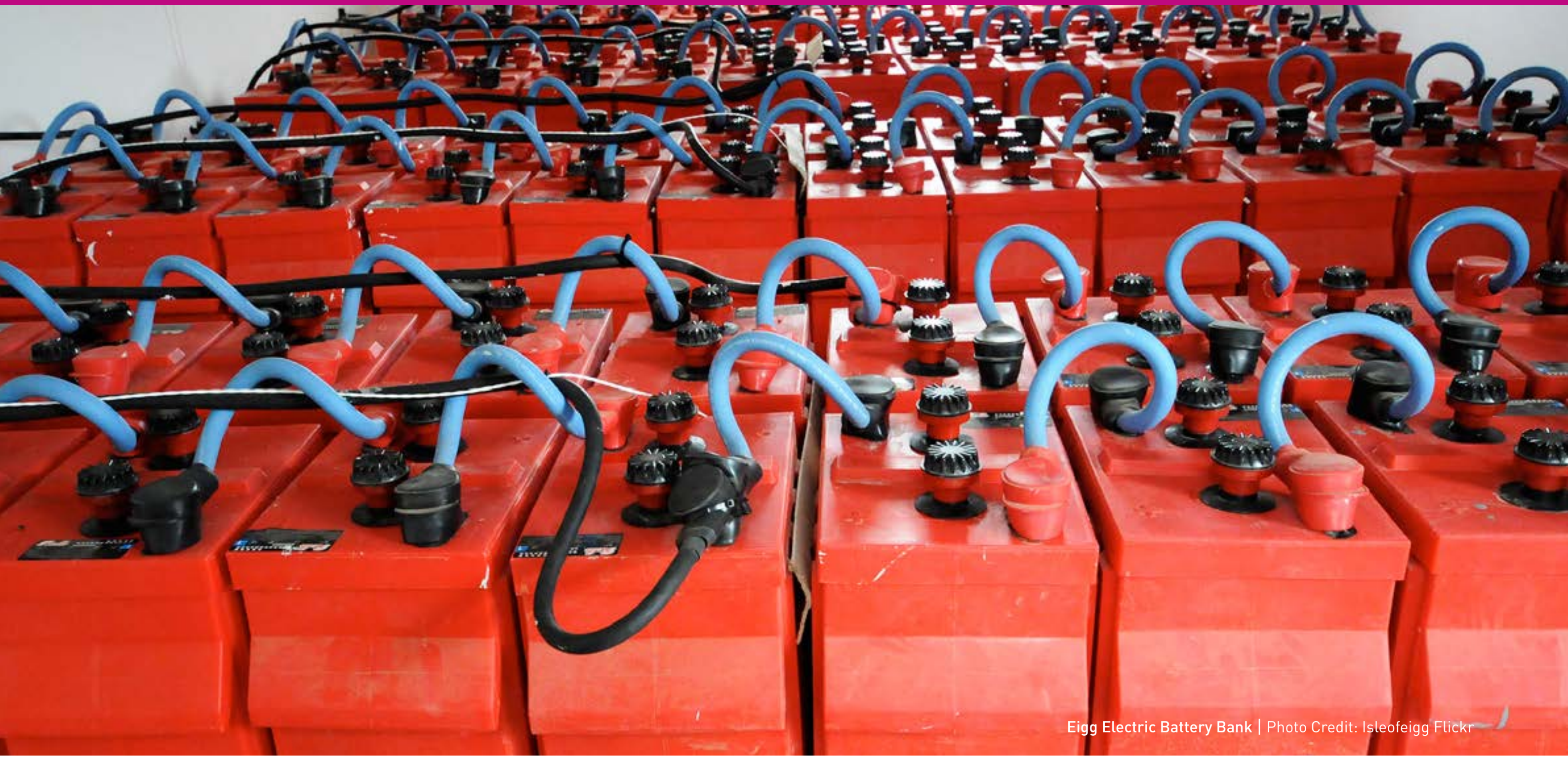
Electric Car and Wind Farm

There is already huge interest in energy storage in Scotland. That interest comes both from those who continue to conduct world-leading research and development in the field, as well as from companies, many of which have been involved in the growth of renewables, now looking towards developing a new generation of energy storage projects:

