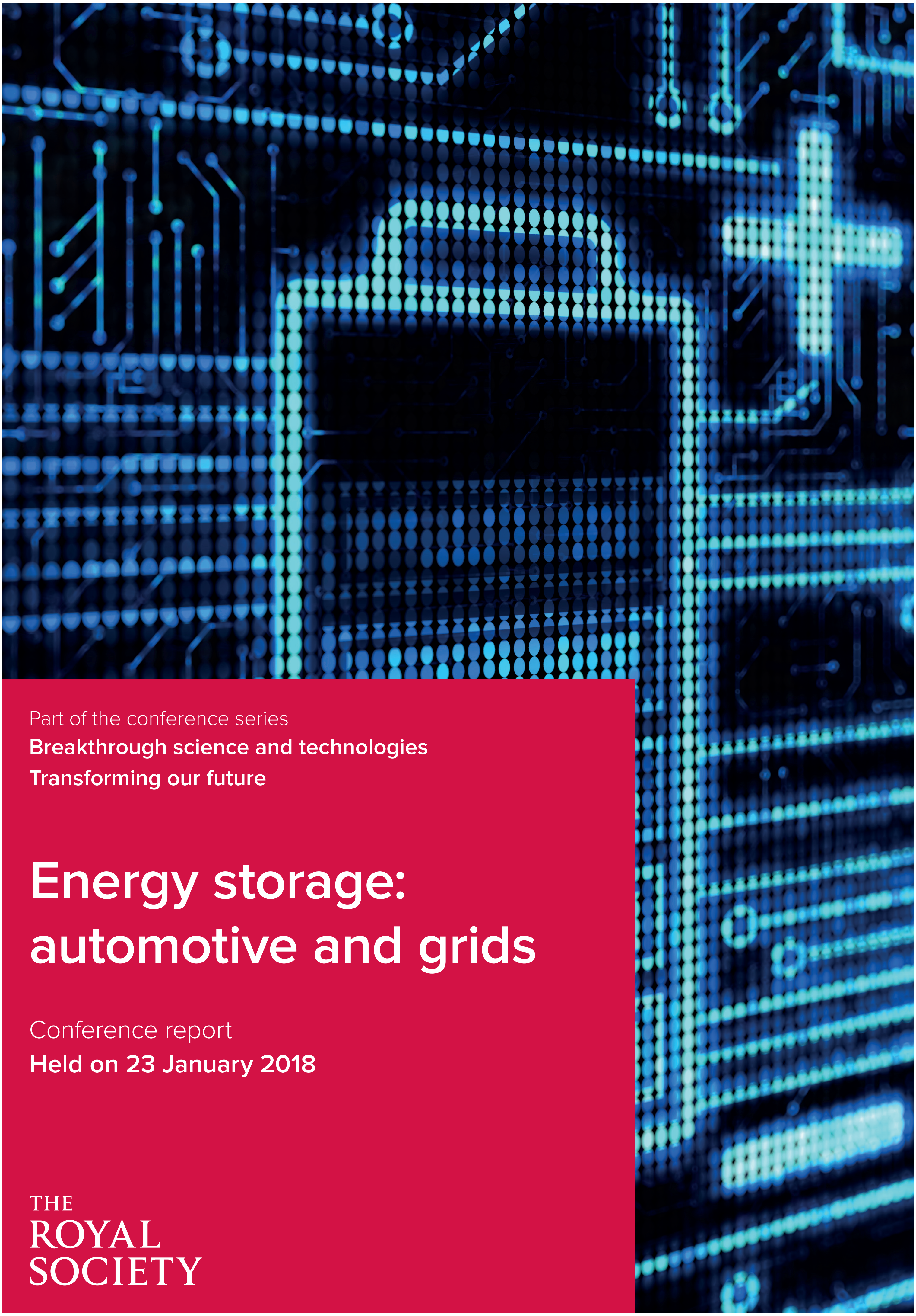


Part of the conference series

Breakthrough science and technologies
Transforming our future

Energy storage: automotive and grids

Conference report

Held on 23 January 2018

THE ROYAL SOCIETY

Introduction

On 23 January 2018, the Royal Society hosted a conference on the subject of energy storage. The conference brought together scientists, technologists and thought leaders from across academia, industry and government, to discuss the potential for energy storage systems to impact all aspects of our modern economy and society.

