ENERGY STORAGE: Technology and Policy Innovation

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Energy systems are coming under pressure to be more flexible, with greater reliability and to meet changing or increasing demands, all within tight economic constraints and over short time periods. Energy storage is being viewed as one of the key enabling technologies that will allow the infrastructure to meet these challenges.[1] In the UK, as generation from variable renewables increases, and our use of energy changes, storage could allow a more efficient system to be developed. However, there are both technical and non-technical barriers to be overcome if new technologies are to play a major role.

THE CURRENT ROLE OF STORAGE

Energy storage is not a new concept: we have long had stocks of coal or reservoirs of natural gas serving power stations or homes, reducing exposure to variations in the supply chain and allowing responses to varying demand over daily and annual cycles. A pile of coal next to a power station can exceed one million tonnes, equivalent to about two months' electrical output.

'Rechargeable storage' gives the extra functionality of absorbing energy or power that is instantaneously available, and being able to return it at a later time (of course with an energy cost). Pumped hydro was built alongside the nuclear programme, as nuclear plant has limited ability to change its output. When excess electricity is available at times of low demand, such as during the night, water is pumped from a lower to higher reservoir. Later, the energy is recovered by letting it flow back down the hill through turbines, meeting the peaks whilst the conventional plant runs efficiently at a constant output. For a few hours, the output from pumped storage can be equal to that of a power station; though around 20% of the initial energy will have been lost.

Hot water tanks provide essentially the same service, but on a distributed basis and providing thermal, rather than electrical, energy. Nearly 50% of the UK's energy consumption goes on some form of heating.[2] With 14 million tanks installed in homes, the total stored energy is three times that from pumped hydro.

For decades, the demand for energy has been largely predictable, generation has been responsive and mechanisms have evolved (driven by varying combinations of engineering and politics) to ensure supplies have been available at the right times.

THE FUTURE ENERGY SYSTEM

To meet climate change mitigation targets, most scenarios for the UK favour reducing emissions from power generation to near zero by 2030, and using that low carbon power for heating and transport needs, displacing fossil fuels, in subsequent decades.

We are now going through a period of rapidly increasing generation from renewables, especially wind. With cost reductions, solar PV is likely to far exceed previous predictions, and be placed on distribution networks, rather than under the control of the system operator, National Grid. Early in the 2020s, it could be common to have variable renewable capacity covering more than half of total demand.

... energy storage can reduce system costs ...

At the same time, if heating is to be electrified, we need to recognise that with the changing weather, demand can quadruple between summer and winter; and by half over a period of a day or two. Transferring provision from natural gas to electricity generation capacity would mean adding ten or more large power stations with low utilisation rates.

These changes in supply and demand will have an impact on the power network and wider energy system across timescales of seconds (and less) to months.

ENERGY STORAGE AS A SOLUTION

'Energy storage' encompasses a broad family of technologies, covering chemical, electrochemical, thermal, mechanical and electrical forms of energy.[3] Each has characteristics for delivering its energy or power, over different timescales, with varying physical features of the devices themselves.

The most obvious services which will avoid the need to build generation plant that would otherwise meet peak demand at low utilisation rates are:

- Daily arbitrage: absorbing energy in periods of low demand or excess supply (when prices are low), and delivering back when demand increases or supply drops (when prices are high).
- Balancing: providing reserve power to balance supply and demand, or maintain the system frequency, over short timescales. National Grid forecasts their Short Term Operating Reserve capacity to increase from 3.5 to 6.5 GW in 2020, with market value increasing from £200m to nearly £1bn.

At a more local level, existing infrastructure could be maintained even if demand for electricity increases, by 'peak lopping'. This would push energy through constrained networks and store it until required by the user, reducing the size of the capacity required.

Many energy storage technologies are able to operate such that they can meet more than one of the challenges that will be experienced, but some are better-suited to certain applications. Technologies such as pumped hydro, liquid air, compressed air, flow batteries and hydrogen can increase the amount of energy held at relatively low cost, and is mostly dependent on availability of physical space. For more power-based technologies, such as flywheels, superconducting magnetic energy storage or supercapacitors, these discharge rapidly.