- Electricity storage has been used in Scotland for 50 years - Cruachan Power Station, a pumped storage hydro scheme, opened in Argyll in 1965
- Scotland is home to UK's first large-scale battery, which connected to the grid network in Orkney in 2013
- A fleet of electric vehicles are reducing emissions and acting as a form of energy storage in Orkney
- Hydrogen fuel cell technology is currently used to power the Hydrogen Office in Fife Energy Park, Scotland
- East Lothian heat battery business Sunamp are set to install over 700 units of SunampPV and other heat storage products in over 1,000 homes across Falkirk, Edinburgh and the Lothians
- There are opportunities for larger thermal stores in Scotland. Potential has already been identified in disused mines in the central belt or abandoned railway tunnels in Glasgow

Scottish Renewables wants to work with companies as well as policy makers, academics and the wider industry to ensure that this progress continues, to improve our energy system and to create a marketplace for energy storage in Scotland.

ENERGY STORAGE CAN BALANCE SUPPLY AND DEMAND FOR ELECTRICITY AND HELP TO MAXIMISE OUR USE OF RENEWABLES GENERATION.



BATTERY STORAGE

How it works: Battery devices store electrical energy in the form of chemical energy and have the ability to later convert that energy back into electricity. A range of potential battery systems exist: lead-acid, sodium-sulphur, lithium-ion, nickel-based, metal-air and flow batteries.

Batteries can be used for a wide variety of applications such as balancing demand and supply or altering the frequency of electricity for the grid. They also operate across a range of scales, from very large-scale schemes connecting to the electricity grid to smaller schemes for individual homes or vehicles.

GRID-SCALE BATTERY STORAGE

Power: Up to 100MW

Duration (running time): From a few seconds (used for frequency control) up to around 10 hours (to balance supply and demand).

Efficiency (energy output as a % of energy input): 50-90%

Energy release time: Variable, but generally almost instantaneous.

Type of energy released: Electricity

Potential for deployment in Scotland: In the long term, battery technologies with long running times could be a good fit for the high levels of renewable energy generation in Scotland and alleviate constraints on the distribution network. In the short term, large-scale batteries can be used for other services such as regulating the frequency of electricity from renewables generation.

Strengths:

- Not reliant on geography
- Can provide a range of ancillary services to the electricity grid
- Variety of batteries, allowing 'best-fit' to site approach

Challenges:

- Immaturity of large scale batteries which can provide power over long periods to balance supply and demand
- High costs

Case study: Scotland is already home to battery storage, with the UK's first large-scale battery connected to the distribution network in Orkney in 2013. The 2MW lithium-ion device connects to the islands' Active Network Management system.

On another Scottish island, Eigg, residents benefit from batteries connected to hydro schemes, wind turbines and solar PV panels. The ability to store energy from these schemes has resulted in 98% of power on the island coming from a renewable source.

Electric Car And Charging Point | Photo Credit: Norbert Aepli

DOMESTIC BATTERIES AND ELECTRIC VEHICLES

Power: Usually around 5 to 7kW but higher capacities becoming available.

Duration (running time): The range for electric vehicles on the market is around 100 miles, while market-ready home batteries could last 1 to 2 days with average usage.

Energy release time: Virtually instant to allow for use in domestic devices and cars.

Type of energy released: Electricity

Potential for deployment in Scotland: With the increase in domestic generation in Scotland (principally through rooftop solar PV) there is a growing market for domestic energy battery storage to allow consumers to better manage their energy usage.

For off-grid communities in Scotland, or those in areas with insufficient grid access, these home-based storage solutions can allow for a secure and stable energy supply.

