

dti

**STATUS OF ELECTRICAL
ENERGY STORAGE
SYSTEMS**

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dti

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Status of Electrical Energy Storage Systems

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Contractor

Swanbarton Limited

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1 Executive Summary

The present and future operation of the UK's power network will require greater flexibility in the integration of renewable energy (particularly wind power) and the control of widespread distributed power resources. Energy storage devices to support these key applications will need to have high power ratings (for connection to both distribution and the transmission networks) as well as a high energy to power rating so as to provide primary reserve as well as system balancing for the dispatch of renewable power.

The UK has had a strong position in the development and use of energy storage. The pumped storage plants in North Wales were leading examples of the technology type when installed, and overall the UK has 3.5% of its generation capacity as storage.¹ Pumped storage is location specific, and more is unlikely to be built. In planning the network strategy for 2010 and beyond, higher proportions of storage are envisaged, at least doubling the present storage inventory. Over the medium to longer term, several energy storage types should be considered, and allowance made to include new forms, which will be developed to meet future requirements, driven especially by the needs to incorporate more renewables.

Some countries are already close to a notional system limit because of the high proportion of non dispatched wind generation, with examples in West Denmark, Ireland, Texas and a number of small island systems. Technically proven, commercially viable distributed storage would appear to have a ready market in some of these areas.

The existing, technically proven, methods of energy storage that are capable of operation at a "utility-scale"² are pumped hydro; CAES (compressed air energy storage); battery types such as lead acid, nickel cadmium and sodium sulphur; and flywheel systems. Examples are given in the following table:

Technology	Examples of current technical status
Pumped hydro	Numerous installations 100 – 2000 MW
CAES	110 MW and 270 MW installations in operation
Batteries	Examples include: Lead acid: 20 MW NiCd: 40 MW NaS: 8 MW 64 MWh
Flywheels	Some installations of more than 1 MW

Until recently, one British company was developing an energy storage business based on flow batteries. Commercial reasons led to the closure of this programme. Another

¹ Electricity Association data from 2003

² Utility scale indicates devices of the order of 1 MW or more, that is a single device would have an impact on the operation of a utility's network.

British company, with interests in flywheels, has had an uncertain commercial profile. Given the potential size of the utility energy storage market, it is appropriate to consider how the UK's businesses and academia could participate successfully in this technical area.

Given the shortage of sites for new pumped hydro and large scale CAES, the emerging technologies of most relevance to the UK will include flow batteries, other advanced batteries and supercapacitors and micro CAES, all of which may gain market share in the 5 – 10 year timeframe.

The UK has skills in several core subject areas that are needed to develop these technologies. Groups or consortia combining industry, research organisations and academia could be formed to develop products and systems in the energy storage sector.

Opportunities exist in areas such as

- Flow batteries: development of flow cell modules, system design and integration
- Advanced batteries: design and development of lithium battery systems, further development of small high temperature batteries for small off-grid renewable systems
- Flywheels: design improvements and increased production of the existing successful product in niche applications
- Supercapacitors: design and development of high power products suitable for use in electrical networks
- Power conversion systems: development of standardised low cost PCS and system integration with all forms of storage
- Micro CAES: demonstration of small systems, especially for remote area projects

The take up of energy storage for energy management applications (as opposed to power quality and UPS applications) has been slow. It is important that some early demonstrations of complete energy storage systems are started and the results disseminated. This will demonstrate the capability and market acceptance of these products. Demonstration of distributed energy storage systems in the UK, especially in conjunction with renewable generation will be a valuable marketing tool for industries wishing to open up export markets.

2 Background

A number of research groups, development companies and utilities are working in the area of electrical energy storage. Electrical energy storage has been identified as a technology of interest in the development of the UK electricity supply industry, especially in the light of increased reliance on renewables and distributed generation in meeting the emissions targets for 2010 and beyond.

The commercial implications of electrical energy storage have been extensively discussed in a number of reports and several groups are continuing to research this activity. Recent extensive studies (such as Investire) have covered developments across a number of technologies and provide useful technical information for the appraisal of technologies. Meanwhile, it is important that progress continues to be made by British enterprises in this important area in the near and mid term.

This report deals with issues at an overview level and therefore should not be considered as a comprehensive review

3 Project aims

This project reviews the outputs of earlier studies with other commercial and marketing information in the form of a summary of the currently available technologies and their market space within the context of "utility-scale" energy storage. This is compared with the development activity of the emerging technologies and a view of their potential for commercialisation.

3.1 *Definition*

Energy storage is defined as the conversion of electrical energy from a power network into a form in which it can be stored until converted back to electrical energy.

3.2 *Scope*

The focus is on the network applications of relevance to the DTI's distributed generation and renewables programme as well as the more general needs of the power industry. The use of hydrogen and associated hydrogen storage has been excluded from this report as it is well covered in other work and is seen as a longer-term option that requires significant wider developments (technical and socio-economic) before it can be widely commercialised. . A commentary is given on developmental activity separated into areas of opportunity that can build on national skills and expertise.

