



## **UKERC ENERGY RESEARCH LANDSCAPE: Energy Storage**

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Prepared by Alan Ruddell, STFC Rutherford Appleton Laboratory

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## 1. Overview

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### Characterisation of the Field

Energy storage can be divided into several broad categories, electrical, thermal and fuel. Electrical energy and thermal energy are usually generated from energy fuel on demand by scheduling generators, however electrical energy storage may be used to increase efficiency. The increasing use of renewable energy sources, where availability may not coincide with demand, increases the need for electrical and thermal storage.

The scope of this Landscape is the storage of electrical energy, where the storage input and output are electrical power (or to use the commonly-used term electricity). This Landscape does not include the storage of thermal energy; the storage of fossil fuels including gas, coal and oil; or the storage of other commodities used in electrical power generation such as uranium. Carbon Capture and Storage (CCS) is covered in the UKERC CO<sub>2</sub> Capture and Storage Landscape, and hydrogen storage is described in the UKERC Hydrogen Landscape.

Technologies used in electrical energy storage are covered, within the broad categories of chemical, mechanical, electrical and thermal technologies.

Electrical energy storage is an enabling technology at various scales, permitting a) the management of intermittency in large scale power generation; b) transportation using electric vehicles; and c) portable electronic applications.

Interest is increasing in grid-scale electrical energy storage, and investigations and reports have recently been completed in the UK and Europe. The Energy Research Partnership published a report describing how new energy storage could help meet the challenges that the UK's energy system will face in the transition to low-carbon over the next

twenty years<sup>1</sup>. The Carbon Trust commissioned a study to address some of the key questions in relation to the future role of electricity storage in the UK<sup>2</sup>. The Low Carbon Innovation Group produced a Technology Innovation needs Assessment (TINA) for electricity networks and storage<sup>3</sup>. The European Commission has published a working paper on the future role and challenges of energy storage<sup>4</sup>. These reports highlight the needs and benefits of electricity storage in future low-carbon electricity systems and the technology developments required.

Funding in the UK for research and development of storage systems has increased in recent years.

In January 2009 EPSRC's grant portfolio in the Energy Programme included 15 grants (3.4% of the energy programme), of total value £8M (2.6% of the Energy programme) in this area. In 2011 EPSRC's [Energy storage grant portfolio](#) remained at a similar level. Noting that the UK is currently world-leading in some niche areas of energy storage such as lithium battery and supercapacitor research but less strong in others, EPSRC identified storage as a priority area. In September 2013, EPSRC support for the energy storage topic includes 23 grants, with total grant

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<sup>1</sup> Energy Research Partnership: [The Future Role of Energy Storage in the UK](#), June 2011

<sup>2</sup> Report for the Carbon Trust: [Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future](#), Imperial College, June 2012

<sup>3</sup> Low Carbon Innovation Group: [Electricity Networks and Storage Technology Innovation Needs Assessment](#), August 2012

<sup>4</sup> European Commission DG for Energy: [The future role and challenges of Energy Storage](#), January 2013

value £37.1M, although the proportion assigned to storage is less than the total value.

Grid-scale energy storage was identified as one of the 'eight great technologies' to drive UK growth in the UK Government's Autumn Statement 2012. In response to EPSRC's [Capital for Great Technologies Call](#), grid-scale energy storage received an [EPSRC Capital Grant of £30 million](#), with capital funding provided to 17 Universities for 5 projects. (See [Section 6](#)).

Funding for storage research and development is also provided by the Energy Technologies Institute, the Technology Strategy Board, and the Carbon Trust, as described in the following sections.

### **Research Challenges**

A particular uncertainty and area for research and development is the cost and lifetime of candidate storage technologies when applied to real duty cycles within electricity networks.

The UK is well established as a centre for battery development, with the main focus on lithium batteries, an important technology for mobile and stationary applications alike. Cryogenic (liquid-air) energy storage is also a UK strength.

The main research and development challenges are to improve storage performance particularly in terms of energy density and round-trip efficiency, and lifetime during charge and discharge cycling, through research into new materials and manufacturing methods.

## 2. Capabilities Assessment

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Within the physical sciences, UK Universities have particular strengths in materials for clean energy applications and in catalysis. There is also significant commercial R&D activity, particularly in materials for electrochemical batteries.

The main areas of activity and expertise are:

### **Lithium batteries**

Significant advances in lithium battery technology have been historically made in the UK. AEA Harwell, working with Dowty Battery Co. in the 1990's, developed solid-state lithium batteries with polymer electrolyte and composite cathode. There are established academic centres, and technology development and commercial exploitation continues with several companies in the field.

[Johnson Matthey Battery Systems \(formerly Axeon\)](#) (Dundee) is Europe's largest independent supplier of lithium-ion packaged battery systems, processing over 70 million cells a year. Battery solutions, including battery management systems, are provided for a range of applications including electric and hybrid vehicles, as well as mobile technologies and power tools. Axeon continues to invest in R&D, and leads a consortium awarded nearly £1 million of funding by the Technology Strategy Board in January 2010. The partners, who will match the funding, will develop new battery chemistries that will deliver high energy densities, thus making them ideal for use in plug-in electric vehicles.

[Nexeon](#) (Abingdon, founded in 2005) has patented unique silicon anode technology, with a way of structuring silicon so that it delivers extended cycle life and significantly increases battery capacity.

[OXIS Energy](#) (Abingdon, founded in 2004) has been at the forefront of building next generation batteries since 2004. The company has

developed its unique technology around sulphur based cathode materials, highly stable electrolyte systems and anode made of Lithium metal and intercalation materials. Additional funding has been provided by UK Technology Strategy Board (TSB) for the development of high energy prototype batteries for low carbon vehicles, and by the Carbon Trust - TTP Incubator which provides a portfolio of consulting services to accelerate the development of start-up and early-stage businesses in the low carbon sector.

### **Flow batteries**

There are two main classes of flow batteries – the redox (reduction-oxidation) flow battery, and the hybrid flow battery where the electrodes are part of the chemical reaction (as in a battery).

The UK has been active in flow battery development. In the 1990's Regenesys (UK) developed polysulphide bromide technology to an advanced stage, and two demonstration plants of 15MW, 120MWh capacity were constructed but not commissioned. The technology rights were acquired by VRB Power Systems (Vancouver) in 2004 to complement its own technologies (vanadium), providing products for very large utility-scale applications from 10–100MW, with eight to ten hours' storage time. VRB ceased trading in 2008 and the assets were acquired by Prudent Energy (USA and China) in 2009.

As part of the Technology Strategy Board's Technology Inspired Innovation programme, in 2009 Plurion Ltd was awarded funds to perform a feasibility study into novel bipolar electrodes to combine chemical stability with cost effectiveness. The aim was to improve performance and provide the battery with further advantages over competing technologies. However, Plurion was put into liquidation in 2010.

[REDT \(Renewable Energy Dynamics Technology Ltd.\)](#) has been developing its vanadium redox battery in the UK since 2001, partly supported by BERR (now BIS, and formerly DTI) funding, and offers a modular product with capacity from 5kWh to 150kWh. REDT is working with several partners, including Scottish Power, and University of Southampton.

Research on zinc-cerium flow batteries continues at the Universities of Strathclyde and Southampton. The University of Southampton is also researching lead-acid flow batteries.

### **Flywheels**

Urenco Power Technologies (UPT) developed a 2kWh capacity flywheel with a high speed composite rotor, using expertise in high speed centrifuges developed at Capenhurst. Although the flywheel was successfully used in field trials in the traction application, and was used to demonstrate smoothing wind power fluctuations from a wind turbine in Japan, UPT ceased production in 2003. Recent technology developments in kinetic energy recovery systems for hybrid automotive drivetrain applications could have application to electrical energy storage.

### **Cryogenic energy storage**

[Highview Power Storage](#) is a developer of utility-scale energy storage and power systems. Its proprietary process uses cryogenic (liquefied) air or its principal component, liquid nitrogen, as the working fluid and the media for storing energy.

### **Pumped-heat energy storage**

[Isentropic](#) has developed an energy storage system that is a reversible gas cycle machine that works as both an engine and a heat pump. It is the first time that a reversible system has been developed both to store and recover electricity using a thermodynamic approach.

### **Consultancy**

Finally, there are several energy storage consultants in the UK, including [EA Technology](#), [Swanbarton Ltd](#) (organiser of the International Flow Battery Forum, held in Edinburgh in 2011) and [Escovale Consultancy Services](#) (publisher of a management report on application analysis and market forecast).