Presentations and discussions outlined the fundamental advances necessary to 'move the dial' in performance and cost, how breakthroughs are pulled through innovation into commercialisation, and the policy issues related to advancing energy storage for automotive and grid applications. Furthermore, challenges to the wider translation and adoption of this technology were highlighted.

This conference is part of a series organised by the Royal Society, entitled Breakthrough science and technologies: Transforming our future, which addresses the major scientific and technical challenges of the next decade. Each conference focuses on one technology and covers key issues including the current state of the UK industry sector, the future direction of research and the wider social and economic implications.

The conference series is organised through the Royal Society's Science and Industry programme, which demonstrates our commitment to integrate science and industry at the Society, to promote science and its value, build relationships and foster translation.

This report is not a verbatim record, but a summary of the discussions that took place during the day and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

Full versions of the presentations can be found on our website at: **royalsociety.org/energytof**

Executive summary

This conference covered the opportunities of energy storage technologies; their technical and economic potential; and the challenges that still need to be addressed for their continued development and deployment:

- For energy storage to boom, breakthroughs in the lab have to be more readily translated and the upfront costs to businesses have to go down.
- The energy storage challenge is closely paired with a desire for a greener energy strategy and decarbonisation of energy supplies.
- Changes in the UK's energy infrastructure will be required, as new storage technologies enable a decentralised energy network that is increasingly digitalised.
- Consequently, the energy market will need to adapt and adjust, as incremental changes will no longer be sufficient.
- Government policy has a big role to play in the progression of this technology, but it must not hinder innovation.
- The public acceptability of these changes to the energy network and market must also be considered.

Image
Professor Peter Bruce FRS, University of Oxford.

"Energy storage is one of the great challenges of our time, and we need breakthroughs in the fundamental science and engineering if we are going to enable transformation in energy storage technologies. We need to make sure those breakthroughs in the lab are translated into commercial products that improve performance and, critically, significantly reduce cost. But even that isn't enough, because one has to also consider the public acceptability of this new technology if increased market penetration is to be achieved."

Professor Peter Bruce FRS, University of Oxford

The opportunities for energy storage

Energy storage is the capturing of energy to be used on demand, and over the last 100 years, energy storage technology has advanced to meet many of society's energy requirements.

Energy storage offers a variety of ways to manage power supplies, contributing to more diverse energy infrastructures, the introduction of more environmentally friendly technologies (eg the replacement of petroleum powered vehicles with electric alternatives), and the reduced costs of utilities and products to consumers. The desire for more robust energy storage technology is paired closely with efforts to reduce the global impact of climate change and pollution by means of decarbonisation, and therefore has a social, environmental, political and economic impact.

Image
Joan MacNaughton CB, The Climate Group.

Energy policy approaches

Joan MacNaughton CB, of The Climate Group, discussed policy and market approaches to the energy transition, focusing on the three pillars of decarbonisation, decentralisation and digitisation.

Some notable action taken by governments and companies include:

- the Paris Agreement, established to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to hold it at 1.5°C[1];
- the Under2 coalition, a group of governments from across the world committed to keeping the global temperature rise well below 2°C. The coalition is primarily driven by state, regional and provincial governments, and together represents almost 40% of the global economy[2];
- the RE100, launched by The Climate Group and Carbon Disclosure Project, a group of over 100 global companies that have committed to using 100% renewable energy to accelerate the scale-up of this energy source across the world[3]; and
- the EV100 group of companies, committed to accelerating the transition to electric vehicles (EVs) and making electric transport the new normal by 2030[4].

1. Adoption of the Paris Agreement FCCC/CP/2015/L.9/Rev.1, United Nations, 2015.
2. http://under2mou.org accessed February 2018.
3. https://www.theclimategroup.org/RE100 accessed February 2018.
4. https://www.theclimategroup.org/project/ev100 accessed February 2018.