4 Status reports on energy storage technologies

A widespread study of energy storage technologies was carried out in the Annex IX programme of the IEA during 1997 and 1998. This culminated in a conference series named EESAT, (Electrical Energy Storage Applications And Technology) which have been held at approximately two yearly intervals since that date under the sponsorship of the US Department of Energy and the Electricity Storage Association.

A significant summary of the “state of the art” of utility-scale energy storage technologies has been published recently by EPRI (The Electric Power Research Institute).³

The EPRI report highlights the technologies of most relevance to transmission and distribution applications. This was the focus of the US Department of Energy, which was a co-sponsor of the report. The US DE plays an important part in encouraging development in the USA.⁴

The use of energy storage in generation applications increases the technical requirements for energy storage technologies above the levels shown in the EPRI report, but the extrapolation is not enormous. A recent study by Baker⁵ summarised the status of various energy storage technologies in terms of the technology options for energy storage applications.⁶

4.1 *Examples of storage technologies categorised by technology type:*

Electrical	Capacitors and ultracapacitors, Superconducting Magnetic Energy Storage (SMES)
Mechanical	Pumped hydro Compressed air energy storage (CAES) Flywheels
Electro-chemical	Batteries, flow batteries, advanced batteries
Chemical	Electrolyser / H ₂ / FC or ICE Other chemical
Thermal	Hot water, Steam, Ice, Ceramics, Molten salt

³ EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications TR1001834, December 2003

⁴ A summary of the US Energy storage programme is given in an Annex to this report

⁵ John Baker, EA Technology, Presentation to the DTI 13 July 04

⁶ The Electricity Storage Association website www.electricitystorage.org also contains much useful information.

4.2 Applications and present status

The following table shows a simple classification of applications by user type and typical parameters:

Sector	Customer types	Typical power	Typical energy
Portable devices		1 W – 100 W	Wh
Transport	Car Train, light transit Marine	25 kW – 100 kW 100 kW – 500 kW 1 MW – 20 MW	100 kWh 500 kWh 10 MWh
Stationary applications:	domestic	1 kW	5 kWh
	small industrial / commercial	10 kW – 100 kW	25 kWh
	distribution network transmission operator generation	MW 10 MW 10 - 100 MW	MWh 10 MWh 10 – 100 MWh

As this report concentrates on energy storage devices for stationary applications of relevance to the new and renewable energy programme of the DTI, storage devices for portable and transport applications are excluded, with exceptions being made for those technologies which may have dual use.

The key issues relating to the development of energy storage with particular respect to the involvement of UK government and industry are concerned with:

- a) the current capability of UK industry to participate in the research, design, development and manufacture of energy storage components, devices or systems;
- b) emerging opportunities for participation by UK industry in (a);
- c) the use and application of energy storage in the UK and overseas by British companies;
- d) the role of the UK government to support the development of energy storage activities.

Energy storage technologies are at various stages of development and deployment. For example pumped hydro is the most widespread large-scale storage technology deployed on power systems, it is technically and commercially mature. It is the lack of appropriate sites, and a high initial capital cost that inhibits further deployment. Lead acid batteries are also a mature technology, widespread in use at small scale, and with several plants in operation at large scale.⁷ In addition, lead acid is widely used in UPS applications and there are several successful UK companies operating in this area. Superconducting magnetic energy storage is technically possible, but is not

⁷ A number of Lead acid battery energy storage plants of 1 MW or more are operating in Germany and the USA. Some notable examples of large scale plants, such as Chino (10 MW, 40 MWh), Puerto Rico (20 MW) and Berlin (18 MW) have now been decommissioned.

widespread and is not commercially mature. The trend is for superconducting materials to be used in wires, generators and motors rather than for storage. The technical capability and commercial availability of several types of storage are shown in figure 1.