**Table 2.1 Capability Assessment**

<b>UK Capability</b>	<b>Area</b>	<b>Market potential</b>
<b>High</b>	World-class expertise in materials science, lithium battery technology, including electrodes, liquid and solid-polymer electrolytes. Several Universities and high technology companies are currently active and collaborate in this area.	Global scope – high potential
<b>High</b>	Cryogenic energy storage	Global scope – high potential
<b>High</b>	Pumped heat energy storage	Global scope – high potential
<b>High</b>	Historic expertise and development of flow battery technology. Two Universities and one UK company are currently active in flow battery technology, including vanadium, zinc-cerium and lead-acid flow battery technologies.	Global scope – high potential
<b>High</b>	Historic expertise and development of flywheels with high-speed composite rotors. There has been research activity in this area in low-loss and superconducting magnetic bearings and cryogenics. Kinetic energy storage technology, developed by two UK companies and partners for the hybrid automotive drivetrain application, could be applied to electrical energy storage.	Global scope – high potential

### 3. Basic and strategic research

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The Research Councils UK (RCUK) Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. Led by the Engineering and Physical Sciences research Council (EPSRC), the RCUK Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

EPSRC's support for the "Energy Storage" topic includes 23 grants with total values in excess of £37M, boosted by awards being processed in response to the [Capital for Great Technologies Call](#) (results were announced in July 2013)

The [E-Futures](#) Doctoral Training Centre at the University of Sheffield includes research into energy generation, storage and utilisation.

The [2013 Call for EPSRC Centres for Doctoral Training](#) included energy storage in the list of priority areas. Grants are expected to be announced in November/December 2013.

[SUPERGEN](#) is part of the RCUK Energy Programme and is a key initiative in Sustainable Power Generation and Supply. It aims to contribute to the UK's environmental emissions targets through a radical improvement in the sustainability of the UK's power generation and supply. With the first consortia launched in 2003, the SUPERGEN program now supports 8 consortia and 5 Hubs and represents the focus of the energy programme's significant contribution to renewable energy research. SUPERGEN projects cover a wide spectrum of energy research and training and include the [Supergen Energy Storage Consortium](#).

The RCUK energy programme also includes funding for the [UK Energy Research Centre \(UKERC\)](#), and the [Energy Technologies Institute \(ETI\)](#).

**Table 3.1: Research Funding**

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
<a href="#">Supergen</a>	<a href="#">Research Councils UK</a>	<a href="#">The UK Energy Storage Consortium</a> is one of 13 projects supported by the Supergen Programme, and includes eight academic partners and two industrial partners. The aims of the Consortium are to accelerate development of energy storage systems and to provide strategies for their rapid implementation into the UK energy sector. The focus is on electrochemical energy storage (lithium ion batteries, flow batteries and supercapacitors). The work programme includes fundamental technology development, as well as production of devices and integration of lithium batteries and supercapacitors to provide practical hybrid devices for electric vehicles and power systems.	£3.401M (Supergen Storage)	2/2010 to 2/2014	£850k
<a href="#">EPSRC Research Funding</a>	<a href="#">EPSRC</a>	Research grants awarded to institutions, including <a href="#">training grants</a> for PhDs and Masters, and <a href="#">research base funding</a> for individual projects. Funding by EPSRC also includes £30m for grid-scale storage R&D (see <a href="#">Section 4</a> and <a href="#">Section 6</a> )		2009 onwards	£2M

**Table 3.2: Key Research Providers**

Name	Description	Sub-topics Covered	No of staff	Field
Aston University <a href="#">Power Engineering and Power Electronics Group</a>	The group are currently working to study aspects of the grid system from Hybrid vehicles up to large HVDC systems with a key emphasis on control, chain link converter technology and energy storage.  Funding of £4.9M has been awarded to University of Sheffield, Aston University, and University of Southampton for a <a href="#">Grid Connected Energy Storage Research Demonstrator</a> .	<ul style="list-style-type: none"> <li>Control, chain link converter technology and energy storage.</li> <li>Grid systems from Hybrid vehicles up to large HVDC systems</li> </ul>	2 Researchers	Electrical and Electronic Engineering
Brunel University, the <a href="#">Centre for Advanced</a>	The CAPF is carrying out R&D of novel compressed-air hybrid powertrain systems for urban buses and commercial vehicles with significant and concurrent improvements in fuel economy, emissions, and performance over current IC engines.	<ul style="list-style-type: none"> <li>Regenerative Air Hybrid Powertrain for Vehicles</li> </ul>	2 Researchers	Mechanical, Aeronautical and Manufacturing



Name	Description	Sub-topics Covered	No of staff	Field
<a href="#">Powertrain and Fuels Research (CAPF)</a>				Engineering
Durham University, the <a href="#">Durham Energy Institute</a>	Durham University has received over £36M of funding for energy research in the past 7 years. The <a href="#">Durham Energy Institute</a> is engaged in research covering seven technological missions, including electricity conversion, transmission and distribution.	<ul style="list-style-type: none"> <li>• Smart grids, energy storage operating strategies and deployment</li> <li>• Mathematical foundations for energy networks: buffering, storage and transmission</li> <li>• Grid-scale energy storage</li> </ul>	5 Researchers	Electrical and Electronic Engineering
Heriot-Watt University, the <a href="#">School of Mathematical and Computer Science</a>	Research in the School of Mathematical and Computer Science aims to develop mathematical techniques to determine how buffering and storage can assist in the balancing of supply and demand.	<ul style="list-style-type: none"> <li>• Mathematical foundations for energy networks: buffering, storage and transmission</li> <li>• Supercapacitors</li> </ul>	2 Researchers	Computer Science and Informatics
<a href="#">Imperial College London</a>	<p>The <a href="#">Energy Futures Lab</a> is the focal point for multidisciplinary energy research at Imperial College, and covers covers five broad multidisciplinary themes, including energy infrastructure. In addition to research activities, the Energy Future Lab is running the EPSRC Energy Storage Network for storage technologies, organising meetings and workshops to link academic, industrial and policy communities.</p> <p>The <a href="#">Control and Power Group</a> in the Department of Electrical and Electronic Engineering is leading a project involving seven Universities on grid-scale energy storage.</p> <p>The <a href="#">Nanostructured Materials and Devices Group</a> includes the application of nanostructured materials to energy storage</p>	<ul style="list-style-type: none"> <li>• Integration of energy supply and storage</li> <li>• Nanostructured matrix material for structural energy storage</li> <li>• Grid-scale energy storage</li> <li>• Batteries and supercapacitors</li> <li>• Multifunctional structural carbon fibre composite supercapacitors</li> <li>• Regenerative braking</li> </ul>	8 Researchers	Chemistry  Mechanical, Aeronautical and Manufacturing Engineering

Name	Description	Sub-topics Covered	No of staff	Field
	<p>technologies (batteries and supercapacitors)</p> <p>Research in Polymer and Composite Engineering (<a href="#">PaCE</a>) aims to develop high performance Composite structural supercapacitors for power storage. These devices could offer dramatic weight reduction for devices and vehicles.</p> <p>The Future Railway Research Centre (<a href="#">FRRC</a>) is investigating the design and implementation of two major types of hybrid energy storage device for use in rail vehicles.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded £14.3 million to a consortium of 10 Universities, led by Imperial College, to develop new technologies for <a href="#">Energy storage for Low-Carbon Grids</a>.</p>	<p>systems for rail vehicles using high performance flywheels and batteries</p> <ul style="list-style-type: none"> <li>• Rail track-side energy storage</li> <li>• Energy storage network</li> </ul>		
<a href="#">Loughborough University</a>	<p>The <a href="#">Energy Research Group</a> in the Chemistry Department carries out strongly focussed R&amp;D on advanced energy storage technologies, primarily industry-funded. Recent commercial projects include high temperature supercapacitors, direct borohydride fuel cells, lithium / thionyl chloride batteries, and polysulfide / bromine cells. Basic and Applied Electrochemistry and Energy Storage expertise includes the application of ionic liquids, electron transfer, metal deposition, and mathematical modelling.</p> <p>The <a href="#">Control and Reliability Research Group</a> in the Department of Aeronautical and Automotive Engineering is investigating the application of regenerative energy storage in vehicle powertrains</p> <p>The <a href="#">Centre for Renewable Energy Systems Technology (CREST)</a> in the School of Electronic, Electrical and Systems Engineering offers an MSc course in Renewable Energy, covering wind power, solar PV, energy in buildings, grid connection &amp; integration and energy storage.</p>	<ul style="list-style-type: none"> <li>• Battery / Supercapacitor hybrids</li> <li>• High temperature supercapacitors</li> <li>• Direct borohydride fuel cells</li> <li>• Lithium / thionyl chloride batteries</li> <li>• Polysulfide / bromine cells</li> <li>• Regenerative Air Hybrid Powertrain for Vehicles</li> </ul>	<p>2 academic staff 4 researchers</p>	<p>Chemistry</p> <p>Electrical and Electronic Engineering</p>

