Grid Scale Energy Storage workshop

Report of workshop held on 18th January 2021

Summary

A virtual workshop was held on 18th January 2021 in order to:

- Gather insights into technical or integration challenges for grid scale storage (GSS)
- Establish priority areas for grid scale storage research
- Consider governance and policy needs for the future
- Establish potential areas for partnerships in this research, both for delivering high quality research and for realising the impacts and benefits.

Thirty-six delegates from the research and stakeholder community, many representing wider groups, participated in the workshop (attendee list is available as Annex 2). At the workshop participants considered the technical challenges associated with development of GSS and the need to integrate this into the infrastructure of the UK.

Background

The UK has committed to reaching Net Zero by 2050[1 2], in addition the UK government's ten point plan for green industrial revolution[3] has a strong focus on renewables and new energy technologies. The increasing reliance on intermittent renewables necessitates alternative and larger scale energy storage technologies. Since the nature of renewable energy generation can create seasonal disparities which must be resolved, this leads to a greater need for energy storage that is larger capacity and longer term duration than currently exists. The cost effective, efficient storage technologies will be a key factor in reaching the decarbonisation goals set out. These storage technologies will not exist in isolation but will need to be integrated with existing and future infrastructure. The aim of this workshop was to receive input on the following problem - given future potential in decarbonisation of energy generation, what can we do to resolve barriers to further progress in developing and integrating grid scale energy storage technologies?

For this workshop, and following interventions, certain areas were not considered within scope. These include fundamental research into battery technologies and the formation of chemical storage vectors (i.e. Hydrogen etc.) which are being considered elsewhere. However, for this activity the integration of such technologies at grid scale is within scope. Both short-term load balancing technologies and long-term inter-seasonal technologies are of interest.

[1] UK Gov, Policy paper - Energy white paper: Powering our net zero future (published Dec 2020)
[2] House of Commons briefing paper, Net zero in the UK (published Dec 2019)
[3] UK Gov, Policy paper - The Ten Point Plan for a Green Industrial Revolution (published Nov 2020)

The Workshop

The workshop brought together a balance of participants from academia and industry, with interests in various aspects of GSS. The sessions covered:

A. Technical challenges
B. Value of whole systems
C. Governance and policy
D. Relevant partnerships

Summary details of the sessions are given below.

Due to being a virtual workshop, attendees were also provided with the questions posed during the sessions as a separate document, through which thoughts not captured during the sessions could be provided. This template is available here as Annex 1. The attendees were divided into four virtual “rooms” to allow discussion within smaller groups

A. Technical Challenges

Cost-effective solutions are required for both inter-day and inter-seasonal storage of energy. A range of options will need to be considered at domestic, local/community and national system levels. What challenges should be prioritised in order to make progress in these areas and in the development of new disruptive technologies?
Given the range of potential technological solutions available/required, what specific challenges should we focus on to make this a reality?

B. Value of whole systems

Potential solutions need to be integrated into the wider energy system, which may create challenges, as well as opportunities. Different systems and sectors will need to co-operate to enable the UK to reach Net Zero by 2050 while ensuring equity for users.
What common barriers need to be addressed to facilitate the deployment and integration of different grid scale storage technologies and how can fundamental research provide the answers?

Following these two initial topics, we asked participants to prioritise areas they see as highest importance.

Main raised topics (outputs)

<u>New Technologies summary</u>

Several areas of new technologies were discussed during the workshop, while this list is not exhaustive, it covered;

- Compressed-air energy storage (CAES)
- Storage of heat/hydrogen/natural gas
- Heat pump, Pumped Heat Electrical Storage (PHES)
- Mechanical storage systems- consideration that mechanical and thermal systems are more challenging to scale up so more research may be needed here

Other topics of discussion while considering new technologies can be largely split into the following topics

Whole systems view

Many of the comments raised related to how the storage of energy at grid scale should be considered at a wider level, with a whole system approach

- The integration of storage directly with generation (e.g. wind power)
- Carbon footprint of storage should be considered, with Net Zero 2050 - the biggest challenge is decarbonising heating
- There is unlikely to be a single solution for all storage requirements so priority should be given to encouraging collaborative solutions
- Potential of energy storage as part of whole system (expanded on during later session on integration)
- Joined-up thinking is needed to tackle the challenge, we don't want to silo tech/ideas for specific applications

Modelling and forecasting

Modelling and forecasting of the energy demand was considered as part of the discussion.

- The prediction of demand, both in terms of seasonally, day/night, as well as future planning.
- Dealing with extreme events, either in supply or demand (Forecasting and optimisation tech)
- Practical implementation of control and scheduling - speed and reliability

Priority of technology

Other comments related to how technologies should be prioritised, and where focus should be considered first;

- Using roadmaps to determine timelines for "market readiness" for technologies, initial focus should be on short term, smaller scale but with planning for future (especially in terms of cost per cycle)
- The need to focus on fundamental requirements for energy storage rather than being led by today's commercial structures and energy trading arrangements

Integration and infrastructure summary

- Whole system approach, from materials for energy to looking at end use
- Integration of storage within the other infrastructure
- Repurposing existing infrastructure to support new technologies and reduce costs

Financial/Cost

Cost of developing, manufacturing technologies, as well as the storage costs over time- specifically for inter seasonal storage needs to be low to be economically viable and of use.

- What is the value of GSS to UK Plc (not just economic), such as environmental and social value, with other benefits such as reducing reliance on fossil fuels in rural communities.
- Need to better understand the cost of technologies - literature has a lot of incorrect or estimations which can make it harder to understand this.

Location

Location as a factor in energy storage at grid scale largely focussed on the question of if it is more appropriate for storage to be near energy generation vs storage near use.