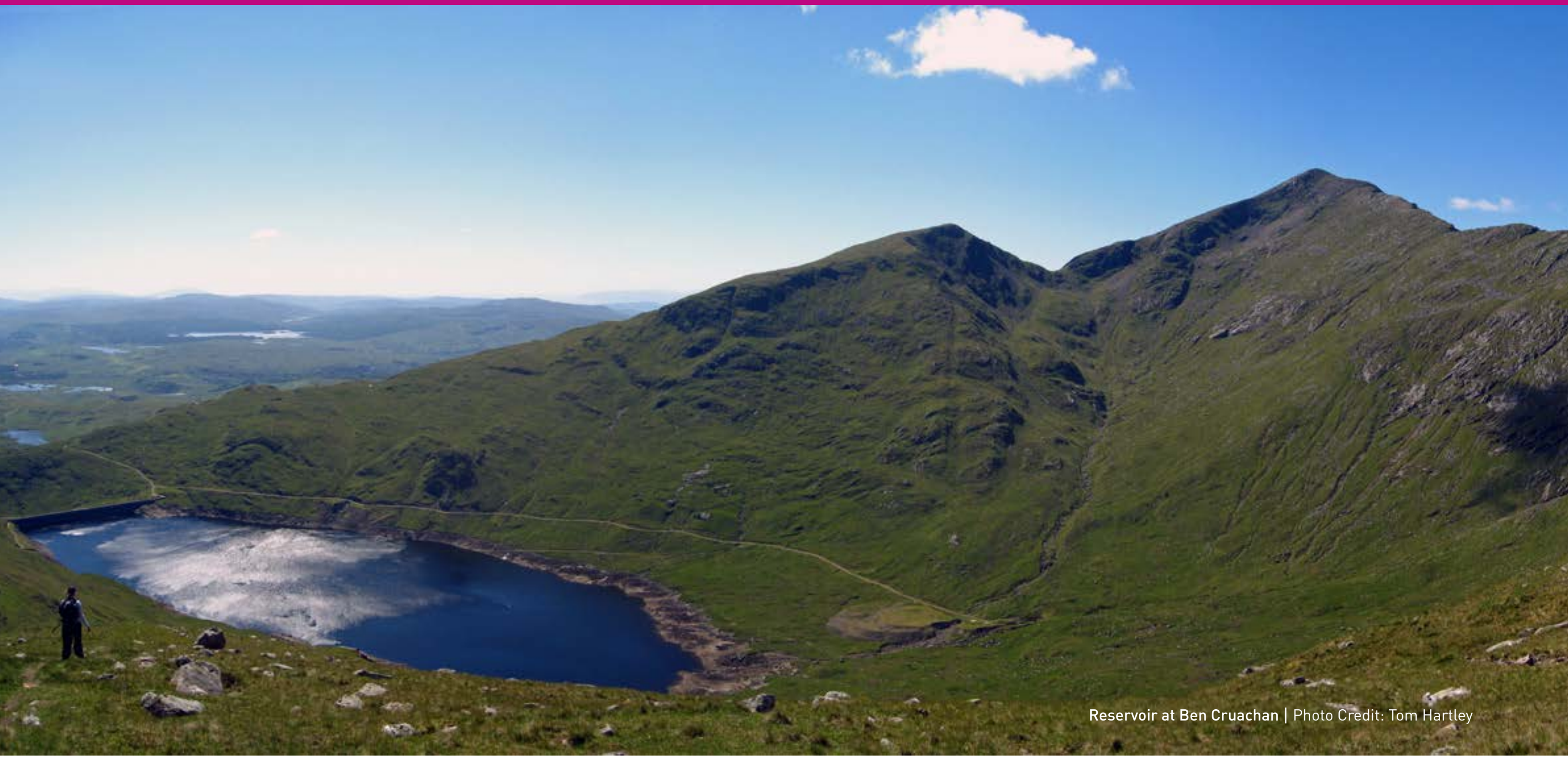
Strengths:

- Batteries in electric vehicles usually charge directly from the grid, and can therefore be used to balance supply and demand
- Domestic batteries can be connected to domestic renewables generation such as solar PV panels, giving consumers a means of maximising use of renewable energy

Challenges:

- Still expensive, as technology is maturing
- Only viable with appropriate infrastructure, such as rooftop solar PV or car parking facilities
- The lifetime of some domestic batteries has yet to be tested in practice

Case study: Electric vehicles are reducing emissions and acting as a form of energy storage in the Scottish should be Orkney Islands. This hub of renewable energy deployment boasts 5 per cent of the Scottish electric vehicle fleet, but just 0.4 per cent of the population. Many households on the islands have their own small-scale wind turbine and generate more energy than they use. By fuelling electric cars with the excess, the clean energy is stored for use later – as a means of transportation.


Reservoir at Ben Cruachan | Photo Credit: Tom Hartley

PUMPED HYDRO STORAGE

How it works: Pumped storage schemes work by using electricity to pump water from a lower to a higher reservoir where it can be stored and then, when required, released to generate electricity, as a conventional hydroelectric power station would.

Power: Approximately 30MW to 600MW

Duration (running time): Dependent on reservoir size, can be anything from an hour to over two days.

Efficiency: 70-85%

Energy release time: 10 seconds to 2 minutes

Potential for deployment in Scotland: Currently the UK is home to just 3GW of pumped storage capacity, a relatively small amount in comparison to Germany (6GW), France (4.5GW) and Austria (8GW).

Schemes can utilise Scotland's many reservoirs and consideration is being given to innovative ways to site developments in abandoned mines and quarries.

Whilst there are initial plans for investment in new and upgraded pumped storage schemes in Scotland, continued progress in developing such projects relies on a satisfactory and supportive long-term public policy and regulatory framework to allow commercial developers to confidently take investment decisions.

Despite the clear benefits and the relatively low capacity levels in the UK, pumped storage only benefits from government support through the capacity market mechanism, which gives additional financial support to power generators who can provide supply on demand. Developers have suggested this is not an appropriate mechanism of support for larger-scale schemes given the short-term nature of the funding rounds and long construction timescales.

Strengths:

- A proven large-scale technology with significant capacity already installed in Scotland and the UK
- Schemes last anything from 50 to over 100 years
- A range of auxiliary services which help to balance supply and demand and increase security of supply

Challenges:

- Large capital costs with long-term investments which require certainty in the market and the right levels of government support
- Requires the appropriate geography, which is often in remote areas

HYDRO STORAGE

Case study: With construction starting in 1959, Cruachan Power Station, a pumped storage hydro power station, opened in Argyll in 1965.

At times of peak demand, water is released from the reservoir through the station's turbines to supply up to 440MW of electricity. It can produce electricity for the grid in two minutes, or 30 seconds if its turbines are already primed on "spinning reserve".

The power station, located near Oban, is built into the hollowed-out rock of a mountain, Ben Cruachan. It uses electricity from the grid to pump water from Loch Awe to a storage reservoir part-way up the mountain. Water is also collected from the surrounding hills, providing a hydroelectric power element to the generation.

The output of the Cruachan station could be more than doubled to over 1GW under plans proposed by ScottishPower.

CRUACHAN STATION COULD BE MORE THAN DOUBLED TO OVER 1GW.


Solar Thermal Panels In Eigg | Photo Credit: Isleofeigg Flickr

THERMAL STORAGE

How it works: Thermal storage can be used to describe any process which stores and then releases heat on demand. Devices can range in size from small-scale domestic tanks and storage heaters to large external heat stores which can supply many homes and businesses. Heat can be generated from various sources such as electricity or solar energy and stored in water, molten minerals, clay or banks, of earth.

LARGE-SCALE THERMAL STORAGE

Power: Enough power to provide heating and hot water needs for numerous homes and businesses. This power can be supplemented with heat pumps to boost power up to the level required.

Duration (running time): Dependent on scale but large underground stores can be vast.