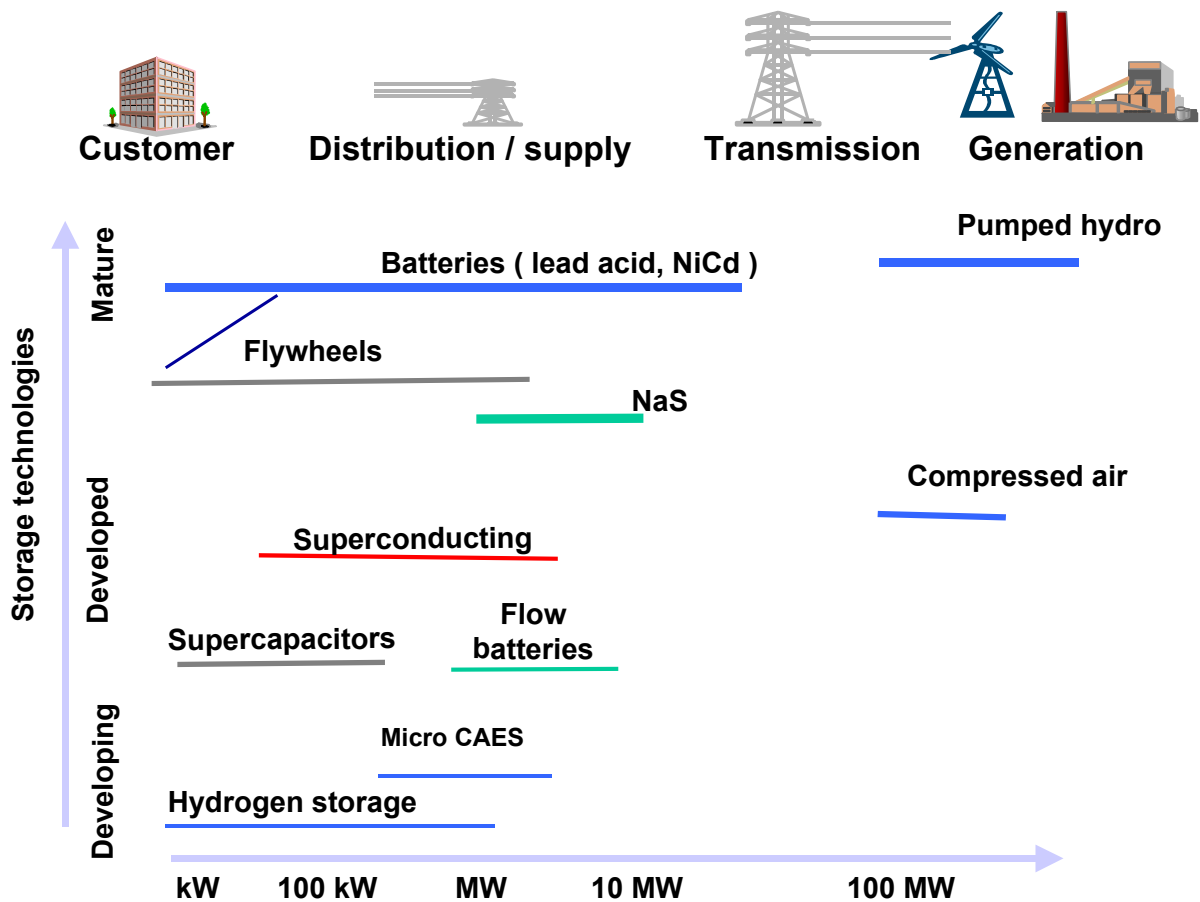


Figure 1: Technical capability and commercial availability of energy storage types

Storage technologies have been categorised into those that are intended firstly for high power ratings with a relatively small energy content making them suitable for power quality or UPS applications; and those designed for energy applications. Such a division is shown in figure 2.

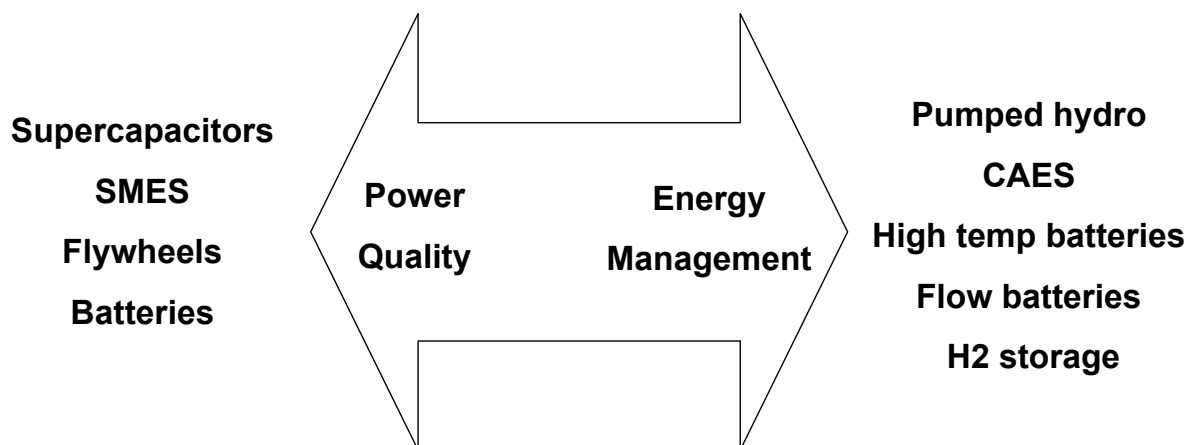


Figure 2: Energy storage types

This simple classification glosses over the wide range of technical parameters of energy storage devices. For example, several flywheel manufacturers are developing flywheels with higher energy to power ratios, and advanced batteries often show good characteristics for pulse power.

The present and future operation of the UK's power network will require greater flexibility in the integration of renewable energy (particularly wind power) and the control of widespread distributed power resources. Efficient running of base load generation such as CCGT, clean coal or nuclear suggests the use of storage as an alternative to fossil fired peaking plant. Energy storage devices to support all these key applications will need to have high power ratings (for connection to both distribution and the transmission networks) as well as a high energy to power rating so as to provide primary reserve as well as system balancing for the dispatch of renewable power.

Small storage facilities, mainly used for power quality and un-interruptible power supplies are commercially available and cost-effective now. Storage facilities for reserve power and energy management duties at utility-scale are typically only cost effective where either multiple value streams can be addressed, or where site specific issues raise the value of storage to a higher level.

Target costs for storage technologies are best expressed in terms of whole life costs, capitalised over the life of the project. Comparisons with cost / kW or cost / kWh can be misleading as both measures are important. Similarly, storage plant efficiency, whilst important, is not necessarily critical as a cost driver.