- Selection of most appropriate storage technology with consideration of location, both for the energy generation, and use

- Most modelling scenarios for future energy storage requirements envisage some subsurface energy storage. There are uncertainties with understanding the locations, capacity and efficiency of subsurface storage volumes

Modelling and forecasting see also in technical challenges
- How do we predict needs of energy storage
- Prepare for extreme events in storage/demand
- Demand management alongside storage and generation - how can we better understand the interaction between these and therefore how balancing can be achieved more effectively

Collaborative/Partnerships summary

While discussing this topic the need for collaboration and partnerships in this research was highlighted, with specific emphasis on consideration of end users of the research and how this can impact many other areas (such as domestic use and town planning), and how research in individual areas fits into the grid-level issues of energy storage. However, for individual areas of energy storage research the range of partners (particularly international, and industrial) was very specific by area. The full comments are given in raw data as annex 3. Key points from this topic are below

- There is unlikely to be a single solution for all storage requirements so a strong focus should be on encouraging collaborative solutions.
- Co-ordination is needed across different energy vectors during scale up research.
- The UK's key features provide a place for the research to excel, islanded energy system with limited interconnection, a strong commitment to net-zero as shown by government policy and existing progress in reducing dependence on fossil fuels.

The outputs given above are the summary of the key points prioritised by the participants on the day, organised by topic. These represent the key areas for research needed in this space as well as work needed to reduce barriers to implementing such technologies in future. From the outputs on the day there is a wide range of need in this space, and while many of these problems can be met within EPSRC energy theme remit, and will be covered in a future call, some of the interdisciplinary areas will be outside of the scope of upcoming interventions, such as the financial costing, and social science aspects of technology adoption, as well as modelling and forecasting need.

The way forward

EPSRC are very grateful to have received a wealth of information particularly as it relates to

- The technical challenges faced by UK research in the grid scale energy storage space and awareness of barriers.
- The importance of considerations of integration into the wider system during development of new technologies
- Awareness of key areas for collaboration

These inputs will be used, along with other advice streams such as the Energy Programme Scientific Advisory Committee, to develop a business case for a call in the grid scale energy storage space

Not all areas in the workshop report will be able to be included in the forthcoming calls due to the limits of the budget and remit. However, they may form the basis of subsequent calls of strategic intervention and will be used as a basis of discussions with the other appropriate organisations for inclusion in other activities.

Detailed workshop output

The output from the last sessions of the workshop is attached in the annex 3 as further background information. Please bear in mind that this is the raw output from a series of facilitated sessions.

Annex 1. Exit Questionnaire

Grid Scale Energy Storage workshop
18th January 2021 09.30– 13.30
We are aware that in current circumstances of virtual working; connectivity issues, other commitments and discomfort with the technology can make it difficult to contribute ideas in this format. If you find there are comments or ideas you weren't able to contribute during the workshop, please use the following document to share these with us following the meeting. This isn't required or mandatory, but if there is anything you want us to know about the topics discussed during this workshop, the questions are listed below to comment against if helpful. Again, thank you for your participation in the workshop, the outcomes will be made publicly available on our website.

A. Technical Challenges
Cost-effective solutions are required for both inter-day and inter-seasonal storage of energy. A range of options will need to be considered at domestic, local/community and national system levels. What challenges should be prioritised in order to make progress in these areas and in the developments of new disruptive technologies?

B. Unlocking the Value of Systems
Potential solutions need to be integrated into the wider energy system, which may create challenges, as well as opportunities. Different systems and sectors will need to co-operate to enable the UK to reach Net Zero by 2050 while ensuring equity for users. How can storage deliver value at a systems level through the services it provides, and what business models can deliver this?

Prioritisation - choose concepts, either from technical challenges, or integration and infrastructure or a combination, that would be of highest priority for action in terms of importance and timeliness
Feel free to expand on any points, and consider barriers for either individual points, of common barriers that need addressing.

C. Governance and Planning
How can the scientific community work with industry to help inform policy maker decisions and help identify and guide the resolution of policy and regulatory issues?
What information is required in the short term and what will be required in the longer term?
What is required of our investments to generate this information and to make it available for relevant decision makers in future?

Who Questions
Who are the key **academic** disciplines and **industrial partners** that need to be engaged to achieve this? What will be required to draw all of this relevant experience in?

Who are the key **stakeholders** in deploying this and building on the outputs of our interventions? How do we ensure these outputs reach them and are built upon?

How should the UK position itself **Internationally** in this area and who should our key collaborators be worldwide? What USP do we offer these collaborators and what do we require of them?

Annex 2. Delegate List

UK Research and Innovation

Grid Scale Energy Storage Workshop

Venue: Virtual Meeting vis Zoom
Date of event: Monday 18 January 2021

Attendee List

Jenny	Baker	Swansea University
Edward	Barbour	Loughborough University
Neil	Bateman	UKRI EPSRC
Keith	Bell	University of Strathclyde
Laura	Brown	University of Newcastle
Solomon	Brown	University of Sheffield
Sue	Carter	UKRI EPSRC
Jennifer	Channell	UKRI EPSRC
Gerard	Davies	UKRI EPSRC
Miles	Davis	Faraday Institute
Yulong	Ding	University of Birmingham
Robert	Dryfe	University of Manchester
James	Fleming	UKRI EPSRC
Andrew	Forsyth	University of Manchester
Ahmed	Gailani	Teeside University
Seamus	Garvey	University of Nottingham
Dan	Gladwin	University of Sheffield
Amelia	Hallas-Potts	UKRI EPSRC
Edward	Hough	NERC (British Geological Survey)
David	Howey	University of Oxford
Edward	Jones	UKRI EPSRC
Amruta	Joshi	University of Birmingham
Nick	Kitchin	Cumulus Energy Storage
Matt	Lewis	Bangor University
Kang	Li	University of Leeds
Chloe	Lianos	BEIS (Science & Innovation- Strategy)
Christos	Markides	Imperial College London
William	McAllister	UKRI EPSRC
Judith	McCann	UKRI EPSRC