Battery technologies sit in the middle – they can deliver high power and large quantities of energy. But increasing the amount of stored energy means having more batteries, and so is an expensive option for large applications. In some cases cost is less of a factor (including for the demonstration of energy storage operation in principle), and given their availability (from electric vehicle production) batteries are often chosen.

As well as energy storage, there are other ways of meeting the supply/demand challenges: installing more responsive generation supplies, increasing network capacity (including to other markets), and making demand more responsive. Any decision to deploy a technology must consider the alternatives. However, studies have shown that energy storage can reduce system costs, compared to the other options.[4]

Much analysis is now focused on assessing which technologies could fit different applications, give their costs and performance, and – critically – what value can be gained from their operation.

TECHNOLOGY INNOVATION

In 2012, energy storage was selected as one the Government's 'Eight Great Technologies'.[5] Major investments have since flowed, including from the Research Councils, the Department of Energy and Climate Change (DECC) and the energy regulator, Ofgem. So whilst public funding for research, development and demonstration activities has increased in recent years, it is still at relatively low levels – funding for energy innovation overall in the UK is behind that of other countries, and low given the scale of the challenge.[6]

On top of this, the different roles of each organisation can make it hard to focus on the objectives of support – whether it is for the benefit of industry, the energy system or science. Coordination to achieve common goals is essential, something the UK has struggled with in the past.[7]

Excellence in some of the underlying science and engineering behind energy storage technologies has meant the UK has several companies developing new technologies that could be exported into other markets.

POLICY INNOVATION

Whilst the benefits of energy storage are being recognised, and the technologies are emerging, being able to access the system value and build a business case for deployment is not yet viable. A report for Government has identified energy storage as having the highest occurrence of market and innovation system failures from across a number of technologies and business areas.[8]

In part this is due to the currently low value of the flexibility offered by energy storage, but which will become more significant as generation from variable renewables increases over the next ten years. Many technologies are too expensive and at pre-commercial stages of development; but the aim is for this to improve, with innovation support reducing costs and de-risking further investment.

At the same time, specific policy and regulatory issues affect how energy storage can operate. Providing multiple services, and gaining revenue from each market, is not always compatible with existing regulatory frameworks. Classed as both a generation asset and consumer, energy storage can be subject to double jeopardy when it comes to a number of environmental levies – effectively being charged twice for 'green' tariffs. This is a rather perverse consequence, as the aim is to improve the efficiency of a system with more variable renewable generation.

The risk is that energy storage withers in the UK whilst other, more progressive, markets promote its early adoption. Without mechanisms to recognise the potential, generation from gas or coal is likely to crowd out the market in the short term, when energy storage may offer longer term cost, carbon and system benefits.

FOOTNOTES

1 E.g. Energy Research Partnership (2011) The future role for energy storage in the UK. Technology Report, May 2011

2 Eames, P., Loveday, D., Haines, V. and Romanos, P. (2014) The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption - Research Report (UKERC:London)

3 Jonathan Radcliffe (2013) Energy storage technologies. Ingenia, March 2013

4 Goran Strbac et al (2012) Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future. Report for the Carbon Trust, June 2012

5 David Willetts (2013) Eight Great Technologies. Policy Exchange report

6 Jim Skea (2013) Energy Research and Training Prospectus. Report for the Research Councils Energy Programme, November 213

7 House of Commons Energy and Climate Change Committee (2014) Innovate to accumulate: the Government's approach to low carbon innovation. Report, August 2014.

8 Department for Business, Innovation and Skills (2014), 'The Case for Public Support of Innovation'

ENERGY STORAGE AND THE 'COLD ECONOMY'

Professor Toby Peters

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Energy storage has long been recognised as vital to a decarbonised and secure electricity grid and low carbon transport. But conventional technologies – batteries, pumped storage, compressed air – all have their drawbacks. Now the idea of storing energy as cold and power – in the form of liquid air or nitrogen – is rapidly gaining support. This is not a panacea but would allow 'wrong time' energy and waste cold to be recycled into zero-emission peak power, cooling and even transport fuel. Liquid air technologies now being developed in Britain would help balance intermittent renewable generation, reduce emissions and cost, and could eventually form a joined-up 'Cold Economy'.