The key comparison in assessing whether to use storage is the cost of alternatives. Typically this will be a small OCGT. These machines are becoming increasingly more efficient and hence have a falling cost of ownership. Nevertheless, they depend on primary fuel. An economic analysis that takes the cost of primary fuel and other environmental issues into account of primary generation would be beneficial to making the case for storage. These factors could be included in the network models that have been developed at UMIST and elsewhere to show the potential value of storage.

As a simple guide, a near term cost target of less than £1000 / kW in terms of power rating for a multi-hour storage device needs to be achieved for storage to be considered as a viable alternative to other technologies. In the medium to longer term, cost targets of less than £750 / kW for a multi-hour storage device are appropriate.

Initial market opportunities will be developed in specific locations, but in any case, multiple value streams are usually necessary to remunerate the cost of a storage device.

The level of technical and commercial maturity of the various technology options shows the likelihood of future development in the utility sector (distribution level or higher) and is illustrated in the following table:

Technology type	Development status	Near term deployment status	Longer term deployment status
Electrochemical capacitors	Near technical & commercial maturity for smaller size applications	Unlikely – technology still under development	Possible in the UK
SMES	Technical proven, not commercially deployed	Unlikely	Unlikely
Pumped storage	Mature	Unlikely in the UK	Unlikely in the UK
Micro pumped storage	Theoretical only	Unlikely	Demonstration in the UK possible
Compressed air	First generation demonstrated	Unlikely in the UK	Unlikely in the UK
Micro compressed air	Theoretical only	Demonstration projects possible some UK work	Low probability, except for small off grid applications
Flywheels	Commercially available	Small projects (non utility) already in progress Demonstration projects (especially with renewables) possible	Probable, but – application specific
Conventional batteries lead acid, NiCd	Commercially available	Technology proven Subsidised demonstration projects possible	Possible for special cases
High temperature batteries sodium sulphur	Commercially available	Technology proven Early projects possible in special cases	Possible / Probable
High temperature batteries sodium nickel chloride	Commercially available	Small projects (non utility) already in progress Demonstration projects (especially with renewables) possible	Possible / Probable – good fit with PV
Flow batteries	Laboratory and demonstration only	Early stage of technical development	Demonstration possible
Fuel cell / hydrolyser	Laboratory and demonstration only	Small projects (non utility) already in progress Demonstration projects (especially with renewables) possible	Demonstrations probable for special cases
Thermal storage	Commercially available	Customer applications only	

A matrix illustrating the current status of scale-up, commercialisation and technical maturity of various technologies is shown in figure 3. Only systems that are currently available and installed are shown in the top right box. CAES for example is theoretically secure, but no plants have been installed for over ten years, indicating the need for greater commercialisation skills.

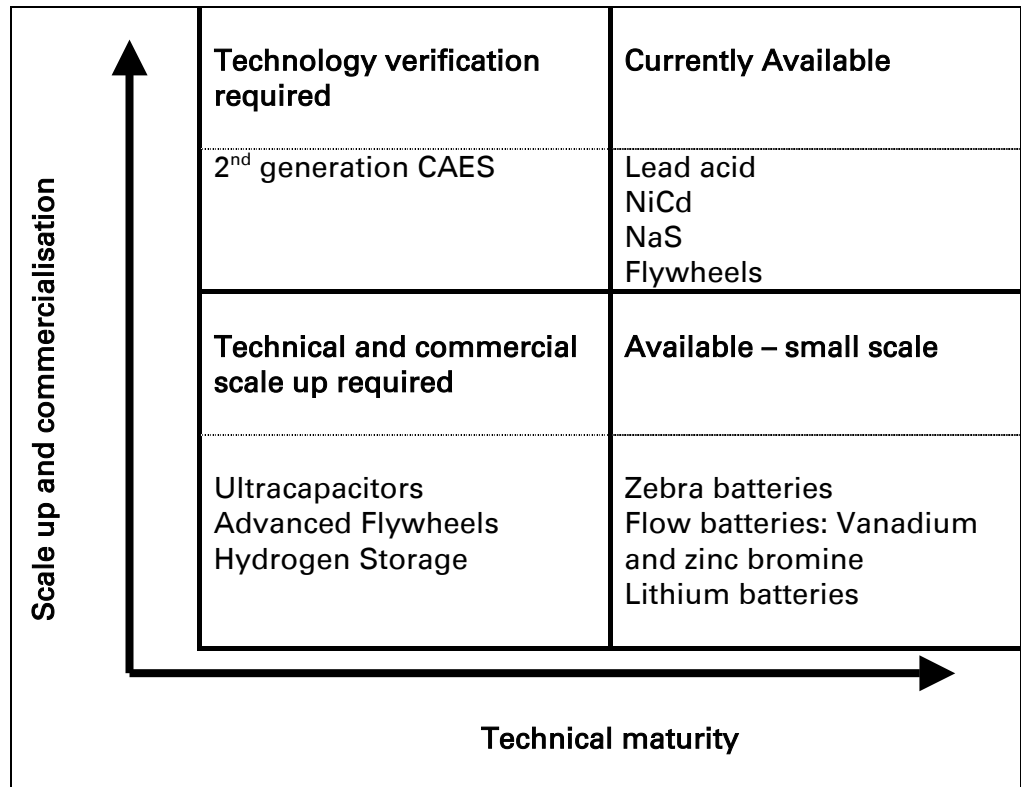


Figure 3: Scale-up, commercialisation and technical maturity of energy storage technologies