Dolly	Parkinson	UKRI EPSRC
Andrew	Pimm	University of Leeds
Jorn	Reniers	Brill Power
Clare	Richardson-Barlow	University of Leeds
Robert	Steinberger-Wilckens	University of Birmingham
Peter	Stevenson	GS - Yuasa
Murray	Thomson	Loughborough University
Sara	Walker	University of Newcastle
Wenbin	Zhang	University of Hertfordshire

Annex 3. Raw workshop outputs

A. New Technologies

Room 1 Session 1A

Life-cycle assessments of potential storage solutions
More work on ES OI (energy stored over invested)
Value and prioritise technologies according to their value to the whole energy system, instead of trying to solve problems with bits of the system such as PV farms or heading of houses
Ensuring there is a materials resource road map for energy storage - likely to be critical shortages
Roadmaps are excellent tools to focus the ‘market-readiness’ for a range of technologies. The UK could be more proactive as a research community in coming to consensus and showing pilot, demonstration and commercial trial of technologies
In my experience, Industry eg OEMs are looking at the ‘market’ options for their products - the markets for GSS are still rather short term with regard to service contracts which will preclude the investment required for GSS to be prominent - the Challenge of Business and Risk (and uncertainty) case would be a great one to help address this investment hurdle
We should have a specific physics-based approach to what technologies have the potential to both (a) achieve >10TWh (output capacity) and (b) <£2/kWh (or whatever the target
Reversible high-efficiency compressor/expander machines for CAES
Technologies for actively shaping caverns in salt to optimise capacity for CAES
Timescales of storage key so costs should also relate to cost per cycle and have a different range of targets for different timescales
Integrating energy storage directly with wind power generation
Keeping track of carbon footprint of use-phase of energy storage for range of operational profiles while integrating with grid
Network/system challenges: how to coordinate operation of storage for system benefits
Should review where we’ve already investigated to date and consider the learnings as a community - eg PHES was demonstrated at significant scale with significant support from EPSRC, ETI, BEIS and other funders but is now non-operational - viable? Not viable? Who decides?
Heat pumps will require all households to integrate a heated storage medium (usually hot water cylinders) need to make sure that alternative options eg phase change materials that are more efficient are examined since this storage is going to be implemented anyway - eg investment available
Net Zero 2050 - the biggest challenge is decarbonising heating. For achieving this, cost effective (not only CPEX but or so OPEX) cross seasonal storage technologies will have a very role. Thermochemical storage materials and thermochemical storage technology integration with grid is crucial
Producing (and using) meaningful measures of performance. For example CAES “efficiency” much misunderstood and “cost-per-kWh” is also much abused
There is unlikely to be a single solution for all storage requirements so priority should be given to encouraging collaborative solutions
A deep investigation into heat exchanger design and development to serve both “AACAES” and pumped-thermal. Specifically the use of additive manufacturing to revolutionise these and incorporation of multiple different pressure levels of “tubes” in shell-and-tube configurations
We need to focus on fundamental needs for storage rather than being led by today’s commercial structures and energy trading arrangements
Scaling-up - can different solutions work at scale to meet the energy system challenges, either distributed or large single facilities
Technologies for formation of caverns in hard rock (other than salt) and then sealing those

Room 2 - Session 1A

Need joined-up thinking to tackle the challenge, we don't want to silo tech/ideas for specific applications
Pence per kWh considerations and how this changes over the year/seasons - cost needs to be appropriate - low cost thermal storage
To scale-up need to reduce the uncertainty for industry - lots of tech out there - need more reporting and available data on the tech to create confidence
There are a number of technologies we know we can scale - need to understand how they integrate and how to connect physically at low cost without using lots of converters - mechanical and thermal systems more challenging to scale up so more research needed here - better integration of power electronics - relatively good understanding of this for batteries
Mechanical: cost, safety, market drivers (mostly high power low energy but need more diversity), more flexible mechanical storage is the goal but no one will invest if they aren't going to get the returns
Prediction is a technical challenge - what type of scale of storage do we need? Storage could be considered a failure to predict supply and demand - can we address this? Will the system be decentralised?
Demand profiles of today will not be demand profiles of tomorrow - need joined up thinking - thinking about trying to tackle today's problems might result in delivering a suboptimal solution - need to ensure market needs are aligned to the future
Integration of energy storage systems into grid network: how do we optimise the uplift transformers? Matching chemistry, AC and EDC requirements to reduced cost of integration
Demonstrator systems around the UK will be really useful for testing in real world scenarios - £10M schemes run by BEIS are really key to this
How can we remove our reliance on Li supply chain?
Location and storage: how can you make these work offshore? Does this require different tech? Integration with transport systems - control rather than technical
?? mechanical energy storage systems: high performance components - bespoke application focused components - room for improvement, need to be careful not to deconnect cost with technol???? machines - eg compressor and turbine combined into one device that can operate in both directions, pump thermal - positive displacement components, materials - de??????
Carbon reduction is the name of the game - can we look at carbon footprint across the tech portfolio with a view to choosing those with a lower impact? Linked to Paris accord need to know when to do this as well

Room 3 - Session 1A(1)