MacNaughton noted that in many cases, a combined energy efficiency and renewable energy approach delivers clean energy outcomes at the lowest cost. The pursuit of new energy storage systems will continue to be intertwined with efforts to tackle climate change, and decarbonisation will shape their implementation. A number of current trends are indicating an increased role for energy storage systems:

- Based upon broad policy commitments and plans already announced by governments, it is expected that renewable-based electricity will lead the expansion in renewable energy use[5].
- The UK Government predicts that the share of electricity generated from renewables and nuclear will be 58% in 2020[6].
- The unsubsidised cost of solar power is predicted to fall below that of coal within a decade[7].
- There has been a 70% cost reduction in batteries from 2010 to 2016[6], although it is widely accepted that this price needs to be significantly reduced for growth in battery numbers to continue to increase.
- 40 – 70 million electric cars are predicted to be on the world's roads by 2025, reducing the pollution and health issues associated with combustion engines[8].

Critically, the introduction of new technologies and devices is changing the nature of the energy market – the way we think of the energy market may no longer be fit for purpose; government policy reform may be overtaken by change introduced by the market and service providers; and the central design and coordinated function of the energy market needs to be considered. Furthermore:

- Customers may need protection of their consumer rights earlier than they are offered it, and the form of this protection will change as the market changes and as digitisation becomes more engrained.
- Debates on energy price need to focus on quality, value and reliability.
- Incremental change in the energy market is no longer appropriate and the policy framework will need to change rapidly to take account of this.

One of the biggest challenges for digitisation will be how companies handle valuable consumer data. Consumers will want to know how their data is being used, whether a company is profiting from it, and if it is safe.

> "We're seeing the marketing of devices to help us manage our homes and our lives… that will change the whole nature of the electricity market, and… transform the way that the market operates."
>
> **Joan MacNaughton CB, The Climate Group**

5. Energy efficiency, OECD/IEA, 2017.
6. Updated energy and emissions projections, BEIS, 2017.
7. Bloomberg New Energy Finance, 2017.
8. Global EV Outlook, OECD/IEA, 2017.

Flexible energy systems

Dr Jorge Pikunic of Centrica Business Solutions discussed Centrica's move from centralised to distributed energy solutions. Growth in renewable energy generation, a greater availability of digital technology, and the shifting attitudes of energy users are all leading to changes in the energy market.

- Technology advances impacting the energy market include connected and smart devices, renewable energy such as solar, and energy storage.
- There has been a growth in the market for flexible power. More flexibility in the energy system is needed to manage the intermittency of renewables. That need for flexibility can be addressed by demand response, flexible generation, and energy storage.
- There is a trend for energy generation being located closer to the customer, eg micro-grids. Energy generated on-site can also be shared with the grid.
- Energy storage has the potential to play a big role in this transition to renewables and distributed local systems, mitigating the costs that will be incurred. However, cost will be critical in determining the rate of adoption of energy storage systems.

Pikunic gave examples of projects involving Centrica that demonstrate the potential for distributed energy solutions:

- The 49MW Roosecote battery facility in Cumbria, designed to provide frequency response, can respond to grid fluctuations in under 1 second.
- The installation of one of the largest commercial batteries in the UK, in Gateshead. This complements the district energy centre and can respond to grid fluctuations.
- The Cornwall local energy market project – a 3 year smart grid trial encouraging customers to buy and sell their flexibility to the local distribution network operator.

Energy storage can help overcome the challenges of transitioning to a greener energy system (eg tackling grid constraints, or increasing the ability of local networks to cope with higher numbers of EVs). However, energy storage struggles to be competitive in markets for flexible power today, with a few exceptions. As technology advances and costs fall, energy storage may become competitive in additional markets for flexible power, at which point the opportunity could vastly expand. But there is still some way to go before this vision becomes a reality.

> "When we talk to customers [about their energy requirements], they want to address specific needs such as improving their performance, increasing the resilience of their facilities or being fit for growth."
>
> **Dr Jorge Pikunic, Centrica Business Solutions**

Electric vehicles

Dr George Crabtree of the Argonne National Laboratory and University of Illinois at Chicago, discussed the development of batteries in EVs.