Name	Description	Sub-topics Covered	No of staff	Field
	The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 3 Universities (including Loughborough) £1.7 million to set up ThermExS Lab: thermal energy storage laboratory.			
Newcastle University, <a href="#">School of Chemical Engineering &amp; Advanced Materials</a>	Research activities include electrochemical power sources, fuel cells, batteries, microbial and biological fuel cells, electrochemical environmental engineering, photochemical processes, membrane materials and membrane separations.  Member of the SUPERGEN Energy Storage Consortium  The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including Newcastle) £14.3 million to run a project : Energy storage for Low-Carbon Grids.	<ul style="list-style-type: none"> <li>Oxygen Electrode for a rechargeable lithium battery</li> </ul>	2 researchers	Chemical Engineering
<a href="#">Queen's University Belfast</a>	The <a href="#">School of Chemistry and Chemical Engineering</a> is examining the use of ionic liquids and their application in Li-air battery systems The <a href="#">Energy, Power and Intelligent Control (EPIC)</a> research group is focused on problems related to distributed sources of energy and their integration into power networks, control and intelligent systems.	<ul style="list-style-type: none"> <li>Lithium-air batteries</li> <li>Grid interfaced vehicles</li> </ul>	2 researchers	Chemistry  Electrical and Electronic Engineering
<a href="#">University College London</a>	The University College London (UCL) <a href="#">Energy Institute</a> coordinates multidisciplinary teams from across the University, and core research focuses on five main areas: buildings, energy systems, people and energy, policy and law, smart energy, and transport.  The <a href="#">London Centre for Nanotechnology</a> (LCN) is a joint venture between UCL and Imperial College London. The LCN has wide-ranging expertise and conducts research in novel photovoltaics, new approaches to exploring current energy supplies, new materials for the nuclear industry and to store hydrogen efficiently at room	<ul style="list-style-type: none"> <li>Spatial modelling to investigate new energy infrastructure, and temporal modelling to investigate energy storage</li> <li>Computer modelling of advanced materials</li> <li>Novel materials for energy storage</li> </ul>	3 researchers	Chemistry  Applied Mathematics  Metallurgy and Materials

Name	Description	Sub-topics Covered	No of staff	Field
	<p>temperature.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including UCL) £14.3 million to run a project : Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>Hydrogen storage</li> <li>Grid-scale energy storage</li> </ul>		
<p>University of Bath, <a href="#">Institute for Sustainable Energy and the Environment (I-SEE)</a></p>	<p>I-SEE engages with 13 Departments/Schools and 7 research centres across the University bringing together experts from the fields of engineering, technology, physical sciences, social sciences and economics.</p> <p><a href="#">Future energy sources and energy storage</a> is one of ten I-SEE research themes.</p> <p>The I-SEE is a member of:</p> <ul style="list-style-type: none"> <li>SUPERGEN Energy Storage Consortium</li> <li>SUPERGEN sustainable hydrogen energy consortium</li> </ul>	<ul style="list-style-type: none"> <li>nano-materials to improve rechargeable lithium ion battery and supercapacitor technology</li> <li>hydrogen storage in novel nanoporous materials</li> <li>storage kinetics and equilibria of different hydrogen storage systems</li> </ul>	5 researchers	Metallurgy and Materials
<p><a href="#">University of Birmingham</a></p>	<p><a href="#">Energy storage</a> was a priority area in 2012 for research fellows. The <a href="#">Centre for Cryogenic Energy Storage</a>, which will be based at the University of Birmingham, will be the UK's first dedicated research facility for energy storage using cryogenic liquids.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including Birmingham) £14.3 million to run a project Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>Cryogenic energy storage</li> </ul>	1 researcher	Physics
<p>University of Cambridge, <a href="#">Energy @ Cambridge</a></p>	<p><a href="#">Energy @ Cambridge</a> brings together the activities of over 250 academics working in energy related research, and energy storage is one of the 11 technology focus areas. <a href="#">Energy Storage</a> research encompasses work done in the Departments of <a href="#">Materials Science and Metallurgy</a>, <a href="#">Chemistry</a> and <a href="#">Engineering</a> and includes investigations into fuel cells (and nanoporous materials for hydrogen storage), batteries and supercapacitors, thermal storage, and grid stability impact.</p>	<ul style="list-style-type: none"> <li>Fuel cells and hydrogen</li> <li>NMR studies of Lithium-ion batteries and supercapacitors</li> <li>Pumped thermal electricity storage</li> <li>Flywheel Energy Storage</li> </ul>	20 researchers	Physics Metallurgy and Materials

Name	Description	Sub-topics Covered	No of staff	Field
	<p>Member of the SUPERGEN Energy Storage Consortium.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including Cambridge) £14.3 million to run a project : Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>• Nano ionics</li> <li>• Energy networks: buffering, storage and transmission</li> <li>• Energy storage in hybrid vehicles</li> <li>• Grid-scale energy storage</li> </ul>		
University of Cardiff, <a href="#">School of Engineering, Institute of Energy</a>	<p>The Institute of Energy has expertise in energy supply, conventional and renewable generation systems, electricity transmission and distribution, as well as the demand-side and efficient utilisation of energy.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including Cardiff) £14.3 million to run a project : Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>• Electricity transmission and distribution</li> <li>• Demand-side and efficient utilisation of energy.</li> </ul>	2 researchers	Electrical and Electronic Engineering
University of Glamorgan, <a href="#">Chemistry and Pharmaceutical Science</a>	<p>Scope of the Chemistry and Pharmaceutical Science department has widened to include applications in environmental sustainability, including fundamental research into cathode materials in lithium batteries and fuel cell membranes.</p> <p>This research is in collaboration with the NMR Group at University of Warwick.</p>	<ul style="list-style-type: none"> <li>• Synthesis and NMR Studies of Electron and Proton Conducting Mesoporous Nb, Ta and Ti Oxide Composites, for use as cathode materials in lithium batteries</li> </ul>	1 academic staff	Chemistry
<a href="#">University of Hull</a>	<p>Part of the <a href="#">Centre for Cryogenic Energy Storage</a> will be led by the School of Engineering at the University of Hull, which will model the integration of energy storage processes into power generation.</p>	<ul style="list-style-type: none"> <li>• Integration of energy storage</li> </ul>	3 researchers	Applied Mathematics
University of Leeds, <a href="#">Institute of Particle Science &amp; Engineering</a>	<p>IPSE is active in several energy storage areas, and has developed a laboratory scale system for the controlled synthesis of inorganic nano-materials (particles &lt;100nm) with potential commercial applications including battery materials and fuel cell components.</p>	<ul style="list-style-type: none"> <li>• Continuous Hydrothermal Synthesis of Nanomaterials</li> <li>• Cryogenic energy</li> </ul>	2 researchers	Metallurgy and Materials

Name	Description	Sub-topics Covered	No of staff	Field
<a href="#">(IPSE)</a>		storage <ul style="list-style-type: none"> <li>• Compressed air based energy storage</li> <li>• Thermal energy storage</li> <li>• Development of nano-enabled phase change materials</li> <li>• Grid-scale energy storage</li> </ul>		
<a href="#">University of Liverpool</a>	<p>The <a href="#">Department of Chemistry</a> is involved in the development of electrochemical energy storage technologies.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded University of Liverpool and University of Manchester £3.3 million to establish state-of-the-art facilities to support the development of <a href="#">advanced electrochemical energy storage R&amp;D facilities</a>.</p>	<ul style="list-style-type: none"> <li>• Alkali metal-air batteries</li> <li>• Lithium batteries</li> <li>• Graphene-enabled materials</li> </ul>	2 researchers	Chemistry
<a href="#">University of Manchester</a>	<p><a href="#">Energy</a> is one of eight research groups in the School of Chemical Engineering and Analytical Science, and is developing and optimizing novel materials and conversion processes, such as in fuel cells and redox flow cells.</p> <p><a href="#">Energy and Environment</a> is one of ten research themes within the School of Chemistry, and includes a research programme to develop the technology of graphene-based membranes, and the use of graphene in supercapacitors and batteries.</p> <p>The <a href="#">Probability and Statistics Group</a> in the School of Mathematics Research is building a team in stochastic modelling of electricity markets, including energy storage.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded University of Liverpool and University of Manchester £3.3 million to establish state-of-the-art facilities to support the</p>	<ul style="list-style-type: none"> <li>• the use of inorganic nanoporous materials for hydrogen storage</li> <li>• fuel cells and redox flow cells</li> <li>• graphene for high performance electrodes and membranes</li> <li>• optimal prediction in local electricity markets</li> </ul>	3 researchers	Chemistry  Mathematics  Chemical Engineering