There are three broad areas for further development in storage technologies:

- Storage technology development
 - storage medium
 - lifetime
 - operational characteristics
 - cost
- Integration development
 - systems integration
 - control
 - improvements to power conversion systems
- Systems Development
 - deployment and demonstration to develop technical and commercial confidence

5 Non technical issues

5.1 UK

Further development of energy storage is dependent both on “technology push” as well as “market pull.” Within the UK, the greater adoption of storage would be encouraged by an opening of the market in ancillary services. The clarification of the roles of network operators and generators would also be welcomed. For example, if a network operator installs a storage plant to support the operation of a power system, there needs to be clarification as to whether the operator is allowed to buy and sell energy, which is currently outside the usual network operators’ licence.

5.2 World-wide

There is no dominant manufacturer or developer of energy storage systems and apart from pumped hydro there is no prevalent technology type. This presents a relatively open market in terms of technology development. Furthermore, there is no single dominant systems integrator, which also presents an opportunity for national and global project development.

The Japanese market is probably the most developed for distributed energy storage. This may be attributed to the very high cost differential between peak and off peak prices for power and also to the extensive work of various organisations in developing battery storage.

Although the North American market has many examples of large scale distributed storage, the actual proportion of storage is relatively low.

6 The UK’s strengths and opportunities for development of energy storage

6.1 Possible activities by UK industries

Although UK industries could be active participants in many storage technologies, screening the technologies by examining their match with applications of relevance to the future UK electrical grids; and their fit with potential development activity by British companies, leads to the identification of six technologies. These placed in an approximate order of priority by considering whether the UK might have a premium position.

- Flow cells
- High temperature batteries
- Flywheels

- Other advanced batteries
- Capacitors
- CAES / Micro CAES

6.2 *Development opportunities*

Taking into account the current status of various energy storage technologies, the capabilities of present and potential British manufacturers and considering the UK objectives for network enhancements to support increased penetration of renewable generation and distributed resources over a seven to ten year time-scale the following opportunities are suggested as candidates for further study:

6.2.1 Flow cells

Flow batteries are of particular interest as they offer the prospect of high power ratings with a low initial cost, coupled with a low cost for additional “hours” of energy storage. These attributes make flow batteries a good theoretical choice for integration with renewables, both on and off the grid, and in a number of different combinations of power rating and energy storage capability. Current interest in flow batteries is mainly at the sub MW level, although a large 3 MW system has been operational in Japan for several years. Flow batteries comprise electrochemical cells with separate electrolyte tanks and pipework as well as a power conversion and control sub-system.

The value chain for flow batteries consists of the following major elements

- Electrochemistry: Cell reactions, electrolyte management, electrolyte recovery, electrode performance
- Cell design: fluid flow, manifold design, electrode manufacture, joining techniques
- Manufacturing: Cell module design / manufacture
- Pumps, pipework and controls
- System design: Whole system integration

The UK held a distinguished position with the development of the “Regenesys” polysulphide bromide flow battery. This was developed by National Power and its successor companies over a ten year period ending in 2003. Particular expertise was developed in the design and manufacture of flow cell modules, modelling of hydraulic flow and shunt currents and in electrochemistry. The project has now been closed, the team dispersed and its assets disposed of or mothballed, but the core intellectual property and some of the experience and knowledge would be available. Although the technology is sound, a significant (£100 million plus) investment would be needed to restart the programme and achieve commercialisation. Areas of expenditure include stack design, process plant design and electrolyte management.

There are only two established “volume” manufacturers of flow battery stacks in the world. Sumitomo of Japan produce stacks designed for the vanadium system, and Cellenium Corporation of Thailand who produce a stack of a different design. VRB Power of the USA has recently announced the start of production of a vanadium stack in the USA.⁸ ZBB of North America is still at an early stage of manufacturing

⁸ After this report was written, VRB Power announced that it has acquired a license to use the polysulphide bromide technology. This gives VRB access to the cell stack

development for its zinc bromine battery, stacks are hand-produced and built to meet specific requirements. There are considerable problems in scaling up flow battery modules to larger sizes and a successful large flow battery module would be expected to be marketable. A robust manufacturing proposal for a generic flow battery system would challenge these existing flow cell suppliers and also open up the market for other battery systems such as zinc bromine and cerium zinc.

A British Company (RE Fuel) has a flow battery stack design of 5 kW nominal and 9 kW peak that shows potential for development to the next stage of commercialisation. This company has supported other vanadium flow battery developers through technology transfer contracts. RE Fuel has in the past investigated the use of flow batteries for electric vehicles, but this work is on hold while the company continues to develop products for stationary applications. Hiltech, another British R&D company, also has expertise in small scale development of flow batteries. There may be some residual British ownership of parts of a zinc bromine project but details are not available.