Although petroleum supplies 92% of transportation fuel in the US[9], and despite it taking 10 – 15 years to turn over a fleet of US cars, the plug in EV market is growing (the number of electric cars on the road globally hit 2 million in 2016).[8]

Crabtree noted that although battery costs have gone down, petroleum-based cars still remain cheaper, easier to charge (ie load with fuel), and have much greater ranges. EVs can now be fully charged in anything from 45 minutes to 6 hours and last up to 200 miles. However, shorter charging times, while desirable, can cause damage to the battery and reduce its working lifetime. More affordable and higher performing batteries will represent a step change for energy storage systems and for EV deployment.

A combination of faster-charging batteries and a network of high capacity chargers across a region can:

- reduce the consumer's anxiety over how far they can comfortably drive;
- promote market penetration of EVs; and
- increase the total number of electric miles driven.

A primary challenge is the search for a non-destructive way to test a battery's health, allowing developers to find out what charging protocols cause damage so that they can be avoided. A second challenge is the recycling of lithium ion batteries, which will help to protect the environment, lower battery costs and conserve critical materials.

Professor Peter Littlewood FRS, Professor of Physics at the University of Chicago and Executive Chair of the newly formed Faraday Institution in the UK, explained that whilst electricity storage is the key for the further electrification of the economy, the technology is still immature. There is an imminent transition in the automotive sector coming, and research needs to be aligned with national policy so that technological innovation can attract funding to the UK. The location of car manufacturers of the future will likely be next to battery manufacturers, therefore the UK car industry needs to be offered this manufacturing capability.

Crabtree explained that the development of EV batteries also impacts the stationary storage market, and has influenced the development of large scale batteries that supplement the grid. Electrification can help drive economic development and leadership in a global and increasingly competitive transportation industry.

> "Lithium ion batteries have to be recycled, especially if EVs are going to take off at the scale we expect them to."
>
> **Dr George Crabtree, Argonne National Laboratory and University of Illinois at Chicago**

Image
Organiser and session chair, Professor Clare Grey FRS, University of Cambridge.

9. https://www.eia.gov/energyexplained/?page=us_energy_home accessed February 2018.

The techno-economic potential of energy storage

The Faraday Institution

The Faraday Institution, the UK's independent institute for electrochemical energy storage science and technology, was established in 2017 as part of the UK's government's £246 million investment in battery technology anounced in its green paper *Industrial Strategy: building a Britain fit for the future*[10].

Richard Harrington MP, Parliamentary Under-Secretary (Department for Business, Energy and Industrial Strategy), noted that "large scale energy storage is a cornerstone to the Government's green energy strategy. Science in the UK needs to be up-scaled, so that the UK can stay ahead of the curve and that manufacturers, designers and inventors can be supported."

> "The core of the Faraday Battery Challenge is the power of collaboration. It shows that science, industry and government can work together."
>
> **Richard Harrington MP, Parliamentary Under-Secretary (Department for Business, Energy and Industrial Strategy)**

Founding Executive Chair Peter Littlewood explained that the goal of the Faraday Institution is the delivery of focused, substantial and managed research projects in areas of fundamental science and engineering, defined at a high level by industry and delivered by consortia of universities and businesses. It will deliver training to the next generation of battery scientists and engineers, who will go on to work in both academia and industry and be responsible for facilitating the transition of new technologies to market.

4 initial projects were announced at the conference, engaging 20 universities and over 25 industry partners, looking at:

- extending battery life;
- battery system modelling;
- battery recycling and reuse; and
- next generation solid state batteries.

These projects will support the enormous market pull to develop better battery technologies of the future, chosen because of the potential to carry out fundamental science that will enable advances in the technologies. The Faraday Institution's mission is to ensure the UK is well placed to take advantage of the future economic opportunities from this emerging technology.