Name	Description	Sub-topics Covered	No of staff	Field
	development of <a href="#">advanced electrochemical energy storage devices for grid-scale applications</a> (July 2013).			
<a href="#">University of Nottingham</a>	<p>Research in the <a href="#">School of Chemistry</a> includes materials for hydrogen storage.</p> <p>The <a href="#">Department of Chemical and Environmental Engineering</a> is developing supercapacitor / battery hybrids, for improved storage capacity and speed, and utilisation efficiency.</p> <p>Research in the <a href="#">Department of Mechanical, Materials and Manufacturing Engineering</a> includes energy storage using compressed-air storage bags with pressure maintained by undersea conditions.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 3 Universities (including Nottingham) £1.7 million to set up ThermExS Lab: thermal energy storage laboratory.</p>	<ul style="list-style-type: none"> <li>materials for hydrogen storage</li> <li>supercapacitor / battery hybrids</li> <li>compressed-air energy storage</li> </ul>	4 researchers	Chemistry  Chemical Engineering  Mechanical, Aeronautical and Manufacturing Engineering
University of Oxford, <a href="#">Oxford Future Energy Research</a>	<p>Oxford Future Energy has a wide portfolio of research activities and academics working on energy, including energy storage, and is involved in several consortia:</p> <ul style="list-style-type: none"> <li>SUPERGEN Energy Storage Consortium</li> <li>SUPERGEN Sustainable hydrogen energy consortium</li> <li>SUPERGEN Highly Distributed Power Systems Consortium</li> </ul> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including Oxford) £14.3 million to run a project <a href="#">Energy storage for Low-Carbon Grids</a>.</p>	<ul style="list-style-type: none"> <li>Materials design of metal borides</li> <li>Nano ionics</li> <li>nanostructured electrochemical systems for lithium batteries</li> <li>Grid-scale energy storage</li> <li>Ammonia-based storage</li> </ul>	3 researchers	Chemistry  Metallurgy and Materials
University of Sheffield, <a href="#">E-Futures</a>	E-Futures, the University of Sheffield's Doctoral Training Centre for Interdisciplinary Energy Research, offers students a broad range of energy-related topics to pursue, spread across 16 academic	<ul style="list-style-type: none"> <li>Oxygen electrode for a rechargeable lithium battery</li> </ul>	3 researchers	Chemistry  Metallurgy and

Name	Description	Sub-topics Covered	No of staff	Field
	<p>departments.</p> <p>Member of the SUPERGEN Energy Storage Consortium.</p> <p>Funding of £4.9M has been awarded to University of Sheffield, Aston University, and University of Southampton for a <a href="#">Grid Connected Energy Storage Research Demonstrator</a>.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including St Andrews) £14.3 million to run a project : Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>• Advanced Cell State of Function Models</li> <li>• Development of lithium batteries with low-dimensional polymer electrolytes</li> <li>• High Energy Metal-Based Compounds</li> <li>• Investigation into the combined battery-supercapacitor for hybrid electric vehicle (HEV) applications</li> <li>• Integrated high temperature battery and fuel cell</li> <li>• Grid-scale energy storage</li> </ul>		Materials
<p>University of Southampton, <a href="#">Chemistry</a>, and <a href="#">Engineering Sciences</a></p>	<p>Research in the School of Engineering Sciences is assessing the suitability of MgB2 high temperature superconductor for application in superconducting magnetic energy storage, (SMES) for future energy networks.</p> <p>Research in the School of Chemistry is investigating new high oxidation state compounds that could be used in rechargeable lithium ion batteries; synthesis and screening of hydrogen storage alloys; and electrochemical materials for energy conversion and storage.</p> <p>The <a href="#">Electrochemical Engineering Laboratory</a> interests include the design of industrial electrochemical reactors such as fuel cells and redox flow batteries.</p> <p>Member of the SUPERGEN Energy Storage Consortium</p>	<ul style="list-style-type: none"> <li>• Superconducting magnetic energy storage</li> <li>• Soluble lead-acid flow batteries</li> <li>• carbon electrodes</li> <li>• lithium battery materials</li> <li>• nanostructured electrochemical systems for lithium batteries</li> <li>• redox flow cells</li> </ul>	4 researchers	Chemistry  Metallurgy and Materials



Name	Description	Sub-topics Covered	No of staff	Field
	Funding of £4.9M has been awarded to University of Sheffield, Aston University, and University of Southampton for a <a href="#">Grid Connected Energy Storage Research Demonstrator</a> .			
University of St Andrews, <a href="#">School of Chemistry</a>	<p>The <a href="#">Solid State/Materials Chemistry and Electrochemistry Group</a> is involved in the fundamental science of ionically conducting solids (including intercalation compounds and polymer electrolytes); in the synthesis of new materials with new properties or combinations of properties; in understanding these properties and in exploring their applications in new devices, especially energy storage devices such as rechargeable lithium batteries.</p> <p>The University of St Andrews is leading a major EPSRC Transport Grand Challenge project, <a href="#">Crossing Boundaries in Energy Storage</a>, together with Newcastle University, University Of Sheffield, and University of Glasgow.</p> <p>Member of the SUPERGEN Energy Storage Consortium.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 10 Universities (including St Andrews) £14.3 million to run a project : Energy storage for Low-Carbon Grids.</p>	<ul style="list-style-type: none"> <li>• O<sub>2</sub> Electrode for rechargeable lithium battery</li> <li>• Ionic Conductivity in Crystalline Polymer Electrolytes</li> <li>• Nano ionics</li> <li>• Intercalation Compounds &amp; Polymer Electrolytes for Lithium Batteries</li> <li>• Lithium-air battery</li> <li>• Grid-scale energy storage</li> </ul>	5 researchers	Chemistry
University of Strathclyde, <a href="#">Chemical and Process Engineering</a>	The <a href="#">Low Carbon Technology</a> research theme aims to develop innovative solutions to the global problem of carbon dioxide emissions, including carbon capture, novel methods for storing and generating energy, and efficient processing.	<ul style="list-style-type: none"> <li>• Hydrogen storage</li> <li>• Network Support using electric vehicle batteries</li> </ul>	1 academic staff 2 researchers	Chemical Engineering  Electrical and Electronic Engineering
University of Surrey, <a href="#">Department of Chemistry</a> <a href="#">Materials@Surrey</a>	<p>Materials and devices for sustainable energy.</p> <p>Co-ordinator of FP7 project <a href="#">AUTOSUPERCAP</a>, Development of high energy / high power density supercapacitors for automotive applications.</p> <p>Member of the SUPERGEN Energy Storage Consortium</p>	<ul style="list-style-type: none"> <li>• hybrid membranes for use in fuel cells, redox flow batteries</li> <li>• novel fabrication techniques for supercapacitors</li> </ul>	2 academic staff	Chemistry

Name	Description	Sub-topics Covered	No of staff	Field
University of Warwick, <a href="#">Department of Physics</a>	<p>The NMR Group in <a href="#">Condensed Matter Physics</a> has a wide range of solid-state NMR research interests, with application to materials science, chemistry, the life sciences and physics. The UK 850MHz solid-state NMR facility, funded by EPSRC and BBSRC is located at Warwick. The research is in collaboration with the Chemistry Group at University of Glamorgan.</p> <p>The Warwick Manufacturing Group is host to a £13m <a href="#">UK storage R&amp;D Centre</a> co-funded by the TSB and Industry, for the advancement of electric and hybrid vehicle batteries.</p> <p>The Engineering and Physical Sciences Research Council (EPSRC) has awarded a consortium of 3 Universities (including Warwick) £1.7 million to set up ThermExS Lab: thermal energy storage laboratory.</p>	<ul style="list-style-type: none"> <li>• Synthesis and NMR Studies of Electron and Proton Conducting Mesoporous Nb, Ta and Ti Oxide Composites, for use as cathode materials in lithium batteries</li> <li>• Integration of grid-scale energy storage</li> <li>• Electric and hybrid vehicle batteries</li> </ul>	2 researchers	Chemistry  Metallurgy and Materials

#### 4. Applied research

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Applied research is funded by the UK Government via several Funding agencies. The Technology Strategy Board (TSB) is the UK's Innovation Agency, and is a business-led non-departmental body of the Department for Business, Innovation & Skills (BIS). Its role is to promote and support research, development and exploitation of technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life.

In 2010 nearly £1 million of funding was awarded by the TSB to a consortium led by advanced battery manufacturer Axion. The partners, who will match the funding, will develop new battery chemistries that will deliver high energy densities, thus making them ideal for use in plug-in electric vehicles (PHEVs). The £2 million project aims to accelerate the introduction of next-generation batteries that will offer higher energy density combined with lower cost. It will take advanced battery chemistry out of the research laboratory and into a

real-world prototype PHEV application and help to consolidate the UK's position as a strategic centre for battery development. Other members of the consortium include the University of St Andrews, a centre of excellence for energy materials, Nexxon Limited, a UK battery materials company developing silicon anodes for the next generation of Li-ion batteries, and Ricardo, a leading provider of technology and engineering solutions to the automotive and transport industries. Successful delivery of this project will thus further consolidate the UK's position and future as a leading innovator and provider of advanced vehicle battery technology.

The TSB also funds competitions such as [IDP9 – Technology Challenge in Low Carbon Vehicles](#). Two of the eight projects announced in September 2013 are for lithium-air and liquid-sulphur battery development.