As well as these developers, there are many university groups, other research organisations and commercial companies with either direct or subcontract experience in flow battery R&D, design and manufacture. For example there are strong electrochemical groups in the universities of Southampton, Newcastle and Bath, and other disciplines relevant to flow batteries exist, for example at Loughborough, Cambridge, Brunel, and Sheffield. Some groups have also been engaged by Plurion, the American developer of the cerium zinc flow battery.

6.2.2 Advanced batteries - Lithium batteries

Although the number of lithium batteries produced is high, their power and energy ratings are still at relatively small scale in comparison to other battery systems. However their good power density make them suitable for several applications, especially in the telecoms and UPS markets. Some manufacturers also consider them suitable for electric vehicles.

The cost / performance characteristics of lithium batteries make them unlikely to be a product suitable for very large-scale battery storage projects. As sales margins are higher for smaller product sizes, battery manufacturers (especially for the lithium batteries) will tend to service the higher value markets for portable appliances before addressing the lower margin market offered by utility scale energy storage. Lithium batteries will continue to be used at smaller scale, and for premium applications such as UPS or standby use in telephone exchanges for several years. However, they are still at an early stage of development and not yet considered mature. They may become suitable for domestic application alongside roof-mounted solar panels or micro wind generators.

Valence Technologies had a factory and R&D site in Northern Ireland. This recently closed as the manufacturing jobs were exported to the Far East.

manufacturing process developed by Regenesys Technologies, parts of which could be transferred for use to the vanadium technology, as well as the capability to develop the polysulphide bromide system.

Lithium batteries will continue to be important in the energy storage arena, and participation in their ongoing R&D should be considered by research groups in the UK, not least because of the breadth of possible combinations of materials and manufacturing techniques that are needed to optimise the product.

6.2.3 High Temperature Batteries

There are two established high temperature batteries, the sodium sulphur system marketed by NGK of Japan, and the ZEBRA battery produced by MES-DEA of Switzerland. The UK has a research group, Beta R&D which undertakes development work in the beta alumina electrolyte.

The NAS battery is a secure technology, offering both high power and high energy, making it a good candidate for utility scale applications.

The ZEBRA battery also has a number of useful characteristics, and its use could be expanded in the off grid and remote area power systems markets. It has already been demonstrated in electric vehicles and is being adopted by Rolls-Royce for use in underwater vessels. For both battery types, if current rates of production were increased, manufacturing costs would fall and if reflected in lower prices, there would be increased market acceptance.

The Beta R&D, as a research company, is concentrating on bespoke systems which use the ZEBRA battery using its associated Swiss company's mass production capability. An investigation of new products, especially linked to small-scale renewables, is recommended.

6.2.4 Flywheels

The British company Urenco has recently been successful in selling its flywheel system, (known as a Kinetic Energy Storage system) to a number of railway operators who use it to reduce the effect of high starting currents on the local power network. This demonstrates the use of such systems on other networks that have either rapidly varying loads or generation.

The company has significant skills in flywheel technology and in the integration of its products with power systems and it is hoped that the company will continue its development to maintain its leadership position in the manufacture and production of kinetic energy storage systems.

6.2.5 Capacitors

Supercapacitors are a relatively new technology, which is being developed by scores of groups around the world. Only a few groups are in commercial production. The core technologies needed to develop supercapacitors can be found in numerous universities and other research groups. The market for supercapacitors will doubtless increase as performance improves and costs fall. Although unlikely to be suitable for storing significant energy, over the longer term, advanced capacitors will continue to be useful for other applications on the power network. A consolidation or consortium of university and other research groups in the UK, could be formed to undertake development work in supercapacitors, using the high intellectual capital available in

the UK. The aim of the group should be to bring a marketable device into production, taking into account the requirements to integrate the storage medium with control and power conversion systems. As well as R & D into the storage medium, developers would require knowledge of volume manufacturing.

6.3 *Power conversion systems and System integration*

There is no world-wide leader in the area of power conversion and system integration. The UK's power electronics industry is fragmented, and as many companies are international it is not clear where the intellectual base lies. Some consultancies, for example Econnect and IPSA have a capability to analyse networks and contribute to the adoption of storage, either in the UK or overseas. Such business is mainly reactive. It is left to the technology developers to be proactive in seeking new business opportunities. There is a role not only for PCS manufactures, but also for system integrators to gain project experience and then transfer their experience and knowledge to other projects. The British engineering industry and consulting engineers gained considerably from the world-wide expansion of the power industry during the 1960's and 1970's. Similar deployment of expertise in distributed generation, and energy storage may also place the UK in a leadership role, albeit not at perhaps the same volume as this example.

6.4 *The All-electric-ship project*

The UK MoD, working with equivalent organisations in other countries, is developing a concept for using electricity for ship propulsion and all other energy requirements on naval vessels. There is expected to be some technology transfer, in both directions, between utility electricity storage and the all-electric-ship project.

All of the above technologies (flow batteries, lithium batteries, flywheels and supercapacitors) have scope for adoption in the electric ship.