> "There is a need to train the next generation of battery scientists and engineers and bring them quickly into an environment where they can contribute to Industry"
>
> **Professor Peter Littlewood FRS, University of Chicago, and The Faraday Institution**

10. Industrial Strategy: building a Britain fit for the future, BEIS, 2017.

Symbiotic technology

Professor Alexander Slocum, Massachusetts Institute of Technology, discussed how automation drives down the costs of renewables and energy storage, and how symbiotic relationships can help push forward these advances. For example:

- the cost of wind power generation can be lowered by 10% by manufacturing the pole from 30% less steel. If the poles were also assembled at the site of installation, this would result in a manufacturing footprint up to 50% smaller, and reduce both transport and labour costs;
- offshore wind farms can host fish farms. These farms are better built offshore (as opposed to near or on-shore where they are currently built due to lower costs), as the water is cleaner and thus fewer antibiotics are needed to keep farms healthy;
- minerals, such as cobalt, uranium, and vanadium, can be extracted from seawater using passive adsorption onto chelating polymers that are loaded into protected cages and attached to the base of offshore wind farms;
- intelligent land design can combine occupied land with new technology, eg by placing wind power turbines in the unused spaces of agricultural land;
- technology can be implemented to access previously unusable land. For example, unused south facing hillsides in California, USA, are ideal for solar panel deployment, but may require autonomous deployment and maintenance equipment in order to be best used; and
- pumped storage hydroelectricity, where water is pumped from a lower reservoir into an upper reservoir, is a cost-effective way to store energy. Integrated pumped hydro reverse osmosis systems are capable of supplying renewable energy, fresh water, and jobs for an entire region.

Slocum thought that part of the challenge scientists and innovators face in the implementation of energy systems are the social and political barriers. The cost of implementation is feasible, it just requires public and political support to enact.

> "With focus and commitment, virtually any industrialised country could, within a decade, move to 100% renewables."
>
> **Professor Alexander Slocum, Massachusetts Institute of Technology**

Chemical energy systems

Professor Ian Metcalfe, Newcastle University, explained that hydrocarbons can be an attractive option for the storage and release of chemical energy. Liquid hydrocarbons are easily transported and have very high energy densities, but unfortunately nature produces them only very slowly as oil, especially if this is compared to their current rate of utilisation.

Whilst the use of hydrocarbons is less environmentally friendly than green energy alternatives and is non-renewable in nature, it is feasible to have 'clean' hydrocarbon fuels. A cleaner fuel could incur a much lower carbon dioxide output compared to current hydrocarbon fuels and improve engine efficiencies. In actuality, it is not the fuel that is 'dirty' but the way in which we use it.

A commonly explored option is the hydrogenation of carbon dioxide to methanol, but this is not a particularly efficient chemical energy carrier.

Alternatively, a better option may be to 'shift' the waste heat from car exhausts from the vehicle to recover this energy at, for example, a hydrogenation facility. This could be performed by using a liquid organic hydrogen carrier such as methylcyclohexane that is dehydrogenated in an endothermic reaction on board the vehicle to produce toluene and hydrogen. Thus, the carrier system not only supplies hydrogen to the engine or fuel cell but also removes waste heat from the vehicle. The depleted hydrogen carrier, here toluene, is re-hydrogenated at a fixed hydrogenation facility and the waste heat is recovered.

In any case, a good chemical energy store or carrier cannot be designed without thinking about the entire production system and infrastructure needed to implement it.

Image
Professor Ian Metcalfe, Newcastle University.

Thermal energy systems

Dr Christos Markides, Imperial College London, explained the merits and limitations of thermal energy storage (TES). Heating and cooling accounts for a high proportion of final energy consumption in the UK[11]. The anticipated electrification of heat and transport in the UK will increase electricity consumption by a factor of 2 or more, and this presents a significant challenge.

TES relies on changes in internal energy of matter, and can be used to store heat, cold or electricity (the latter requiring an energy conversion step). Energy can be stored in hot water, steam, inorganics (eg salts), heat transfer fluids, organics (eg waxes) and by using direct or indirect heat exchange. TES is good for energy management but not for fast power management. Suitable large-scale electricity-storage technologies include:

- pump-hydro;
- compressed air;
- liquid air energy storage (LAES); and
- pump thermal energy storage (PTES).