Q - Given the range of potential technological solutions available/required, what specific challenges should we focus on to make this a reality?
Does the diversity of individual inter-day energy demand mean that efficiencies can be had at the community scale?
Environmental impacts of large scale energy storage in the underground
Challenge: how to extract best value from integration across heat and electricity in order to better understand the options for storage vector, and scale or location on the network
I guess there could be a role for academics in informing potential future markets through quantifying potential UK capacity of different forms of storage (under different sets of assumptions)
Practical implementation of control and scheduling - speed and reliability
Storage in solution-mined caverns is not possible across the UK - are there viable alternatives for hydrogen/compressed air in reservoirs/aquifers?
Storage of heat/hydrogen - what are the effects on microbial populations and do they impact on reservoir efficiency?
Energy vs power for sizing
Determining the optimal service within the grid that each storage should provide.
Understanding behaviour of storage under abnormal conditions to ensure grid integrity

Good point by Kang around sensing technologies: optimal use of energy stores depends on knowing what the 'state of charge' is. Are we currently able to measure that well for all storage media?
Dealing with extreme events, either in supply or demand
There are different 'layers' to control: system level and 'device' level, both of which probably have room for improvement. (The latter to do with respecting constraints of the materials or media, but also understanding 'soft' constraints that might enhance system value albeit at a cost for materials' degradation)
Control and how that can balance user preference and network need
Selection of most appropriate storage technology and location
Understanding optimal use of the subsurface - eg capacity and location of solutions for Hydrogen, compressed air and natural gas storage
Lots of the system issues around use of storage are the same as general energy system operation and planning issues, which I think are under-explored in the current EPSRC portfolio, including lack of related CDT(s)

Room 4 - Session 1A

Technical Challenges
V2G for daily/short-term storage - challenge is to develop and demonstrate this at ever larger scales
Main challenge is seasonal storage and exploring the technologies capable of this and the cost benefits
How much storage is needed? With new hydro (Coire Glas - 30GWh) and proposed new battery (eg Intergen, 1.3GWh in Essex), this will soon escalate to very large capacity…. How much is enough and where is it needed/works best?
Who is best to deliver energy management across a range of technologies across the grid on a national scale?
(Dave H)
Very low (essentially zero) marginal cost of extra kWh stored is going to be key for longer duration storage
A clear understanding of the way markets, supply and demand might change over the next 30+ years is going to be key
Forecasting and optimisation tech
How to deal with the vast amount of batteries that will be available from EVs as they head towards end of life. This could be a useful tech for grid storage IF they can be rapidly diagnosed as good/bad, integrated, and controlled properly for grid
Flow batteries are still of interest. There are many issues to deal with from new chemistries to improved modelling, control to value for money and tech-economics
Medium term storage (eg flow batteries) with very low cost required to better shift demand effectively
Integration of short-term storage with chemical storage - to decrease costs of overall system but provide time-scale storage needed
The role of second life batteries in supporting behind the meter storage
Prerequisites for reasonable storage capacity:
    Reduce overall energy consumption (esp heat)
    Use energy weather forecasts
    Energy storage will then be 'only' necessary for forecast error ironing out - totally different scale

B. Integration and infrastructure

Room 1 Session 1B

Materials supply is going to be constrained during the drive to net zero
Yulong's point about what we are good at in the UK is really important - but also important is what do we have the physical resources for!

I endorse the comment made earlier about thermal storage in houses. We need to understand how storage at the LOAD and at the GENERATION ends of things can contribute to flexibility because these may be more cost-effective than mid-grid storage
I agree when you say "MAY" be more cost-effective than mid-grid storage" - we need to work out which is most cost-effective (rather than what today's industry likes to promote)
Barrier - no supply chain for GSS technologies in UK. Work with Innovate UK to marry up fundamental academic expertise in GSS with industrial organisations/companies from other fields eg automotive to show the overlaps and opportunities for Clean Growth eg DER, Faraday etc
Barrier: cost of system research - cost per system improvements, - identify supply chain efficiencies in the manufacturing processes; - grid connection/control innovation to limit the need for expensive reinforcement costs that need to be put in place with most GSS technologies
There is some fundamental stuff still to be done about trying to predict how effective "learning by doing" will be in reducing costs in some sectors. Battery tech has a huge lead for the relatively short-term storage (<2hrs) but could other tech take back some of that?
Circularity has been mentioned, mostly from materials perspective, we should also consider energy aspect from whole energy supply chain, looking at efficiency with respect to the primary energy sources
A massive issue for all of the thermo-mechanical systems is about how to value the fact they will typically serve for 60-100 years. Private finance is not compatible. National infrastructure views need to be developed
Put a price on carbon
More clarity on implementation plans at local/council level vs National strategies
Barrier - making the case for GSS Fundamental research - what is the value of GSS to UK Plc (not just economic) - include deferrance of investment in Grid Resilience for example and also social value - reducing reliance on fossil fuels in rural communities
Demonstrators are key to ensure that people are confident to invest
Storage has to be introduced to existing grid infrastructures. The lack of a separate classification of energy storage from generation has been a barrier for many years. Similar barriers should be avoided in future
One of the barriers is too many roadmaps and also technologies but we do not have infrastructure, and manufacture capabilities. The other barrier is lots of 'paper based' integration strategies do not take into account specific UK conditions (what we have already, what we could have with our means) over the time (eg 2050)
I echo that "put a price on carbon" comment. Everything becomes very simple if you just do this
The complexity of grid services is a huge barrier to technical process. It MAY be possible to operate our grids using a relatively simple "Real time pricing" model where price depends on location as well as time. If this model was implemented, storage prospects would rocket up!
This is perhaps a bit provocative but a major existential threat to all of the grid-scale storage prospects is the power of the oil-and-gas companies who are lobbying hard towards achieving flexibility via gas-peaker-plant with CCS
Co-ordination across scales - between local and national to achieve common objectives integrating between heat, power and transport demands - technically and institutionally
Security of data for digitalisation of energy storage integration with grid
The point about lead-times for big energy stores is also very important. Caverns can take ~4 years to form
Get more (true) whole systems thinking in decision making, and not just energy system
Something often said in energy storage conferences is that a key problem is that the party who provides the storage does not reap most of the benefits of that storage. This goes back to market structure
Financial barriers: I echo that "put a price on carbon comment. Everything becomes very simple if you just do that
Put a price on carbon