6.5 *Compressed air energy storage*

The UK has not taken a leading role in the development of compressed air energy storage. Most UK sites suitable for large-scale air storage have instead been allocated to gas storage, which tends to be a more profitable activity. Proposals for new large scale CAES, particularly in the USA remain in the planning stage, despite several years of project development activity. Nevertheless there are some initiatives which are worthy of note.

A small British company is developing a micro CAES system for standby and off grid power using air compressors designed originally for use in the cryogenics industry. Other companies are also developing micro CAES systems for operation in association with renewable generation. The Isopower engine, developed initially by National Power and now allocated to RWE can also be used in an energy storage configuration.

Large scale CAES is well thought out but dependent on the right combination of sites for air storage. Micro CAES is a more adaptable solution, especially for distributed generation that could be widely applicable to future power networks. A modest collaborative effort between an engineering company and thermodynamics specialists could make significant and timely progress in this area.

6.6 *Opportunities for development - Deployment*

Many studies have indicated the necessity for storage in the power networks of the future. The requirement for network (or utility scale) storage means a power rating of at least 1 MW, and a more useful rating would be 5 MW or more. The required energy capacity needs to be at least 30 seconds discharge at rated power for reliability, regulation or reserve requirements. A greater range of benefits can be achieved with higher energy storage capability, such as a discharge of one hour or more. To a large extent, modelling the behaviour of systems under variable conditions only mimics predicted behaviour and does not allow the system operator to evaluate storage under actual conditions.

The speed of response and ramp rate for storage can be flexible. Very fast acting storage is required only for very specialist applications, particularly in power quality duties on customer sites. For network applications, response times in the order of seconds would be suitable.

For general purposes in reviewing energy storage, the following technologies are currently of most interest to network planners for operation at utility-scale with low technical risk:

- Pumped hydro
- CAES
- Batteries: Lead acid, NiCd, NaS
- Flywheels

Given the low likelihood of new pumped storage in the UK, and the probable use of air storage capacity for natural gas storage, the technologies of immediate interest are the three battery types and some flywheel systems.

6.7 *Small scale systems*

For small-scale demonstration (for example in domestic applications or small commercial customers or small off-grid applications) low technical risk would be associated with the following currently available storage types:

- Batteries: Lead acid, NiCd, Zebra, ZnBr
- Flywheels

Emerging battery technologies would include lithium ion and vanadium flow batteries

6.8 *Demonstration programmes*

At present, the UK's power networks can generally be operated without additional storage. However, niche applications can demonstrate benefits but the main competition is nearly always the low cost OCGT.

A programme to deploy storage in the UK, in specific instances would provide field data and illustrate benefits as well as providing valuable lessons learned. Projects

should be identified with low technical risk, so that the commercial impact of the storage can be assessed. Later, other technologies can be deployed.

This deployment pattern follows that for other new technologies such as wind turbines and even mobile phones. The first generation models were reasonably technically secure, although considerably “low tech,” however their deployment acted as trailblazers. These industries then developed, with both the original manufacturers and new manufacturers engaging in the new markets that grew as deployment showed benefits.

In the UK environment, where the plant mix of power generation equipment is expected to change with increased pressure to incorporate renewables, we are working towards deployment of a small number of distributed storage resources in the near term. We expect that this will grow at a compound rate as the plant mix becomes skewed towards stochastic generation.

The US Department of Energy has supported many storage projects over at least the past 15 years. Significant grants (in percentage terms) have been given to technology developers, and grants have also been made available for many demonstration projects across a range of technologies. The program is run in conjunction with other organisations with an interest in promoting energy efficiency and industrial development.

6.9 R & D issues

Research and development issues for energy storage can be grouped as follows:

- Technology improvements
- Field tests
- Planning models to aid uptake of storage devices
- Validation

A parallel process is recommended. Field tests using storage devices based on existing technology should be supported in the near term, while encouragement given to improvement of technologies and new technology development in the medium to longer term.

A near term demonstration of electricity storage in a MW scale could be achieved within an 18 month – 24 month timeframe. The application should be for integration of a storage plant with renewable stochastic resources, preferably in an area where there are some current distribution or transmission constraints. The demonstration should illustrate as many storage functions as possible, including regulating power, voltage control, reserves, energy management and black start, although not simultaneously. One criterion is that the storage device must be connected to the transmission or higher voltage distribution lines in order to ensure that the high power requirements are met. An objective of a potential DTI programme is to accelerate the installation of the UK’s first storage system in order to encourage follow-on developments.

As the proportion of renewable generation in the UK is still relatively low, some encouragement needs to be given for the project to be installed in advance of the true commercial requirement. The programme could be accelerated by a grant to cover initial project costs such as site development, system integration issues and the

operational costs of executing a range of specific energy storage applications during a specific time frame.

There are two possible methods of support. One method is for a contract to be placed with a developer for a subsidy on the storage plant's output. The alternative is that the subsidy is placed on the initial capital cost, making the project developer reliant on ongoing technical operation to cover the ongoing costs of the project. As the circumstances in the UK move towards an increasing requirement for storage plant services, the revenue would be expected to increase.

An estimate would be that the grant should be no more than 33% of the total project cost. The project would then be expected to be self-financing through the sale of electricity storage services to the DNO, TSO or other market participants. The linkage with the OFGEM project on Regional Power Zones should be explored.