Efficiency: Around 50-80%

Energy release time: Seconds to minutes depending on geography of the site and distance from heat source.

Type of energy released: Hot water and/or heating

Potential for deployment in Scotland: There are opportunities for larger thermal stores in Scotland. Potential has already been identified in disused mines in the central belt and abandoned railway tunnels in Glasgow. As yet, larger scale heat storage has not been proven in Scotland although there are more examples emerging from Europe.

Strengths:

- Waste heat from industrial processes and power stations could be stored in large quantities
- Reduces need for increased peak generation capacity
- Can be used to store seasonal heat in summer for use in winter

Challenges:

- Efficiencies for some systems are still quite low – some amount of heat loss is inevitable
- High capital costs, and the technology is only emerging in the UK

Case study: Suffolk One college utilised seasonal heat storage as part of a redevelopment of its site. Technology from clean-tech company ICAX stored heat in thermal banks in the ground for retrieval in winter by ground source heat pumps to provide an additional source of heating.

DOMESTIC THERMAL STORAGE

Power: Domestic schemes offer hot water and heating services which can be boosted by a boiler if required. They can be powered directly by heat from the sun through solar thermal panels or through electricity from the grid or domestic renewables generation.

Duration (running time): Dependent on capacity of storage tank or storage heater in the user's home.

Efficiency: Around 50-80%

Energy release time: A few seconds

Type of energy released: Hot water and/or heating

Potential for deployment in Scotland: Efficient hot water storage tanks which can store heat from solar thermal technology are now becoming more widespread. Furthermore, storage heaters, which were previously common in Scotland, are now being utilised again. New designs are increasing efficiency and storing electricity from the grid or domestic renewables in the form of heat for the home.

Strengths:

- Domestic thermal storage is relatively cheap and well tested
- Performance and cost are continually improving
- Domestic storage can help balance national demand and supply of electricity and/or heat and can utilise domestic solar thermal

Challenges:

- If utilising solar thermal technology, space is required for the installation of the hot water cylinder in the home or a larger external or underground store
- High capital costs of installation in comparison to a new gas or electrical boiler

Case study: SSE and Glen Dimplex have produced a modern domestic storage heater that provides a storage solution for the grid as well as increased efficiency. Further energy management will be possible with the addition of a small hub, similar to a broadband router, with the advent of smart metering. This allows the heaters to store excess capacity from renewable generation sources like wind in thousands of properties when demand is low. These heaters are commercially available with the first prototype trialled in properties in Perth.

Also in Scotland, East Lothian-based Sunamp have developed the SunampPV system which is designed to store excess electricity from a solar PV array as heat. It can later deliver fast-flowing hot water on demand. Sunamp are set to install over 700 units of SunampPV and other Sunamp heat battery products in over 1,000 homes across Falkirk, Edinburgh and the Lothians.

SunampPV thermal storage device

Hydrogen Powered Bus | Photo Credit: Spsmiler

HYDROGEN

How does it work: Hydrogen is a fuel and is therefore a natural energy store. Through a process called electrolysis, electricity supplies can create hydrogen, which doesn't emit carbon when used in place of conventional gas for cooking and heating or when powering a fuel cell to create electricity.

Power: Fuel cells can be used to power homes, offices and vehicles in a similar way to smaller-scale batteries of up to around 10kW, with larger-scale technology in development.

Duration (running time): Fuel cells in electric vehicles have a range of around 300 miles.

Efficiency: Around 50-80%

Energy release time: Almost instant

Type of energy released: Electricity or heat

Potential for deployment in Scotland: There is significant interest in using this technology as a way of ensuring Scotland's renewable generation can be used effectively and at times of low demand. Many Scottish universities, such as the University of St Andrews and the University of Strathclyde, are conducting leading research in the field.

There are also a number of distributed gas grids in Scotland - Campbeltown, Oban, Wick, Thurso and Stornoway - where local emissions could be lowered by using locally produced hydrogen.