Also mentioned was the Dearman Engine, which generates power from liquid nitrogen or air, without emissions of CO_2, NO_x or particulates.

TES can also be combined with current renewable energy systems such as solar and wind to improve performance and cost. In some scenarios it can make more sense to store energy as heat and then convert this to electricity, because it has a lower cost of storage. The economics and scalability of these systems are important to address, and a number of UK-led large-scale electricity storage technologies based on TES are currently under development and in trials.

> "Heating and cooling is very important, and in the context of the UK we need to remember that over 50% of the final consumption of energy is due to heating and cooling, and not electricity."
>
> **Dr Christos Markides, Imperial College London**

11. Energy consumption in the UK, BEIS, 2017.

The development and deployment of energy storage

Commercialisation of innovative technology

Dr Jeffrey Chamberlain of Volta Energy Technologies explained that whilst the development of energy storage technology may be relatively easy, the political and social issues that concern its deployment are trickier. Batteries and energy storage are key to a transition to sustainable energy systems, and one way to encourage development in this area is to leverage private capital to fund research.

A suite of technology is required for energy storage, including not just batteries but materials, new manufacturing processes, hardware and software (including AI and new business models). Therefore, commercialisation of this technology will require collaboration between corporations, venture capitalists and researchers. Volta, an energy storage technology company, approaches this challenge by bringing technologists and business experts together with business partners who will deliver the technology. It also works with national research departments to 'de-risk' and develop the technology, eg its research agreement with Argonne National Laboratory[12].

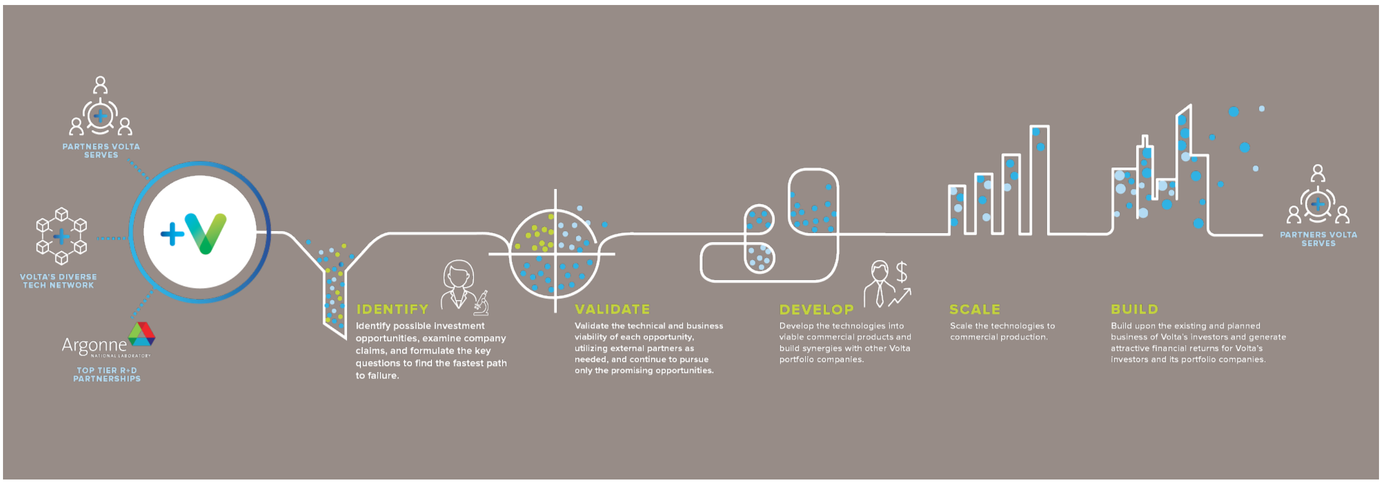
Federal investment in early-stage research faces a 'valley of death' (the phase where a new company moves from lead generation, the initial consumer interest in products, through to the first stages of product development, and during which many hurdles have to be overcome). Volta's business model aims to bridge this valley by connecting four critical elements that will accelerate development and deployment of promising energy storage technologies. These elements are end-users with insight into market needs; world-class R&D knowledge and facilities; technical experts coupled with business analysts; and length minded investors with patient capital.