Complexity of the grid: this is perhaps a bit provocative but a major existential threat to all of the grid-scale storage prospects is the power of the oil-and-gas companies who are lobbying hard towards achieving flexibility via gas-peaker-plant with CCS

Room 2 - Session 1

We don't know what type of storage nor how much? Don't have the tools yet to downscale the climate models. Need to understand prediction better. Energy storage here for short and medium term

Need to better understand the cost of technologies - literature has a lot of incorrect or over egged estimates which makes it harder to understand this - Lazards producing realtime economic analysis

Lack of understanding how we value a system - resilience costs a lot of money

Need fundamental research into compressors, thermal energy storage systems which have high power - could have different applications - perception issue around some of the technologies which can be addressed through fundamental research

Geographical location - GSS locations currently chosen by investors based on cost but are there locations actually where the power is needed? Do we need batteries in houses or batteries which can serve a collection of houses? Operational costs - research can address how the system is assembled. How do you control the assets together? Currently market driven but should be driven by the best solution

Difficult to find out the answers to the geographical location question - appears to be a lack of strategy currently. Strategy to put reactive power where it is needed, reduce losses, remove constraints etc required - frames as a strategic way to help decarbonise the UK - thought leadership

Control within systems - potentially lack of research into these areas because they aren't considered exciting - "old school" control, systems and electrical engineering

Does the modelling take into account "spatial" requirements as well as temporal? Yes there are at least 3 models at ICL which are spatiotemporally aware - need to ensure link between technologies and how they are integrating with whole system which are of course sensitive to spatial and temporal requirements. How do we create the link to reduce uncertainty?

Disconnect between the technology and the modellers

Needs to be co-ordination between stakeholders for use and application. Lots going on in V2G

Disconnect on the stakeholder level - need integration of stakeholders to develop systems which integrate well

Policy and strategy is playing a role in slowing things down - how will the assets operate and who will own what? This could be preventing investors from moving - holding back for clarity. Well recognised modelling could be done around this

Legacy infrastructure systems in place which make it difficult eg the way people are charged for electricity. People operate within existing constraints

Pricing - lots to be done here

Room 3 - Session 1A

Things like leakage/"self-discharge" make optimal scheduling tricky

Inter-seasonal and inter-day storage: can we better understand the interaction between these?

Inter-seasonal - geothermal, how can we improve economic performance to make this "cost effective"

Thermal storage need could be improved if we improve the efficiency of the overall heating system, so it is key to think whole systems

Policy/market: how can the market incentivise storage, who bears the cost of installation and O&M and who benefits from the service that storage will end up providing

The main characteristics of interest from a system operation point of view are maximum charge/discharge rates (and control of charging/discharging) and energy capacity. However,

capacity degradation also of interest. Are these are easily characterised for every technology?
Most modelling scenarios for future energy storage requirements envisage some subsurface energy storage. There are uncertainties with understanding the locations, capacity and efficiency of subsurface storage volumes
Integration of storage within the other infrastructure (Kang's point)
Whose responsibility is it to estimate potential storage capacity for different media?
The scaling of optimisation is tricky. If, for example, we might attempt to optimally use every household's energy store, an opti

Room 3 - Session 1

How can we control a multiplicity of storage technologies rapidly and reliably on a massive scale
How do we demonstrate concepts practically at scale?
How to take advantage of industrial clusters, and optimal storage systems for different regions of th
Technical co-operation modelling needed, in order to understand trade offs
Back to the earlier points about models of the different technologies, methods for optimal utilisation, forecasting of need, and the ways needs are articulated in markets/commercial structures
Thinking of developing a hydrogen economy to help decarbonise industrial clusters - if H is produced by steam methane reformation, this will need to be done in tandem with Carbon Capture and Storage. Do we have options for rH-storage and CO2 storage in the right places?
Economic modelling of financial mechanisms for co-operation
Regulatory barriers - gas and electricity separately regulated, heat weakly regulated, what would a joined regulatory approach look like? Perhaps an IGov type project for a 2050 target
It seems to me that, while academia can be good at developing different optimisation or forecasting methods, useful academic engagement in the development of business models or regulatory and commercial frameworks is a bit thin at the moment. To be fair, it is difficult: it depends on a lot of 'tacit' knowledge and inter-disciplinary working
Thermal energy storage development/deployment can unlock various aspects of grid-scale storage
Technical performance response to charge/discharge cycles
System appraisals need good data on cape x and opex and the things on which they depend for different storage media
Understanding through life costs of storage. Exploring market concepts for storage to provide different grid support services - local and
Who owns the storage, operates the storage, provides price signals to the storage, gets revenue from the storage - economic questions but also some key social science issues around behaviours/drivers/needs of these different stakeholders
We currently have a poor understanding of energy storage options in the offshore and links to energy demand onshore
Demand management along side storage and generation - how can we better understand the interaction between these and therefore how balancing can be achieved more effectively
Repurposing existing infrastructure to support ES and reduce costs
I think there can be value in having quite simple, approximate models of different storage media to allow you to test how different market structures might work in terms of utilisation of different facilities and investment in making them available in future. How simple a model is simple enough but not too simple?
Barrier: lack of co-ordination across vectors, solution to look at storage within wider system models, to see their value within an integrated system