A parallel stream is to encourage technical development of sub utility scale technologies that would have the potential for scale up to the MW class. The emphasis here is to encourage storage technologies to be seen as alternatives to the hydrogen economy and thereby encourage early deployment of these technologies. Grants could be made for smaller scale demonstrations or for pursuing technical development, either through the EPSRC or other DTI programmes.

A suggested programme is shown in the following table:

	2004	2005	2006 onwards
Emerging Storage technologies	Solicitations – Proposals for development work that will lead to commercially production of storage devices	Assessment of developments in key areas (eg flywheels, flow batteries, capacitors)	Solicitations for pre-production demonstrations, possible demonstrations in 2006 / 2007
Existing technologies	Solicitations for initial storage demonstrations (MW scale)	Storage and wind / renewable demonstration	Operational experience of Storage and wind / renewable demonstration

The advantage of a two-stream programme is that it encourages early deployment of storage technologies, while at the same time indicating to the market that other technical improvements and solutions are expected.

7 Electricity storage: conclusions and recommendations

The current UK power network is expected to require substantial investment if it is to incorporate a significant proportion of renewable (mainly wind) generation without incurring control problems.

Utility-scale energy storage can provide an attractive, relatively low cost, and environmentally benign means of modulating renewable generation and providing reserves. At present, the only large scale storage technologies capable of commercial deployment at the 5 MW level or above are pumped hydro; compressed air; lead acid, nickel cadmium, and sodium sulphur batteries; and some flywheels. Other technologies are emerging and may also be able to address this market in the next few years. Contenders are flow batteries, flywheels and capacitors. The hydrogen / fuel cell combination is seen as a potential rival, but hydrogen is more likely to become an energy vector rather than to be used as stationary energy storage.

As the UK government is committed to a programme of renewable energy alongside the increased use of distributed energy, it should encourage the development of energy storage technologies that have the potential for scale-up to the MW class. The emphasis here is to encourage storage technologies to be seen as alternatives to the hydrogen economy and thereby encourage early deployment of these technologies. The development work must be in the context of systems development. Although incremental improvements to components of storage systems are important, it is necessary to concentrate support on those programmes that have a clear development route which will lead to commercial products. Grants could be made for smaller scale demonstrations or for pursuing technical development, either through the EPSRC or other DTI programmes.

The UK could demonstrate electricity storage in a MW scale demonstration within an 18 month – 24 month timeframe. The application should be for integration of a storage plant with renewable stochastic resources and ideally be connected to the transmission network.

The demonstration should illustrate a range of storage functions, including regulating power, voltage control, reserves, energy management and black start. The demonstration programme would therefore accelerate the installation of other systems and encourage follow on developments. The programme could be accelerated by a grant to cover initial project costs such as site development, system integration issues and the operational costs of executing a range of specific energy storage applications during a specific time frame before the increase of renewables makes the plant truly self financing. A grant of 33% of the capital project cost would encourage the initial development. The project would then be expected to earn income through the sale of electricity storage services to the DNO, TSO or other market participants.

8 Annex: The US Department of Energy Energy Storage Program

The US Department of Energy Office of Electric Transmission and Distribution runs a small program on Energy Storage. The program has an annual budget of about \$6 – 8 million. The exact amount varies, and specific allocations often mean that money is diverted into “non-storage” projects. Recently, the program has linked with the California Energy Commission (CEC) and the New York Energy Research and Development Authority (NYSERDA) to announce joint programs with a more regional focus. The CEC and NYSERDA initiatives tend to favour demonstration projects.

The energy storage systems program covers projects in four areas⁹

System Integration pursues a strategy to reduce the costly, labor intensive and error prone assembly and debugging of individual components in the field which were traditionally required when utility energy storage systems were designed and built. The major storage system components (storage device, power electronics, control system, AC connection) are designed as interfacing modules so that integration can occur either at the factory or seamlessly at the customer site. Storage system projects in response to reliability and the needs of the digital economy will be initiated.

System Evaluation involves data collection and analysis from existing systems. A lack of reliable, published data on the performance of systems has hampered the widespread introduction of energy storage systems. This data collection and analysis effort documents the technical and economic performance of systems, yields quantitative cost benefit evaluations, identifies areas in which further research should be focused and provides "Lessons Learned" for future projects.

Component Research and Development focuses on advancing technology of the individual components that make up a system. Development of advanced storage devices (flywheels, high energy density capacitors, advanced batteries), associated power electronics, intelligent control systems and component testing provide a base for future energy storage systems.

Research and Analysis applies analytical methodologies to identify utility and customer requirements and to estimate the technical and economic benefits of energy storage. Efforts undertaken in this area help position the program to respond to the emerging needs of the restructured electricity marketplace. Modelling of complex interactions of aggregated distributed energy resource devices with each other will be initiated.

The program has had a number of successes. Some specific technology developments, such as zinc bromine batteries, advanced flywheels, systems integration of capacitors and battery management are leading to commercial products. The program also brings together a number of technology developers and users in a common forum.

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http://www.electricity.doe.gov/program/electric_rd_estorage_projects.cfm?section=program&level2=estorage