By bridging the gap between early stage innovation and manufacturing and deployment, 'for good' motives can be coupled with 'for profit' motives.

> "We can leverage the motive of profit to enable science and technology to change the world"
>
> **Dr Jeffrey Chamberlain, Volta Energy Technologies**

FIGURE 1

Volta Energy Technologies' business model



12. https://plusvolta.com/about-us/ accessed February 2018.

The UK battery storage market

Dr Ben Irons, Aurora Energy Research, discussed how to 'unlock the £5bn investment' needed to establish new grid-scale battery technology in the UK. This investment is only going to emerge if the owners of that capital will be able to make an acceptable return on a risk-adjusted basis.

Energy storage generates revenue by moving power from low-priced to high-priced time periods. For example, batteries are charged when energy prices are low and discharged when energy prices are high, thus saving money. However, Irons argued that investment to build storage will occur when the present value of these anticipated revenues exceed the upfront and operational costs, which include not only the battery cells but other parts of the energy storage system that are currently fixed, such as connection and system balancing costs. Although battery costs are falling, they only represent a small percentage of the total cost of energy storage systems, and the costs of the other parts of the system are more challenging to reduce.

The revenue from batteries will also be determined by factors related to their operation and use, and it is important to bear in mind that:

- batteries are not 100% energy efficient, therefore energy is always lost;
- charging and discharging a battery is not instantaneous. This means peak buying and selling times can be missed;
- batteries degrade and lose their efficiency over time;
- the user is subject to imperfect foresight, ie they may not know the best time to sell;
- the rate of battery usage also affects profit return, eg a battery used intensively for 2 years will return a different profit to one used less intensively over a different period of time; and
- longer duration batteries can capture higher gross profits, but this benefit may not always be proportionate to the increased upfront costs.

Battery performance under different conditions is very complicated to predict. Ideally, batteries will have detectors to observe the impact of degradation throughout their lifetimes, ensuring they are used in the most effective way. This technology is set to be developed under the 'extending battery life' challenge set by the Faraday Institution.

Storage is key to making the investment case work for renewable energy, but to advance the energy storage market, progress is needed.

- Costs of energy storage systems need to be reduced in order to increase profits.
- Discount rates (the value of an investment over a long period of time) need to be decreased to improve investment prospects, as the returns are currently too low.
- Stable government policy is required.
- The value, and thus profitability, of energy storage will increase when it becomes more relied upon, eg when prices for wind and solar power fluctuate with the weather, energy storage technology will allow consumers to save money.

The importance of policy

Professor Laura Diaz Anadon of the University of Cambridge described the potential benefits that can be derived from policies designed to promote innovation in energy technologies. This innovation helps to meet societal goals that range from increased competitiveness and climate change mitigation, to energy, security and access.

Many of the energy technologies we use today (eg solar and nuclear power, solid state lighting, and hydrofracking) are established due to investment in R&D and market creation policies enacted by governments across the world. The long-term nature of innovation (ie the long diffusion times from invention to market), and the multiplicity of policy goals and actors involved in innovation, means that often a combination of policies is necessary.

Effective government policy can reduce the cost of innovating, increase the supply of knowledge through 'technology push' policies, and increase the payoff to innovators (ie increasing the demand for innovations) through 'market pull' policies.

Recent research provides new insights into how governments can make decisions on the allocation of finite budgets across the development of different energy technologies. To support these decisions, accounting for the inherent uncertainty in the innovation process as well as the interactions among technologies in the market place (some are complementary and some are substitutes) is important.

> "The opportunity for industry to benefit from new energy storage technology is enormous but industrial policy must be designed and communicated to benefit society if it is to last."
>
> **Professor Laura Diaz Anadon, University of Cambridge**

Anadon explained that:

- investments in energy storage R&D can result in the highest returns on investment in terms of welfare (measured in terms of increases in consumer and producer surplus);
- the more aggressively that climate targets are pursued, the more 'valuable' cheaper energy storage technology becomes;
- even small improvements to vehicle costs through advances in energy storage would have very positive impacts on consumers because of the size of the expenditures, their number in the market, and the rate at which they are replaced;
- most important inventions in the field of energy benefited from spill-overs from other industries or fields, suggesting that attracting researchers from different fields into storage efforts could yield improvements; and
- focusing on the funding gap in hardware development mid-way between basic research and commercialisation is essential for upscaling or demonstration projects to serve the public interest.