The Scottish Hydrogen and Fuel Cell Association (SHFCA) works to develop Scottish expertise in the area among industry and academia.

Strengths:

- Hydrogen can be stored for a long term in liquid or in gas form, and can be transported as a gas without losses
- Can help to resolve electricity network demand and supply issues by using excess generation, particularly from renewables, to create a clean gas for use when required
- Increasing hydrogen gas production could reduce reliance on gas imports and strengthens energy security

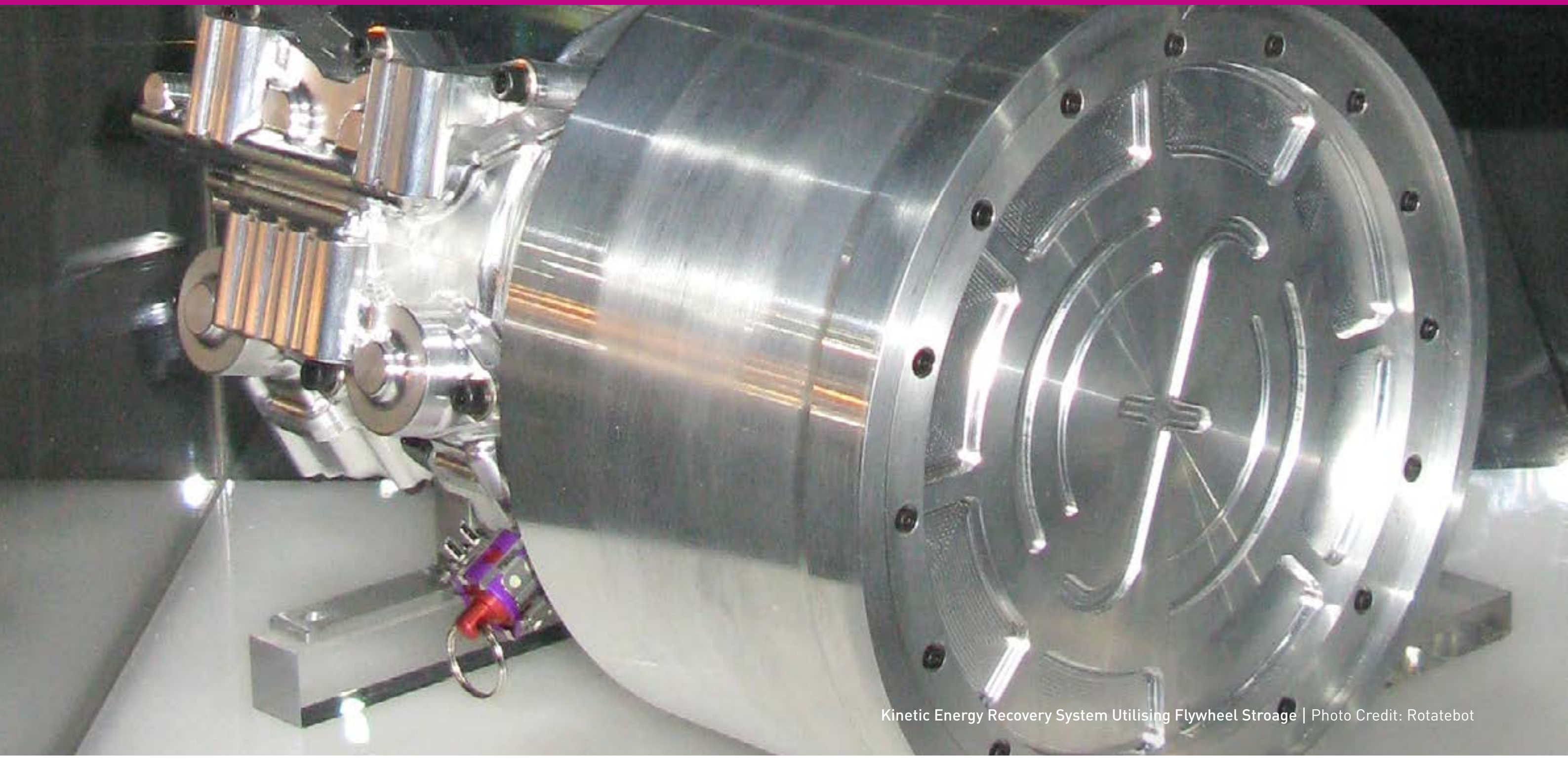
Challenges:

- Hydrogen-based infrastructure, such as transport fuelling points, is yet to be fully developed and deployed
- Costs remain high, and a commercial case for integration with renewables is still being developed

Case study: Hydrogen fuel cell technology powers the Hydrogen Office in Fife Energy Park, Scotland. Surplus electricity from a wind turbine is converted to hydrogen and a 10kW fuel cell is used to generate electricity to power the office when required.

Also in Scotland, the European Marine Energy Centre plans to convert electricity generated from a tidal test site into hydrogen, having procured a 0.5MW electrolyser. Orkney's grid connection to the mainland currently cannot absorb the amount of renewable generation from the islands. This project will be the first in the world to use tidal technology to generate hydrogen, and will ensure renewable generation is used more effectively.

HYDROGEN CAN BE STORED AND TRANSPORTED AS A GAS, AND DOESN'T EMIT CARBON WHEN USED.



Kinetic Energy Recovery System Utilising Flywheel Stroage | Photo Credit: Rotatebot

FLYWHEEL STORAGE

How it works: Flywheels are considered as one of the earliest mechanical energy storage mechanisms. Flywheels store kinetic energy in the form of a spinning rotor. When short-term power is needed, the energy in the spinning rotor is used to generate electricity.

Power: Most commonly between 1kW and 100kW, but more advanced systems have been installed in the US and Japan reaching around 23MW.

Duration (running time): Around 15-30 minutes

Efficiency: Up to 85%

Energy release time: From as little as a few seconds to several minutes depending on size.

Type of energy released: Electricity

Potential for deployment in Scotland: A Scottish Government review found that there is limited, if any, work on advanced flywheels in Scotland or the UK. Despite this, it is recognised that flywheel storage could play a role by integrating with wind projects, helping to improve availability of electricity as well as improving grid stability.

Strengths:

- Low maintenance requirements
- Long lifespan
- Unlike batteries, not as adversely affected by temperature changes, so less cooling is required

Challenges:

- Safety risk if a flywheel is loaded up with more energy than it can handle
- Capital cost is high
- Larger-scale systems are not commonplace and are expensive

Case study: Flywheel energy storage technology is being installed on the Isle of Eigg and Fair Isle by Williams Advanced Engineering to help to improve the grid networks, which are heavily reliant on a range of renewable energy sources. The technology was first pioneered by Williams for Grand Prix racing following the introduction of Kinetic Energy Recovery Systems (KERS) into the sport in 2009. Flywheels will reduce the reliance on generators and lighten the load on batteries currently in use.

SUPERCAPACITORS

How it works: A supercapacitor stores power using a static charge, rather than using a chemical reaction like a battery. As a result supercapacitors can last for millions of charge and discharge cycles without losing energy storage capabilities and 'wearing out'.

They are less useful for long-term demand management, but can be used effectively for producing short bursts of energy or storing power surges. This allows supercapacitors to smooth the frequency of electricity generation when, in technologies such as wind turbines, it can be variable.

Power: From very small-scale in individual large-scale supercapacitors which can regulate supply and demand on the grid.

Duration (running time): Generally very short-term to provide an almost instant burst of energy or to help store power surges, but technology is developing for storing more power allowing extended use.

Efficiency: 90 – 95%

Energy release time: Almost instant

Type of energy released: Electricity

Potential for deployment in Scotland: Supercapacitors have been used in hybrid electric vehicles (often helping with sudden braking and accelerating) and in other machines such as wind turbines for many years. In terms of larger-scale energy storage, the technology is still relatively new, but it has the potential to play an important role for renewables, particularly solar pv and wind.