**Table 4.1: Research Funding**

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
<a href="#">Technology Strategy Board - Competitions</a>	<a href="#">Technology Strategy Board (TSB)</a>	<p>The Technology Strategy Board is one of the sponsors of the Energy Technologies Institute and, in addition, is working closely with other funding agencies such as DECC, the Research Councils, the Regional Development Agencies and Carbon Trust to develop a coordinated Energy R&amp;D programme for the UK.</p> <p>The TSB three-year strategy for 2008-2011 outlined key application areas, and electrical energy storage was identified as a challenge. In 2008-09 funds were committed to two flow battery storage development projects.</p>	£2m	2013	

		<p>A Small Business Research Initiative (SBRI) Competition to develop and demonstrate innovative, pre-commercial energy storage technologies which can address grid-scale storage and balancing needs in the UK electricity network. <a href="#">Phase 1</a> (£2m awarded to 16 organisations) is complete, Phase 2 demonstrator projects (up to £17m available) by 2015.</p> <p>A <a href="#">competition for feasibility funding</a> was opened in June 2013, with up to £3m available for technical feasibility studies in emerging energy technologies. Integration of energy storage is one of four priority areas.</p>			
<a href="#">Grid-scale energy storage R&amp;D</a>	<a href="#">EPSRC</a>	<p>Grid-scale energy storage was identified as one of the 'eight great technologies' to drive UK growth in the Autumn Statement 2012. Grid-scale energy storage will receive an <a href="#">EPSRC Capital Grant of £30 million</a> with additional funding contributions of £9.8 million from higher education institutions and £5.8 million from industrial partners (total of £45.6m). Funding is to be provided to 17 Universities for 5 projects. (see <a href="#">Section 6</a>)</p>	£45.6m	2013 on	
<a href="#">Energy Technologies Institute - Energy Storage and Distribution</a>	<a href="#">Energy Technologies Institute</a>	<p>The Energy Technologies Institute (ETI) is a UK based company formed from global industries - BP, Caterpillar, EDF, E.ON, Rolls-Royce and Shell - and the UK Government via DECC, BIS, EPSRC and TSB. The Energy Technologies Institute (ETI) mission is to accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals.</p> <p>Since it was established in January 2007, by early 2011 the ETI has announced projects worth over £62 million in all programme areas with a further £100 million in development.</p> <p>Energy storage and distribution is one of ETI's eight technology programme areas.</p>	£14m	2012 - 2017	£3m
<a href="#">Carbon Trust</a>	<a href="#">Carbon Trust</a>	The Carbon Trust funds projects to identify and help		2002 to	

<a href="#">Technology R&amp;D programmes</a>		<p>accelerate emerging low carbon technologies. There are several Technology funding streams including the Applied Research Scheme offers grants up to £500k to projects which develop new low carbon technologies that will benefit the UK.</p> <p>The Polymer Fuel Cells Challenge (PFCC) was launched in 2009 to help bridge the gap between UK polymer fuel cell technology developers and mass market applications.</p>		2014	
<a href="#">Challenge Led Applied Systems Programme (CLASP)</a>	<a href="#">Science &amp; Technology Facilities Council (STFC)</a>	<p>STFC External Innovations runs a Challenge Led Applied Systems Programme (CLASP) to support the application and commercialisation of STFC research in the key global research challenge areas of energy, environment, healthcare and security. Individual annual calls are aligned to specific challenge areas.</p> <p>STFC offered £1.5M to fund a range of projects from short feasibility studies to large developmental projects that will use STFC funded research to solve key challenges in the Energy sector. Key priority areas in the 2013 CLASP Energy Call included grid-scale storage methods.</p>	£1.5M	2013	

**Table 4.2: Key Research Providers**

Name	Description	Sub-topics Covered	No of Staff	Sector
<a href="#">Centre for Low Carbon Futures</a>	The Centre for Low Carbon Futures is a collaborative membership organisation that focuses on sustainability for competitive advantage. Formed by the University of Birmingham, University of Hull, University of Leeds, University of Sheffield and University of York. <a href="#">Energy storage</a> is one of four current research themes.	<ul style="list-style-type: none"> <li>• Cryogenic energy storage</li> <li>• Pathways for energy storage technologies</li> </ul>		R&D Science and Engineering
<a href="#">Johnson Matthey Battery Systems (formerly Axeon)</a>	Johnson Matthey Battery Systems (formerly Axeon) is Europe’s largest independent designer and manufacturer of lithium-ion battery systems, for electric and hybrid vehicles, as well as high volumes of batteries for e-bikes, power tools and mobile technologies. An EU-funded project <a href="#">SmartBatt</a> (Jan 2011 - March 2013) to develop the next generation of electric vehicle propulsion batteries which are both lighter and safer than their predecessors, relied on technology and input from Axeon. Axeon was the leader of a consortium project on <a href="#">Electric Vehicle Battery Chemistry</a> , awarded almost £1m in funding in 2010 by the Technology Strategy Board.	<ul style="list-style-type: none"> <li>• Lithium-ion battery solutions for a range of applications</li> <li>• State-of-the-art battery management systems</li> </ul>		R&D Science and Engineering
<a href="#">Nexeon</a>	Nexeon was founded in 2005 and has patented a unique way of structuring silicon so that it delivers extended cycle life and significantly increases battery capacity. Nexeon's silicon anode materials enable lithium-ion batteries with greater energy storage capacity and/or smaller battery size, or for greater battery life between charges.	<ul style="list-style-type: none"> <li>• Patented silicon anode materials for lithium-ion batteries</li> <li>• Increased energy capacity and battery lifetime</li> </ul>		R&D Science and Engineering

Name	Description	Sub-topics Covered	No of Staff	Sector
	Nexeon was a member of a consortium project on <a href="#">Electric Vehicle Battery Chemistry</a> , awarded almost £1m in funding in 2010 by the Technology Strategy Board.			
<a href="#">OXIS Energy</a>	OXIS has secured two grants: 1. The Technology Strategy Board (TSB) – Oxis, in collaboration with Imperial College, Cranfield University and Lotus Engineering, is the lead partner in a 3 year project to develop high energy prototype batteries for low carbon vehicles 2. The Carbon Trust - TTP Incubator which provides a portfolio of consulting services to accelerate the development of start-up and early-stage businesses in the low carbon sector.	<ul style="list-style-type: none"> <li>• sulphur based cathode materials</li> <li>• highly stable electrolyte systems</li> <li>• anode made of Lithium metal and intercalation materials</li> </ul>		R&D Science and Engineering
<a href="#">University of St Andrews, School of Chemistry</a>	University of St Andrews School of Chemistry is a member of a consortium project funded by the TSB, and is conducting research on potential new electrode materials.	<ul style="list-style-type: none"> <li>• Electrode materials</li> <li>• Lithium-ion batteries</li> </ul>		University, R&D Science and Engineering
<a href="#">Ricardo</a>	The TSB provided part-funding for the <a href="#">KinerStor</a> project, announced in November 2009. Ricardo led a consortium including of industrial partners including CTG, JCB, Land Rover, SKF, Torotrak and Williams Hybrid Power, to demonstrate the viability of low-cost flywheel hybrid systems.	<ul style="list-style-type: none"> <li>• Kinetic energy recovery systems in automotive hybrid drivetrain</li> </ul>		R&D Science and Engineering
<a href="#">Williams Hybrid Power</a>	Williams Hybrid Power Ltd (WHP) has developed a novel, patented electromechanical composite flywheel system that provides a high-power solution for mobile or stationary energy recovery and storage. WHP is a member of the <a href="#">KinerStor</a> project consortium project, part-funded by the TSB. The hybrid flywheel technology was integrated in a car that won the	<ul style="list-style-type: none"> <li>• High power electromechanical composite flywheel system</li> </ul>		R&D Science and Engineering

Name	Description	Sub-topics Covered	No of Staff	Sector
<a href="#">ITM Power</a>	<p>24-hr Le Mans for two consecutive years.</p> <p>ITM Power is participating in a collaborative project together with E.ON, University of Nottingham and others, on <a href="#">coated metal hydrides for hydrogen energy storage</a>. The project is part-funded by the Technology Strategy Board over the period 2011-2014. Hydrogen storage in metal hydrides would be part of an electrical energy storage system based on electrolysers and fuel cells. The Carbon Trust's <a href="#">Polymer Fuel Cell Challenge</a> is supporting <a href="#">development of polymer fuel cells</a> by ITM Power and ACAL Energy.</p>	<ul style="list-style-type: none"> <li>• Metal-hydrides for hydrogen storage</li> <li>• Fuel cell membranes</li> </ul>		R&D Science and Engineering
<a href="#">REDT (Renewable Energy Dynamics Technology Ltd.)</a>	<p>REDT has been developing its vanadium redox battery in the UK since 2001, partly supported by BIS (formerly DTI) funding, and offers a modular product with capacity from 5kWh to 150kWh.</p>	<ul style="list-style-type: none"> <li>• Vanadium redox flow battery</li> </ul>		R&D Science and Engineering



## 5. Development and Demonstration Funding

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The former DTI Technology Programme funded the Regenesys Technologies Ltd pilot utility scale energy storage plant at Little Barford, Cambridgeshire, UK, July 2003. However the installation was not commissioned due to technical and funding problems.

In 2011 ABB commissioned its first DynaPeaQ energy storage installation for UK Power Networks at a site in Norfolk, England. The system is based on ABB's SVC Light technology, combined with Lithium-ion (Li-ion) battery storage and is connected to an 11kV grid with considerable penetration of wind power. This is the first time an electrical energy storage device has been installed on an 11kV

distribution network in the UK. The installation will yield dynamic voltage control in the distribution system and at the same time enable dynamic storage of surplus energy from wind farms, which can be utilized to level out peaks in grid loading and increase grid stability. Using this strategy, the power harnessed from the wind can be put to more efficient use than would otherwise be possible.