Room 4 - Session 1B

Unlocking the Value of Systems

Exploring cost sensitivities by consumers… eg cost for grid electricity to home, or for powering ir source heat pump… but are they willing to pay 3 x more for same electricity at motorway fast charger for their car?
Agree with Robert.. need to investigate how energy management across different storage technologies and scales can/should be managed and by whom
We seem to completely forget the input from local solar thermal that will be able to support the heating markets; large scale solar thermal storage is an established technology. Don't get me started on 'no sun in the UK'… the largest projects are in Denmark
Co-ordination across different energy vectors - (eg flow batteries + electrolysis for hydrogen for heating). This will need granularity in terms of use-cases
Integration of other sectors - storage industrial process heat
A barrier is the cost review cycle within electricity industry… should a longer term regulatory cycle be considered?
Integrating different storage technologies according to their individual merits and managing their interfaces
Time co-ordination of auctions from different markets to allow storage revenue optimisation in advance. For example, Fast frequency response or other balancing services with Capacity market auctions
The need for data from current grid-scale techs to inform integration scenarios and modelling
Understanding the intersection between storage technology physical constraints (like efficiency, temperature, degradation) vs the market opportunity (eg price spreads and operation under imperfect forecasts) will be interesting. For example you would not despatch storage if the cost of doing so was lower than the cost of degradation associated with a particular cycle. And for some tech the cost of degradation is a moving target which depends on operating conditions
Common barriers: Need for open energy data. Energy data is notoriously difficult to access. Simple example: not even each tech installed has a unique ID! This is a huge problem
Need better modelling tools for electrochemical devices. Within Faraday Institution the modelling project has developed a very nice open source battery modelling tool but this is still at a single cell level and mainly Li-on. Would be great to see work like this happening for system level, for other tech like flow batteries, sodium-ion (more suited for grid)

Prioritisation

Participants were asked to consider points raised during sections A and B, and prioritise which points were most important from previously discussed. While several rooms chose only a couple of key areas, for those which chose many more options, they were asked to vote which of them is most important -in the notes, these votes are shown with*.

Room 1 Session 1C - Prioritisation

The policy-market-technology nexus is hugely important. A joint ESRC-EPSRC thing?
Demonstrators that both give some experience of the large-scale and also provide opportunity to explore the small-scale (eg CAES test-bed that combines a large-scale working plant with the resource for smaller-scale stuff to test alongside)
Admitting blatant self-interest…. Integrating storage with offshore wind power!
Access to the time-series data that underpins all of the decision-making in energy policy and the associated assumptions about costs (maybe this is not EPSRC)
Simultaneous optimisation of cost-effective and low carbon footprint energy storage operational profiles for different applications for grid services
The location of storage (where it fits) within the grid has big cost implications for grid upgrade, again affecting the value of different types of storage
A clear understanding of volumes of storage required at each timescale (seconds to months)
Cost effective medium to long term storage technologies providing multi-vector services, and also can provide services for short term grid needs
Development of cost-effective scale-up methods of thermal energy storage materials manufacture and understanding the underlying physics

Understanding the materials supply constraints and then focussing funding on technologies that will avoid this
Systems modelling to indicate areas where storage is necessary over DSR or over capacity
Could “real-time pricing” be explored as a mechanism
Time series data that someone mentioned is useful, BUT demand profiles will change
Thermochemical storage using eg iron/iron oxide paris for medium and long term storage, integration with multi-vector grids and cross sector coupling

Room 2 - Session 1, Prioritisation

How do we make the system profitable?
Predicting supply and demand - linking climate modelling and behavioural scientists
Control dispatch - how to optimise? How do policies and markets relate to this?
Ensuring thermomechanical technology performance continues - UK is a world leader
Technology scale-up scoping - define costs, power, energy
Location - make this more strategic, where are the services needed?
Joining up thinking - people need to be working together to develop integrated solutions and systems eg linking energy and transport systems

Room 2 - Session 2 - Prioritisation

3-4 year funding which brings in partners (seek match funding) to understand the real-world functionality of the tech - may be some tech that needs further development first
Technology scale-up scoping - define costs, power, energy
Infrastructure requirements change between lab scale and demonstrator scale - sharing of knowledge but also equipment between academia and industry
Joining up thinking - people need to be working together to develop integrated solutions and systems eg linking energy and transport systems
Multidisciplinary approach - bring in team members from different disciplines
How do we make the system profitable?
Control dispatch - how to optimise? How do policies and markets relate to this?
Predicting supply and demand - linking climate modelling and behavioural scientists
Ensuring thermomechanical technology performance continues - UK is a world leader
Location - make this more strategic, where are the services needed?
Modelling needs to be open - black box will not allow us to scrutinise
Need to be able to explore uncertainties in models
Use existing modelling and data and introducing some sensitivity testing to test assumptions - integrated projects needed

Room 3 - Session 1C, Prioritisation

Business models or what would be the ‘right’ regulatory and commercial framework(s) for different forms of storage. However, evaluation of options depends on access to adequate models (physical models and optimisation approaches) and data. Thus, the provision of adequate models might be seen as a key contribution from engineering and physical sciences
Link between storage options in the subsurface and what we expect the energy system will need in terms of demand - and then on to spatial locations in the subsurface
Prioritisation difficult for such an integrated problem. Need to consider how models will be used to understand whether they are adequate
System view of value of storage, particularly in more integrated system storage view of performance/effectiveness regarding charge/discharge, leakage, sensing SoC
Is every storage medium that might be of value to the UK equally well-developed in terms of efficiency of the technology? There’s been a lot of work on batteries, but rather less in terms of ‘sub-surface’ storage, whether for heat or different gases, for example?