Cold is the Cinderella of the energy debate. Governments have developed policies governing most sectors – electricity, heat, transport – but the energy consumed for cooling gets much less attention. Yet cooling underpins many vital aspects of modern life: air conditioning; data centres; superconductors; medicine; industry; and the 'cold chain' of refrigerated warehouses and vehicles needed to preserve food from farm to fork. Cooling already consumes 15% of global electricity, and demand is soaring worldwide – nowhere more so than in emerging markets – causing higher emissions of greenhouse gases and air pollution. Global cooling demand in 2030 could equate to three times the current generating capacity of the UK.

The pollution from cooling is little recognised but poses a growing threat. One particular culprit is the transport refrigeration unit (TRU) – the secondary diesel engine that powers refrigeration on trucks worldwide. TRUs not only consume up to 20% of the truck's fuel, but also emit up to 29 times as much particulate matter (PM) and up to six times as much nitrogen oxide (NOx) as a modern propulsion engine. Such local air pollution causes 29,000 premature deaths in Britain each year; 400,000 in the EU; and 600,000 in India.

... the solution to the intermittency of renewable generators ...

Leaks of TRU refrigerant gases have a grossly disproportionate impact on greenhouse gas emissions; the most commonly used 'F-gas' is almost 4,000 times more potent than CO_2. The global fleet of refrigerated trucks is forecast to double to 9 million by 2025 – so we must find a way to 'do cold better'.

Even as cooling demand is soaring, vast amounts of cold are lost to the environment. The biggest source is the cold required to turn natural gas into compact Liquefied Natural Gas at -160C for transport by ship, which is simply discarded when the LNG is re-gasified at the import terminal. The projected global trade of LNG in 2030 would give off enough waste cold to provide cooling for over 4 million refrigerated trucks – more than the current global fleet. The trick is to find a means of storing, transporting and harnessing that cold, and one exciting new idea is liquid air.

Air turns to liquid when refrigerated to -196C, and can be conveniently stored in insulated but unpressurised vessels. Exposure to heat – including ambient – causes rapid re-gasification and a 710-fold expansion in volume, which can be used to drive a turbine or piston engine. Re-gasification also gives off lots of usable and valuable cold.

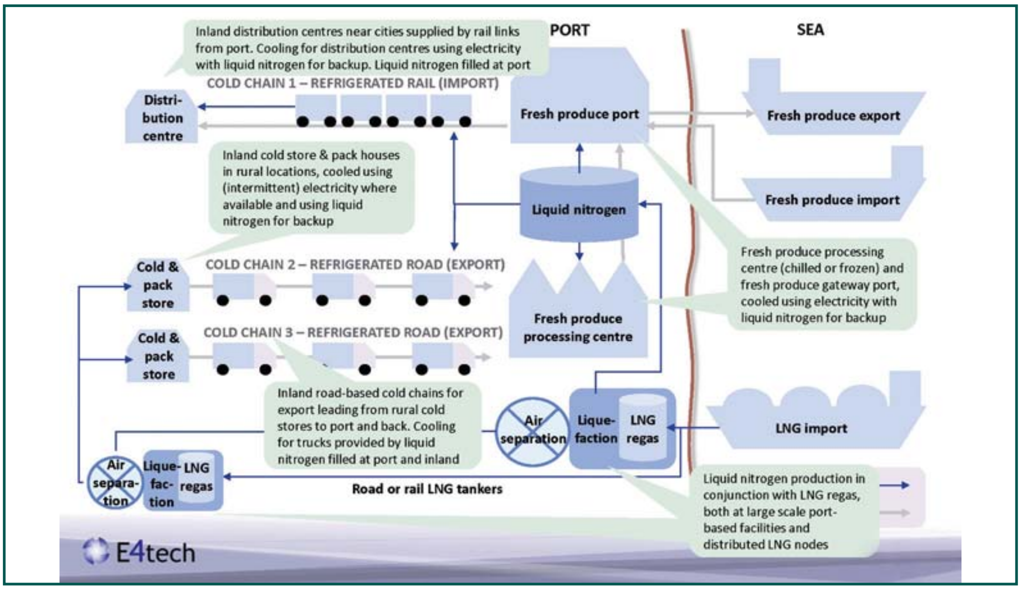
The key to exploiting liquid air is a novel piston engine invented by Peter Dearman, an archetypal British 'garden shed' inventor. Cryogenic expansion engines have existed for over a century, but the Dearman engine is innovative because the liquid air mixes with a 'heat exchange fluid' (water and glycol) to promote rapid and efficient re-gasification inside the engine cylinder.