Further demonstration projects are currently being funded by the Department for Energy and Climate Change (DECC), Technology Strategy Board, and the Energy Technologies Institute.

**Table 5.1 Demonstration Funding Programmes**

Programme	Funding Agency	Description	Number of projects	Committed Funds	Period	Representative Annual Spend
New and Renewable Energy Programme	DTI	In 2003, the DTI's New and Renewable Energy Programme, funded the Regenesys flow battery technology and demonstration at Little Barford. The intended power output was 12MW with an energy capacity of 120MWh. The aim was to investigate and demonstrate the benefits that storage can bring to renewable generators, in this case wind. Technical difficulties in the development of the technology and other issues resulted in only half of the programme deliverables being completed.	1	£881k	2003-2004	
DECC's <a href="#">Energy</a>	DECC via the	A Small Business Research Initiative	3 Demo	£20m	2013-2015	£7m

<a href="#">Storage Technology Demonstration</a>	<a href="#">Technology Strategy Board</a>	(SBRI) Competition to develop and demonstrate innovative, pre-commercial energy storage technologies which can address grid-scale storage and balancing needs in the UK electricity network. <a href="#">Phase 1</a> (£2m awarded to 16 organisations) is complete, Phase 2 demonstrator projects (up to £17m available) by 2015.	projects			
<a href="#">Energy Storage and Distribution</a>	<a href="#">Energy Technologies Institute</a>	<p>The aim of the Energy Storage and Distribution Programme is to enable and develop the UK's energy infrastructure to manage fundamental long-term changes in</p> <ul style="list-style-type: none"> <li>• Energy generation source types and their geographic location</li> <li>• Energy demand patterns and energy usage requirements</li> </ul> <p>The programme currently includes an investment of £14m in a project led by <a href="#">Isentropic</a> to exploit Pumped Heat Electricity Storage (PHES) for large scale electrical energy storage.</p>	1	£14m	2012 - 2017	£3m

**Table 5.2: Major Demonstration Projects**

Name	Description	Sub-topics covered	Total Project Cost	Public Sector Funder	Public Sector Funding	Period
<a href="#">DynaPeaQ Energy Storage (Norfolk)</a>	A dynamic energy storage system deployed by UK Power Networks, and designed and built by ABB is the first time an electrical energy storage device has been installed on an 11kV distribution network in the UK. As well as providing dynamic voltage control, it will enable it will enable dynamic storage of surplus energy from wind farms, and can be utilized to level out peaks in grid loading and increase grid stability. Using this strategy, the power harnessed from the wind can be put to more efficient use than would otherwise be possible. Monitoring and analysis in being undertaken by Durham University.	<ul style="list-style-type: none"> <li>• Deployed by UK Power Networks in an 11kV grid in Norfolk</li> <li>• Based on ABB's SVC Light® technology, combined with Lithium-ion (Li-ion) battery storage</li> <li>• Storage capacity 200kWh, power delivery 200kW for 1 hour or 600kW short-term</li> <li>• Reactive power control and dynamic voltage control</li> <li>• Provides active power control and grid stability improvement</li> </ul>				2011
Isentropic Pumped Heat Electricity Storage (PHES)	An <a href="#">Energy Technologies Institute (ETI) funded project</a> will develop and demonstrate a cost-effective 1.5MW/6MWh energy storage system that will operate on a UK primary substation owned by Western Power Distribution (WPD) in the Midlands.	<ul style="list-style-type: none"> <li>• Pumped Heat Electricity storage</li> <li>• 1.5MW / 6MWh energy storage</li> </ul>	£15.7m	TSB/EPSRC via ETI	£14m	2012 – 2017

## 6. Research Facilities and other Assets

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In response to EPSRC's [Capital for Great Technologies Call](#), grid-scale energy storage received an [EPSRC Capital Grant of £30 million](#) in July 2013, including capital funding for 5 projects at 17 Universities:

- **Energy Storage for Low Carbon Grids** (£14.3m)  
Imperial College London, University of Birmingham, University of Cambridge, Cardiff University, Newcastle University, University of Oxford, University of Sheffield, University of St Andrews, University College London
- **Grid Connected Energy Storage Research Demonstrator** (£4.9m)  
University of Sheffield, Aston University, University of Southampton
- **Manchester-Liverpool Advanced Grid-scale Energy Storage R&D facilities** (£3.3m)  
The University of Manchester, University of Liverpool
- **Centre for Cryogenic Energy Storage** (£5.9m)  
University of Birmingham, University of Hull
- **ThermExS Lab: thermal energy storage lab** (£1.7m)  
Loughborough University, University of Nottingham, University of Warwick

## 7. Networks

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Networking is mainly via conferences and events on energy storage, including electricity storage, organised by [Institution of Engineering and Technology](#) (IET), [Institution of Mechanical Engineering](#) (IMechE), [Institute of Physics](#) (IOP), and the [Energy Institute](#) (EI).

The EPSRC-funded [Energy Storage Research Network](#) was set up in October 2012, bringing together researchers from academic, industrial and policy domains with an interest in energy storage and its application to future low carbon energy systems.

The UK [Electricity Storage Network](#) was formed in 2011, and complements the activities of the main trade association, the [Electricity Storage Association](#) which is mainly focussed on the USA but has an increasing international scope.

More-recently established Networks include : [STFC Global Challenge Network in Batteries and Electrochemical Energy Devices](#) (founded in 2013) , [Liquid Air Energy Network](#) (founded in 2013) and [UK Innovation Forum - Energy Storage](#) (founded in 2012)

Conferences addressing mainly commercial and business aspects of electricity storage include the [Energy Storage Forum](#) which is held twice each year, in Europe and Asia. London is the planned venue for the 7<sup>th</sup> World Forum in 2014. IQPC organised the [Pan European Energy Storage Forum](#) in London in 2010. A forum for flow battery developers, suppliers and users is provided by the [International Flow Battery Forum](#), which holds annual conferences at international venues, including Edinburgh in 2011, and Dublin in 2013.

**Table 7.1 Networks**

Network	Established	Description	Membership	Activities
<a href="#">Energy Storage Research Network</a>	Started in October 2012, funded for a period of 3 years, and run by the Energy Futures Lab at Imperial College	The Energy Storage Research Network is bringing together researchers from academic, industrial and policy domains with an interest in energy storage and its application to future low carbon energy systems.	<ul style="list-style-type: none"> <li>• Researchers</li> <li>• Industry</li> <li>• Other stakeholders</li> </ul>	Organising events, workshops and seminars on energy storage research and policy. Support and events with the aim of promoting UK energy storage research in both academia and industry.
<a href="#">Electricity Storage network</a>	Formed in January 2011, with a focus on activities in the UK.	The group is examining the issues for the greater deployment of electrical	<ul style="list-style-type: none"> <li>• Policy makers</li> <li>• Developers</li> </ul>	Activities include organising annual

	<p>As of 2013 it is now in its third year of activity, and has a leading position in bringing together those interested in electricity storage in Government, the Regulatory bodies, industry and academia.</p>	<p>energy storage and provide a network for discussion of key issues.</p> <p>Mission:</p> <ul style="list-style-type: none"> <li>• To demonstrate the social, technical and economic benefits of electrical energy storage</li> <li>• To inform and educate</li> <li>• To present electrical energy storage as an integral part of the power network</li> </ul>	<ul style="list-style-type: none"> <li>• Researchers</li> <li>• Users</li> <li>• Other interested organisations</li> </ul>	<p>conferences organised jointly with the Institution of Mechanical Engineers.</p> <p>The network expects to cover the following activities over the next year:</p> <ul style="list-style-type: none"> <li>• Workshop meetings / seminars on key policy points</li> <li>• Further development of the strong interaction with policy makers</li> <li>• Dissemination of relevant news to members</li> <li>• Establishment and reinforcement of links with related organisations</li> <li>• Responses to other significant consultations</li> <li>• A major energy storage conference in March 2014</li> </ul>
<p><a href="#">Electricity Storage Association (ESA)</a></p>	<p>Established by more than 30 utilities in 1991 as the Utility Battery Group (UBG).</p> <p>In May 1996, the scope was</p>	<p>The Electricity Storage Association is an international trade association established to foster development and commercialization of energy storage technologies.</p>	<ul style="list-style-type: none"> <li>• Electricity utilities</li> <li>• Technology developers involved with advanced batteries, flywheels, CAES, pumped hydro,</li> </ul>	<p>ESA Goals:</p> <ul style="list-style-type: none"> <li>• Promote the commercial application of energy</li> </ul>