Do we have a good understanding of the material and life-time emissions impacts of different storage media, and do different economic and commercial models take those factors adequately knot account?
Whole life cycle approach to storage evaluation, alongside the rest of the energy system

Room 3 - Session 2A

Q - Model of storage media
Cost models
Models for different time scales ***
Potential for reservoir/porous media storage - capacity and location *
Characterisation of degradation of storage capacity
The interval coupled optimisation of large system under uncertainty ***
Operational parameters for compressed air/hydrogen storage in solution-mined caverns: engineering barriers *
System evolution over time: aquifer thermal energy storage
Q - Systems models - optimisation - forecasting
Diversity in storage response to need, based on model of control methods
Multi-vector system models
Operation/co-ordination of shared storage systems
Forecasting of demand for energy at different time horizons, especially a few minutes out to a day ahead *
Operational models linked to performance, safety *
Forecasting demand for inter-seasonal storage under climate uncertainty ***
Highly decentralised markets versus high centralised *
Q - Business models/regulation
Different contracting methods for storage, eg ‘cap and floor’
Storage as generation or demand response?
Speed of service and duration of service
Integration of CO2 storage and hydrogen production/storage
Integration of different markets for use of H2. (Once manufactured, can be stored but then used in transport, or industrial heat or industrial feedstock, or in electricity production *
Signals to investment vs efficient operation *
Q - Demonstration
Behaviour under normal and extreme conditions/resilience ******

Room 4 - Session 1C

Management of intersectoral energy exchange across different energy vectors and/or markets:

- P2G, P2H etc
- Storage for grid support
- Storage for de-risking energy supply contracts
- Forecast of energy and power flows to optimise storage levels and capacities

- not only modelling tools but more management, incl economic aspects
We have talked about modelling and markets - all good, and study of the longer term economics - again all good, but also lifecycle analysis and markets for recycling products, and/or multiple use of assets (ie EVs used for large scale V2G grid scale storage) need to be addressed
I think a similar workshop but including Ofgem, Nat Grid etc would be very useful
Unlocking value by developing new models (in the same vein as eg pybamm for faraday institution MSM) that capture the essential physics of storage (eg flow batteries) to a high enough fidelity but are open source and reasonably fast and therefore can be used for design optimisation and techno-economic studies

Partnerships

Room 1 Session 2C(1)

Don't look too much to the existing engineering multi-nationals for insight into the future directions. In an ideal world, the oil-and-gas companies would be good stakeholders but this would be "turkeys voting for Christmas"
Need interdisciplinary research - experts from different fields and people to work across disciplines Energy Futures (Social Science)
ESRC/economists
IUK, knowledge transfer
Had engagement with breweries on waste heat - they are all fighting to get net zero
Newport brewery second biggest energy user in south Wales!
There is scope to make the offshore wind farm operators very major stakeholders by expecting them to solve some of the flexibility challenge - and of course allowing them to benefit from that
Again large energy users, TATA foundation industry eg metal making/shaping, cement, glass and chemical
Who are the key stakeholders in deploying this and building on the outputs of our inventions? How do we ensure these outputs reach them and are built upon?
IRENA has been active and we did a report with the on TES published in December 2020
A proper definition of "net zero" would be really useful. Many parties conveniently interpret this to being net zero consumption of electricity and burning nothing but this is not "honest zero"
Does "Mission Innovation" have some role to play in shaping EPSRC research and vice-versa?
SMEs close interactions to be encouraged - they are more deeply involved from what I have seen
Existing utilities obviously should be stakeholders
Big energy users TATA in case of Swansea. Tata steel have a lot of waste heat and a lot of energy demand we are working how we can balance the two
Major Energy Users Council would capture Tata etc
Energy UK would also be a good partner especially now with Emma Pinchbeck leading them
Ofgem and BEIS
Local councils
Committee on Climate Change (hopefully goes without saying but I'll say it anyway 😊
Companies of all sizes need to see a product at some stage. UK companies need to increase the time and cost horizons or be supported by government
Infrastructure for EVs will show up weak grids - eg mid Wales - storage can support this and could be lower capital cost than reinforced grid in some circumstances
How should the UK position itself internationally in this area and who should our key collaborators be worldwide? What USP do we offer these collaborators and what do we require of them?
Work with the best in individual areas, eg CAES with China, TES with Germans
India with sodium ion they have looked strategically at their lack of Lithium reserves and are exploring this at pace
Note that the poor countries are (inadvertent) stakeholders here. The EPSRC attention should not be focused purely on "UK Net Zero". Possibly the UK could achieve far more by helping eg the Philippines to become Net Zero
There is strong reticence in Japan for UK research collaboration with Chinese entities. IP protection will become increasingly important
Medium and long terms storage for renewables with North Europe, Canada and possibly Australian
Work with US to help them with ESI as at the moment they are focussed on Power only
Canada are doing good things with Subsurface energy storage and exploration - Iceland and Scandinavia too
CESI are involved with both IEA ISGAIN and they are excellent groups of expertise
Point should be made to government that there's a risk that RD&D will migrate to markets that value storage