Strengths:

- Highly efficient
- Quick storage and response times
- Long life with the potential to be used millions of times without damage

Challenges:

- High costs for larger scale systems
- Only holds around a fifth of the energy of an electrochemical battery of similar scale

Case study: Freqcon GmbH, a German developer and distributor of renewable energy systems, has deployed an energy storage system for the Tallaght Smart Grid Testbed in Ireland which uses supercapacitors to support grid stability in both residential and industrial settings. Freqcon's Microgrid Stabilizer addresses the variable electricity generation challenges which accompany high renewable energy penetration.

The system will demonstrate how energy storage can minimise electricity distribution issues and grid instability. With multiple sources of energy generation, the grid network in Ireland must deal with voltage and frequency issues before distributing the electricity to end users.

SUPERCAPACITORS CAN BE USED MILLIONS OF TIMES WITHOUT WEARING OUT.

COMPRESSED AIR ENERGY STORAGE

How it works: Compressed Air Energy Storage (CAES) is a mature technology which converts electrical energy into high-pressure compressed air. This air can be released at a later time to drive a generator and produce electricity. The conversion process requires the input of heat.

The compressed air can be stored underground in existing infrastructure, such as salt caverns or abandoned mines.

Power: Large-scale projects can be up to 300-400MW but small-scale uses also exist.

Duration (running time): Dependent on the size of store of compressed air.

Efficiency: Around 70%

Energy release time: C. 15 minutes

Type of energy released: Electricity

Potential for deployment in Scotland: There are currently no sites developed in Scotland, though there has been significant interest in the technology. This is a mature technology, with sites in Germany and the USA. The British Geological Survey believes coal mines in the central belt of Scotland could offer an opportunity.

Strengths:

- Practical and proven at a large scale
- A long lifespan which improves economics
- There are various methods to compress and store air with some increased efficiencies from more novel approaches

Challenges:

- High pressure and high temperature environments require maintenance and management
- Less electricity is generated as cavern pressure decreases, requiring pressure management for a steady supply
- Cavern space and suitability required

Case study: Innovative compressed air storage methods have been undertaken in Scotland. In 2011, Professor Seamus Garvey, from the University of Nottingham, tested his storage concept in the waters off Orkney. He developed 'energy bags' – large balloon type bags, anchored to the seabed, designed to store compressed air underwater – with the water pressure countering that of the compressed air and reducing storage costs.

THE BRITISH GEOLOGICAL SURVEY BELIEVES COAL MINES IN SCOTLAND'S CENTRAL BELT COULD OFFER AN OPPORTUNITY FOR COMPRESSED AIR STORAGE.

Cryogenic Air Separation Plant | Photo Credit: Engineer09

LIQUID AIR ENERGY STORAGE

How it works: Liquid air energy storage is the storage of liquid air or liquid nitrogen in insulated low pressure tanks after it has been cooled to very low temperatures. This process allows higher compression, and therefore has lower storage requirements than compressed air storage. When energy is required this liquid air can be re-heated, which turns it back into a gas to drive a generator and produce electricity.

Power: Current schemes are generally only a few hundred kWs. Larger schemes of multiple MW are being considered, but none are operational as yet.

Duration (running time): Dependent on the size of store.

Efficiency: Around 50-60%

Energy release time: Variable, but generally within minutes.

Type of energy released: Electricity

Potential for deployment in Scotland: There are currently no sites developed in Scotland, though there has been significant interest in the technology.

Strengths:

- Air is a cost-free feedstock
- Not constrained by geography so can be located anywhere
- Efficiencies can be improved by utilising waste heat

Challenges:

- The technology is not yet demonstrated at a very large scale
- Efficiency is still relatively low

Case study: UK-based Highview Power Storage developed a 350kW system which is operating at a biomass power station in Slough. The company has also received funding from the Department of Energy and Climate Change for a 5MW demonstrator project at a landfill gas plant.

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