	<p>broadened to all energy storage technologies, and the name was changed to the Energy Storage Association.</p> <p>In April 2001, the name was changed to the Electricity Storage Association.</p>	<p>The mission is to promote the development and commercialization of competitive and reliable energy storage delivery systems for use by electricity suppliers and their customers.</p>	<p>supercapacitors and component suppliers, such as power conversion systems</p> <ul style="list-style-type: none"> <li>• Researchers advancing the state of the art in energy storage solutions</li> </ul>	<p>storage technologies as solutions to power and energy problems</p> <ul style="list-style-type: none"> <li>• Coordinate and attract international interest and involvement in energy storage.</li> <li>• Provide a forum for technical and commercial information exchange between suppliers, customers, and researchers.</li> </ul>
<p><a href="#">Energy Storage Council</a></p>	<p>Established in USA</p>	<p>The ESC was founded to promote the research, development and deployment of storage technologies and to raise awareness of the importance of storage for the future of electricity supply and energy security in the USA.</p> <p>The mission is to ensure that the benefits of energy storage are fully realized by identifying, creating and executing programs that integrate energy storage into the national and state legislative agendas for energy production and delivery, environmental management, infrastructure, commerce, and national security.</p>	<ul style="list-style-type: none"> <li>• Technology providers</li> <li>• Policy makers</li> </ul>	<ul style="list-style-type: none"> <li>• develops policies on key legislative and regulatory issues affecting the energy storage industry</li> <li>• acts as a central source of information and media contact</li> <li>• provides research and analysis of current market factors and developments in energy storage technologies</li> <li>• provides information about energy storage</li> <li>• maintains an online library of energy storage white papers</li> </ul>

<a href="#">STFC Global Challenge Network in Batteries and Electrochemical Energy Devices</a>	June 2013	<p>The <a href="#">objectives</a> of the network are to:</p> <p>Bring together an international community of researchers with an interest in battery and electrochemical energy device research.</p> <p>Encourage collaborations between researchers using large-scale facilities to promote standardisation of techniques and best-practice methodologies.</p>	<ul style="list-style-type: none"> <li>• industry</li> <li>• academia</li> <li>• national laboratories</li> <li>• and all stakeholders with an interest in the application of large scale facilities</li> </ul>	<ul style="list-style-type: none"> <li>• networking events</li> <li>• best practice workshops</li> <li>• grants to ensure mobility of students and early-career researchers</li> </ul>
<a href="#">Liquid Air Energy Network</a>	2013	To provide a forum for the advocacy and development of liquid air as an alternative way to harness waste and surplus energy within power and transport	<ul style="list-style-type: none"> <li>• open to all</li> <li>• academia, commerce, industry and government</li> </ul>	<ul style="list-style-type: none"> <li>• a hub to stimulate collaboration</li> <li>• publishing reports and briefing notes</li> <li>• seminars</li> <li>• market feasibility</li> </ul>
<a href="#">UK Innovation Forum - Energy Storage</a>	2012	The <a href="#">UK Innovation Forum</a> provides forums and other services, to promote collaboration between businesses, Universities and research institutions, and to turn technological innovations into commercial success	<ul style="list-style-type: none"> <li>• industry</li> <li>• academia</li> <li>• research institutions</li> <li>• laboratories</li> </ul>	<ul style="list-style-type: none"> <li>• provide forums for Universities to showcase their technologies</li> <li>• arrange partnering meetings</li> </ul>



## 8. UK Participation in EU Framework Programmes

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The table below lists the most relevant EU Framework projects with UK participation. The projects are presented in order of project start date (most recent first).

Some hydrogen storage projects are included where the developments may be relevant to electrical energy storage, although the targeted application may be the storage of fuel in mobile applications.