To establish more breakthroughs in and commercialisation of energy storage technology, Anadon argued that recent quantitative research on policy impacts suggest a few key ingredients:

- use a combination of 'technology push' and 'market pull' policy;
- ensure researchers and technology experts have autonomy and influence over funding decisions in organisations that fund or conduct research;
- incorporate a range of technology transfer mechanisms into research efforts (eg researcher mobility programs, licensing support, access to user facilities), ensuring basic and applied research are not separated; and
- provide policy consistency across electoral cycles (to attract and sustain private sector investment) and adjusting policy based on emerging information.

Energy market regulation

Chris Brown, Ofgem, explained the responsibilities of Ofgem as the UK's independent National Regulatory Authority and as an energy market regulator. As a regulator, Ofgem must ensure that the right markets are in place, service providers and customers are incentivised to operate in beneficial ways, and that the right framework exists for the system operator.

The wider adoption of EVs, the increased adoption of smart meters in homes and businesses, the decarbonisation of energy, and the increased digitisation of technology will all be coupled in the evolving future energy system. The challenge is to ensure that timely regulation is in place to help support this process.

For example, the introduction of EVs requires an understanding of how and when consumers will charge them. If everyone charges their car at home at the same time, this causes local network congestion and increasing peak demand, requiring significant network reinforcement and new generation plants. Smart charging helps avoid this by using new technology to provide information and control, coupled with pricing signals that reward consumers who seek out low demand/congestion periods for EV charging. Furthermore, vehicle-to-grid (V2G) technology offers the potential to let electricity flow from the vehicle back to the electric distribution network during times of need, which could help ease energy demands on the local grid and avoid additional reinforcement.

Ofgem has a number of initiatives in place to address these upcoming system transformations, and has published the 'smart systems and flexibility plan' that advises the UK Government on the need for flexible energy markets and how to remove barriers to smart technology, smarter homes and smarter businesses[13]. Regulation should not stand in the way of innovation, but it needs to ensure all consumers benefit from the energy transformation. This includes both today's and tomorrow's consumers, and encompasses those who are in a good place to seek and embrace innovation as well as those who are less well-off and vulnerable. In terms of the ownership of energy storage systems, there could be conflicts of interest for network companies (who are monopoly providers) to both own and operate such assets, in direct competition with independent storage providers and other sources of flexibility in an open transparent market. Regulation changes may be needed in this area to ensure a level playing field for all storage operators.

> "In partnership with BEIS, Ofgem's aim is to create a level playing field, so that energy storage can compete fairly with other forms of flexibility and more traditional energy storage systems."
>
> **Chris Brown, Ofgem**

13. Upgrading our energy system: smart systems and flexibility plan, Ofgem and BEIS, 2017.

Acknowledgements

Organisers

Professor Peter Bruce FRS, University of Oxford

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Dr Ralf Speth KBE FREng, Jaguar Land Rover

Professor Nigel Brandon OBE FREng, Imperial College London

Dr Ryan Bayliss, University of Oxford and The Faraday Institution

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Joan MacNaughton CB, The Climate Group

Dr Jorge Pikunic, Centrica Business Solutions

Dr George Crabtree, Argonne National Laboratory and University of Illinois at Chicago

Professor Peter Littlewood FRS, The University of Chicago and The Faraday Institution

Professor Alexander Slocum, Massachusetts Institute of Technology

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Dr Ben Irons, Aurora Energy Research

Chris Brown, Ofgem

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The Society's strategic priorities emphasise its commitment to the highest quality science, to curiosity-driven research, and to the development and use of science for the benefit of society. These priorities are:

- Promoting excellence in science
- Supporting international collaboration
- Demonstrating the importance of science to everyone

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