The Dearman Engine Company is developing the engine for a range of applications that will reduce cost and carbon emissions, and eliminate NOx and PM. The first is a highly efficient TRU, currently being tested on a vehicle by MIRA (formerly the Motor Industry Research Association), and is due to start fleet trials in 2015. Because diesel TRUs are so polluting, the impact of even a modest fleet of Dearman units could be huge. Modelling suggests 13,000 Dearman TRUs would reduce PM emissions by the same amount as taking 367,000 Euro VI trucks off the road – more than three times the entire UK articulated truck fleet – or more than 2 million modern diesel cars.

... Cooling already consumes 15% of global electricity ...

The next is a 'heat hybrid' combination of a Dearman engine with a diesel engine, in which waste heat and cold are exchanged to raise the efficiency of both, and reduce fuel consumption by 25%. A heat hybrid bus would cut carbon emissions by as much as an electric hybrid but at a fraction of the cost. A consortium led by Dearman has been awarded nearly £2 million by Innovate UK (formerly Technology Strategy Board) to build a heat hybrid prototype by 2016.

Dearman is also developing an electricity generator to displace the diesel 'gensets' that provide emergency power – often for cooling – to many hospitals, data centres and companies, and which also supply electricity to the grid to meet the highest demand peaks. Diesel gensets are reliable and cheap, but like TRUs they also emit large amounts of carbon, NOx and PM. With Britain's grid capacity margin down to just 4%, such backup generation is more vital than ever to ensure security of supply. Yet as concern over urban air pollution grows, relying on diesel gensets will become increasingly untenable – they are already banned for grid support in the City of London. Providing reserve services in Britain with a Dearman liquid air zero-emission genset would reduce annual CO_2 emissions by 100-500 tonnes of CO_2 per MW installed, a saving of 35-54%, which would rise further as grid decarbonisation targets are met. It would also eliminate NOx and PM emissions – allowing it to operate unconstrained in urban areas – and provide 'free' cold for businesses with high cooling loads such as supermarkets and data centres.



How waste cold from LNG re-gasification could power the 'Cold Economy' in India. Source: E4tech

Liquid air is not yet produced commercially, but liquid nitrogen, which can be used in the same way, is already widely produced for industrial purposes. Both are produced by electric-powered plants, so either could provide the solution to the intermittency of renewable generators such as wind and solar: absorbing and storing 'wrong time' or surplus renewable energy to use on demand in grid or transport applications. Liquid nitrogen is delivered to industrial users daily by road tanker, so the distribution system already exists, and can be supplied at prices that make the technology competitive with diesel – liquid air would be even cheaper to produce. A liquid air TRU would cost broadly the same as a diesel system to build but £1,200 per year less to operate, as well as being zero emission.

Liquid air or nitrogen production plants could be integrated with LNG import terminals to harness the waste cold given off during re-gasification. This approach reduces the electricity required to produce liquid air, and its carbon intensity, by two thirds. The LNG waste cold resource is vast: we estimate the cold given off by the Isle of Grain LNG terminal over the course of a year would be enough to fuel London's entire 7,600 strong bus fleet as liquid air 'heat hybrids' more than six times over.

Liquid air cold chains could be particularly effective in rapidly emerging economies such as India and China, which suffer appalling levels of local air pollution, and post-harvest food losses of up to 50%. On current trends, India may produce barely 60% of its own food by 2030, but if developing countries had the same level of cold chain capacity as do developed countries, they could save 200 million tonnes each year that currently goes to waste. Both India and China are investing furiously to expand their insufficient cold chains and may have to add over a million refrigerated vehicles by 2025 to meet demand, so they badly need a zero-emission alternative to diesel TRUs. At the same time, their LNG import capacity is expanding rapidly, raising the possibility of producing cheap, lower carbon liquid air or nitrogen to fuel a more sustainable cold chain. India's projected LNG imports of 60 million tonnes in 2022 could in principle produce enough liquid air to fuel over half a million zero-emission Dearman TRUs. In December, Dearman visited India to present its technology and the Cold Economy to the country's National Center for Cold Chain Development and Automotive Research Association.