**Table 8.1: EU Framework Programme Participation**

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
<a href="#">INFLUENCE</a> Interfaces of Fluid Electrodes: New Conceptual Explorations	The project aims to improve the fundamental understanding and control of interfaces of a battery type based on Li-ion and Na-ion active materials: semi solid flow batteries (SSFB).	<a href="#">FP7-ENERGY</a>	Collaborative project (generic)	Imperial College of Science, Technology and Medicine	<a href="#">Vito Vlaamse Instelling Voor Technologisch Onderzoek N.V.</a> Belgium  + 7 partners	€3.50M	€2.58M	2013-09-01 to 2016-08-31	
<a href="#">HI-C</a> Novel in situ and in operando techniques for characterization of interfaces in electrochemical storage systems	The primary goals are to: 1) Understand the important interfaces in an operating battery on an atomic and molecular scale. 2) Characterize the formation and nature of interfaces in situ. 3) Devise methods to control and design interface formation, stability and properties. 4) Prepare ion-conducting membranes, mimetic of the polymeric part of the SEI, in order to study their mechanical and	<a href="#">FP7-ENERGY</a>	Collaborative project (generic)	Uniscan Instruments Limited	<a href="#">Danmarks Tekniske Universitet</a>  + 7 Partners	€6.319	€4.646	2013-09-01 to 2017-02-28	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	electrochemical properties.								
<a href="#">SIRBATT</a> (Stable Interfaces for Rechargeable Batteries)	SIRBATT is a collaborative project including 6 Universities, 1 Research Institute and 5 industrial partners. The organisations provide complementary expertise in experimental and theoretical studies of battery electrode interfaces.  SIRBATT will develop microsensors to monitor internal temperature and pressure of lithium cells in order to maintain optimum operating conditions to allow long-life times that can be scaled for use in grid scale batteries.	<a href="#">FP7-ENERGY</a>	Collaborative project (generic)	The University of Liverpool  Johnson Matthey PLC	<a href="#">The University of Liverpool</a>  + 5 Universities, 1 research institute, and 5 industrial partners.	€4.415	€3.144	2013-09-01 to 2016-08-31	
<a href="#">ELECTROGRAPH</a> Graphene-based Electrodes for Application in Supercapacitors	The technical development is the optimised production of graphene with its properties specifically defined and adjusted for application as electrode material in energy storage devices. The project will use an integrated approach in development of both electrode materials as well as the electrolyte solutions to optimise overall performance.	<a href="#">FP7-NMP</a>	Collaborative project (generic)	University of Nottingham  University of Exeter	Fraunhofer Institute for Manufacturing, Engineering and Automation  + 9 partners	€4.94M	€3.58M	2011-06-01 to 2014-05-31	
<a href="#">AUTOSUPERCAP</a> Development of high energy	The aim is to develop supercapacitors of both high power and high energy density.	<a href="#">FP7-NMP</a>	Collaborative project (generic)	University of Surrey	<a href="#">University of Surrey</a> + 8 partners	€5.43M	€3.97M	2011-01-01 to 2013-12-31	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
<p>/ high power density supercapacitors for automotive applications</p> <p>Project website: <a href="#">AUTOSUPERCAP</a></p>	<p>This will be achieved by:</p> <p>(a) computer simulations to optimise power system design</p> <p>(b) use of carbon-based electrodes to reduce the amount of rare and expensive metals</p> <p>(c) use of electrolytes of high operating voltage to increase both power and energy density</p> <p>(d) development of innovative electrode structures</p> <p>e) development of novel methodologies to integrate the innovative electrode materials in the fabrication process.</p>			Mast Carbon International Ltd					
<p><a href="#">POWAIR</a> – Zinc-air flow batteries for electrical power distribution networks</p> <p>Project website: <a href="#">POWAIR</a></p>	<p>The project is to create a new class of electrical energy storage system with characteristics of high energy density, modularity, fast response and low cost. To achieve these aims, the project will radically extend performance of a zinc-air flow battery.</p> <p>A system approach will be adopted to develop a working and robust energy store from the individual components (flow battery, power conversion, grid interconnection, control system), suitable for industrialisation.</p>	<a href="#">FP7-ENERGY</a>	Collaborative Project – (generic)	C-TECH Innovation Ltd, University of Southampton, E.ON New Build & Technology Ltd	<a href="#">C-TECH Innovation Ltd</a> , UK + 7 partners	€5.13M	€3.56M	2010-11-22 to 2014-11-21  48 months	
<a href="#">StorAGE</a>	StorAGE will develop revolutionary concepts for	<a href="#">FP7-TRANSPORT</a>	Small or medium-	Imperial College of Science,	Imperial College of Science,	€3.39M	€2.51M	2010-01-01 to 2013-06-	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
Composite structural power storage for hybrid vehicles	lightweight energy storage to realise efficient energy needs of future vehicles.		scale focused research project	Technology and Medicine	Technology and Medicine + 8 Partners			30	
<a href="#">G4V</a> Grid for vehicles - Analysis of the impact and possibilities of a mass introduction of electric and plug-in hybrid vehicles on the electricity networks in Europe  Project website: <a href="#">G4V</a>	The G4V consortium will analyse the impact of a mass introduction of G4V in order to optimise the grid infrastructure and make use of the opportunities for the operation of smart grids and energy efficiency. The objective of the project is to develop an analytical framework for the planning of technological developments in the grid infrastructure and the definition of related ICT and policy requirements. The project will provide an analytical framework to evaluate the impact of a large scale introduction on the grid infrastructure and a visionary road map for the year 2020 and beyond.	<a href="#">FP7-ENERGY</a>	Collaborative project (generic)	Imperial College of Science, Technology and Medicine	<a href="#">RWE Rheinland Westfalen Netz AG</a>  + 11 Partners	€3.78M	€2.54M	2010-01-01 to 2011-06-30	
<a href="#">IRENE-40</a> Infrastructure roadmap for energy networks in Europe	The IRENE-40 project will identify strategies for investors and regulators to build a more secure, ecologically sustainable and competitive European electricity system. The strategies will be presented in a roadmap, i.e. a	<a href="#">FP7-ENERGY</a>	Collaborative project (generic)	AREVA T&D UK LTD  Imperial College of Science, Technology and Medicine	<a href="#">AREVA T&amp;D UK LTD</a>  + 8 Partners	€5.52M	€3.85M	2008-09-01 to 2012-08-31	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
Project website: <a href="#">IRENE-40</a>	timeline with actions and a description of development stages towards future electricity networks over the coming 40 years. It will provide investment strategies for the individual stakeholders. The roadmap will rely on a scenario selected from a set of options, identified during the project and in discussion with the stakeholder community.								
<a href="#">HYFLEET-CUTE</a> Hydrogen for clean urban transport in Europe  Project website: <a href="#">HYFLEET-CUTE</a>	The HyFLEET:CUTE project will comprise the continued operation of the FC-fleet from the former CUTE and ECTOS projects, the development and demonstration of a new FC hybrid pre-prototype and the development, construction and demonstration of a fleet of 14 hydrogen powered internal combustion engine (ICE) buses in regular service in Berlin including the required hydrogen infrastructure. It will be a part of the European Hydrogen & Fuel Cell platform.	<a href="#">FP6-SUSDEV</a>	Integrated project	BP Gas Marketing Ltd  London Bus Services Ltd	Daimler Chrysler AG, Germany  + 29 partners	€43.03M	€18.98M	2006-01-10 to 2009-09-09  44 months	
<a href="#">MORE MICROGRID S</a> – Advanced architectures	The proposed project extends the work of the FP5 Project MICROGRIDS significantly with the following Scientific and Technical Objectives:	<a href="#">FP6-SUSDEV</a>	Specific Targeted Research Project	Imperial College of Science, Technology and Medicine	Institution of Communication and Computer Systems,	€8.03M	€4.68M	2006-01-01 to 2009-12-31	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
and control concepts for More Microgrids  Project website: <a href="#">MORE MICROGRIDS</a>	<ol style="list-style-type: none"> <li>1. Investigation of effective operation of Microgrids.</li> <li>2. Development of alternative control strategies.</li> <li>3. Alternative network designs</li> <li>4. Technical and commercial integration of Multi-Microgrids</li> <li>5. Field trials of alternative control strategies.</li> <li>6. Standardisation of technical and commercial protocols and hardware.</li> <li>7. Quantification of impact on power system operation.</li> <li>8. Impact on the development of electricity network infrastructures.</li> </ol>			<p>The Turbo Power Systems Ltd</p> <p>The University of Manchester</p>	<p>Greece</p> <p>+ 26 partners</p>			48 months	
<a href="#">NESSHY</a> – Novel efficient solid storage for hydrogen  Project website: <a href="#">NESSHY</a>	The proposed work programme will cover porous storage systems (particularly at reduced temperatures), regenerative hydrogen stores (such as the borohydrides) and solid hydrides having reversible hydrogen storage and improved gravimetric storage performance. Initially, two categories of reversible stores will be investigated - light/complex hydrides, such as imides and intermetallic systems involving magnesium.	<a href="#">FP6-SUSDEV</a>	Integrated project	<p>Johnson Matthey PLC</p> <p>University of Birmingham</p> <p>University of Salford</p>	<p>National Centre for Scientific Research "Demokritos", Greece</p> <p>+ 22 partners</p>	€11.60M	€7.49M	<p>2006-01-01 to 2010-12-31</p> <p>60 months</p>	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
<p><a href="#">HYLIGHTS</a> - coordination action to prepare European Hydrogen and fuel cell demonstration projects</p> <p>Project website: <a href="#">HYLIGHTS</a></p>	<p>HyLights is a CA facilitating the planning of HyCOM. Focus is an assessment of concluded/ongoing H2/FC demonstration projects and recommendations for the preparation of HyCOM/Lighthouse Projects LP. Although HyLights's assessment focuses on transport stationary and portable H2 applications will be considered if synergies become apparent. HyLights will comprise 3 phases of 12 months each. Phase I includes a methodology definition and assessment, Phase II gaps analysis and development of recommendations and Phase III continuous monitoring. HyLights will need to draw from a network of relevant experts.</p>	<a href="#">FP6-SUSDEV</a>	Coordination action	<p>BP PLC</p> <p>Air Products PLC</p>	<p>L-B Systemtechnik GmbH, Germany</p> <p>+ 20 partners</p>	€3.40M	€3.16M	<p>2006-01-01 to 2008-12-31</p> <p>36 months</p>	
<p><a href="#">ALISTORE</a> - Advanced lithium energy storage systems based on the use of nano-powders and nano-</p>	<p>An INTEGRATED network of 18 top research groups (from 7 member states and 3 candidate/associated members), accounting for about 70% of European Lithium battery research bring together a range of skills and expertise to work on lithium-ion batteries, including the use of nano-</p>	<a href="#">FP6-SUSDEV</a>	Networks of Excellence	<p>University of St Andrews</p> <p>University of Kent</p>	<p>Centre National de la Recherche Scientifique, France</p> <p>+ 10 partners</p>	€5.86M	€5.00M	<p>2004-01-01 to 2008-12-31</p> <p>60 months</p>	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
<p>composite electrodes/electrolytes</p> <p>Network website: <a href="#">ALISTORE</a></p>	<p>materials, and to revolutionize battery design.</p> <p>The network worked within a Virtual Centre, and has now formed a European Research Institute with an expanded list of partners including (in the UK) university of St Andrews, Kent University, University of Bath, University of Cambridge.</p>								
<p><a href="#">GREENNET</a></p> <p>Guiding Large Scale and Least Cost Grid and Market Integration of RES-Electricity in Europe</p> <p>Project website: <a href="#">GREENNET</a></p>	<p>The core objective of this proposal is to enhance the proportion of electricity from renewable energy sources (RES-E) in the EU by applying a least-cost approach.</p> <p>The supply-side and demand-side options considered are:                      (i) the technical constraints of the grid for access, transmission, and storage for RES-E;                      (ii) the cost of an upgrade and/or extension of the grid to integrate an increased amount of new RES-E;                      (iii) the costs and technical opportunities of advanced storage technologies;                      (iv) the cost of reducing electricity consumption or load</p>	<a href="#">FP5-EESD</a>	No contract type	IT Power Ltd	Vienna University of Technology  + 12 partners	€1.54M	€1.10M	2003-01-01 To 2004-12-31  24 months	



Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	by means of DSM.								
<a href="#">INVESTIRE NETWORK</a> - Investigation of storage technologies for intermittent renewable energies : evaluation and recommended r&d strategies  Project poster: <a href="#">INVESTIRE NETWORK</a>	A summary of the state-of-the-art of the existing storage technologies: - The requirements of the various types of renewable energy systems for the storage function, - An evaluation report on the promising emerging storage technologies , - A proposal for a mid- and long-term RTD strategy in this field, - A network which will act as a place for open discussion between manufacturers, system designers and users, and laboratories.	<a href="#">EESD</a>	Thematic network	IT Power Ltd  STFC Rutherford Appleton Laboratory	Genec - Laboratoire de Valorisation Technologique CEA Cadarache, France  + 28 partners	€0.86 M	€0.64 M	2001-05-01 to 2003-10-31  30 months	

## 9. International Initiatives

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The IEA R&D programme Efficient Energy End-Use Technologies contains 14 different Implementing Agreements (IAs) of which one is the IA on energy storage. The Energy Storage IA is called the “Implementing Agreement for a Programme of Research and

Development on Energy Conservation through Energy Storage.” The aims are cooperative research, development, demonstrations and exchanges of information in the area of energy storage.

**Table 9.1: International Activities**

Name	Type	Description	UK Contact Point
<a href="#">IEA - Energy Conservation through Energy Storage (ECES)</a>	IEA Implementing Agreement Annex 9 and Annex 26	The IEA implementing agreement contains 17 completed and 10 on-going and planned Annexes. The main focus is thermal energy storage, while three Annexes are about Electrical Energy Storage: <a href="#">Annex 9</a> , Electrical Energy Storage Technologies for Utility Network Optimization, started in July 1996 and completed in July 2000, examined the potential role of electrical storage technologies in electricity supply and utilization. <a href="#">Annex 26</a> , Electric Energy Storage: Future Energy Storage Demand (FESD), started in June 2010, is developing a method to calculate the regional energy balancing demand taking available technical solutions into account. <a href="#">Annex 28</a> , Integration of Renewable Energies by Distributed Energy Storage Systems, is planned	Annex 9: completed in 2000 Annex 26: <a href="#">Christian Doetsch</a> , Fraunhofer, Germany. (currently no UK participants) Annex 28: <a href="#">Andreas Hauer</a> , ZAE Bayern, Germany (currently no UK participants)