Room 2 - Session 2D

Q - Who are the key academic disciplines and industrial partners………
Control, systems and electrical engineering
Link with academics involved in decarbonising heating
Social and behavioural scientists
Economists
Business school - people looking at supply chain, cradle to grave tech
Energy Systems Catapult
Supergen Hubs
SPF - climate resilience
Fluence - unicorn businesses
Tech providers (DC + AC)
System integrators eg fluence distributers eg national grid
Generators
Aggregaters (combine assets together) eg Octopus Energy
Traders
Gas networks
Transport operators
Electricity storage network
Energy Storage CDT
Faraday Institution (FBC)
Driving the Electric Revolution
Include them in the governance
Would be useful to have more flexibility in the initial years to set strategic direction
"Champions" can be useful but are not tech agnostic so can push their agenda - they need to be neutral
Q - Who are the key stakeholders in deploying this and building on the outputs……..
Energy generators
End users
Transmission distribution of the energy
Investors - long pay back times
General public
Government
Regulators
UKCP18 - 2 way interaction and whether data is useful for future
UK PLC - certain amount of sovereign capability
Needs Government investment £Bn demonstrators to prove the technology
Q - How should the UK position itself internationally in this area……..
COP26
Battery manufacturing expertise and production capacity (needs Government policy to back it)
Can the tech be applied overseas through UK aid? Yes - supporting high tech businesses to provide overseas aid and solutions
IEEE committee on energy storage
????? - potential KE in stability, interseasonal, shifting from solar - CRC centres eg Blue economy ce?????? Different challenges)
??????
????UK leader in thermomechanical tech - systems do not yet exist - this tech will serve medium term needs
UK expertise in batteries
UK world leader in disaster relief - establishing electricity after flooding?
UK perceived as market leader - how we evolve tech and move away from state managed assets
UK risks isolation through not engaging in international collaboration

Room 3 - Session 2C

Q - who are the key academic disciplines and industrial partners…..
Should try to complement existing programmes, eg UKERC
Grid operators, distribution companies, equipment manufacturers
Mathematicians
Similar to earlier Q on IPL which companies will be prepared to put money in to some research and on what terms?
Existing storage operators (eg pumped storage)
Network operators
Integrated projects
Gas storage companies
Cavern design consultancies
Social scientists - public perception
Engineering and Business
Reservoir geoscience
In respect of the models of storage media: the chemists, physicists, geologists, engineers and data scientists to make and validate models
For system models, operations researchers and energy system modellers
For business modellers, etc, energy system modellers, economists, social scientists
Energy modellers - mechanical eng, electrical eng, mathematicians, chemical eng, geology
Mining industry
Requirement: draw experience in through extensive dialogue and allow time for discipline language development
Need industry and regulator collaboration in order to design and carry out demonstration
Major commercial developers of buildings
Q - Who are the key stakeholders in deploying this and building on the outputs……….
OFGEN
Storage owners
Control system manufacturers
National Grid ESO
CCC
Energy network owners
Energy suppliers/retailers/aggregators
Electricity generation developers
Manufacturers of energy conversion equipment
BEIS
Environment Agency/DEFRA
Coal Authority
Flexible funding that enables KT and embedding knowledge/secondments
Outputs can reach them through trade associations, professional body networks, catapults, KTNs
Energy aggregators
Our USP might be that we have an islanded energy system (with limited interconnection capacity), a strong commitment to net-zero, and have already made progress in reducing dependency on fossil fuels (that can be easily stored), but are now facing the more difficult part as we decarbonise heat and transport. In other words, our USP is that we really have to get this right so are motivated to play seriously!
Hydrogen production companies
Q - How should the UK position itself internationally in this area…………………
NREL
Nanyang Technological University Singapore
Position: leaders in H2 storage
NTNU (Norwegian National Technical University)
European Energy Research Alliance

For colder northern European partners we can learn from their approaches to inter-seasonal storage
USP in terms of energy storage worldwide is that so many different types of ES are possible in the UK, and are carried out on commercial scales already
European Network on
Chinese Energy Storage Alliance
One challenge we face is the relative fragmentation of the energy sector (something that we want in order to foster competition
ENeRG: European network for Research in Geo_Energy
Small island grid with large wind asse
Partner with regions committing to net-zero targets
Export potential for renewables underpinned by energy stor……

Room 4 - Session 2C

Who are the key academic disciplines……
Engineering - power electronics, chemical eng/chemists, civil (infrastructure), construction companies (eg new housing/commercial developments), local authorities (planners etc)
Whole system modellers with input from everyone (!!) else
Diverse disciplines: Engineers, energy economics, data sci and social sci people.
DNOs/DSOs/BEIS involvement is needed with OFGEM
OFGEM and National Grid
Energy policy people
Energy economics people
Power systems people
Macro-energy systems
Other utilities/regulators (gas, water)
Forecasting and ML folks
Energy storage tech suppliers (eg battery companies, novel tech eg highview, etc, etc)
System integrators and asset optimisers
Who are the key stakeholders in deploying this and building on the outputs………….
Key players: energy service providers (balancing services) - not fully developed yet, but emerging with rising levels of renewable power on the grid
Local authorities, LEPs, transport companies (road/rail/aero/sea), finance/insurance industries
The various publics that need to interact with them - how does storage fit in with their lives?
The current regulatory system encourages third-p[arty investors to be the key stakeholder rather than a utility or network operator
Technology developers - who would perhaps want to use any new tools we develop (eg models)
How should the UK position itself Internationally in this area……..
NREL in the USA (and possible other national labs in the US) - already good links with Faraday Institution
I think UK is seen internationally as a comparative leader in terms of grid decarbonisation in the last 10 years. Good to push that! And think about learnings and next steps/next challenges
Can UK develop ‘export’ market for renewables, via P2G or other form of ‘storage’?
UK seen as a ‘good market’ for energy storage at present, with easily understood (though complicated) markets to operate in
Decarbonisation is a world wide concern hence knowledge should be exported to developing countries also. Second life batteries for instance can help stabilise the electricity network there
Australia - seems to have very different market structures to Europe, so an interesting comparison case. Plus very different climate!! Organisations? Not sure - maybe universities, CSIRO