iti Energy

FORESIGHTING REPORT

Energy Storage
(ES)

Addressing technologies needed for large scale and micro/portable energy storage.

For Members Only

23rd March 2005
V1.0

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ITI ENERGY INTRODUCTION

ITI Energy is one of three operating groups that make up ITI Scotland. Together with ITI Techmedia and ITI Life Sciences, we will be investing in excess of £450 million over the next ten years in research and development. Publicly funded, but 100% commercially driven, our collective aim is to create new technologies and stimulate business growth in Scotland.

ITI Energy will select and invest in programmes based on assessing future market needs, identifying technology opportunities, and responding to ideas, initiatives and proposals from the research and business communities. We will use our £150 million funding to commission and direct applied research projects in collaboration with partners from industry, academia and finance.

Throughout this process, we will protect the Intellectual Property (IP) that our investments generate, enhancing its competitive positioning, and helping to bring the resultant technology to market.

Participation in our activities and projects is open to all businesses and research organisations, regardless of where they are located. We are based in Aberdeen, but our scope and vision is global. We closely follow research activities in other countries, and welcome involvement and collaboration from overseas. Our success depends on being able to develop new technologies that address market needs around the world.

Further information on this foresighting study and ITI Energy may be obtained from:

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EXECUTIVE SUMMARY

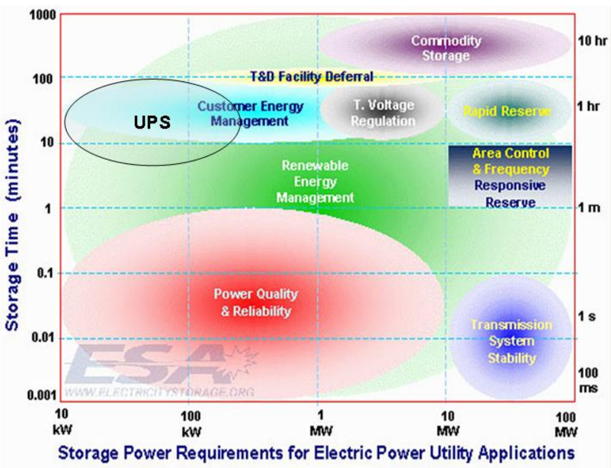
This report provides a summary of ITI Energy's foresighting study focused on the Energy Storage (ES) technology market. The report aims to:

- Provide a structured analysis of ES market needs and technology opportunities on which ITI Energy might focus
- Present conclusions to ITI member companies for their review and input
- Catalyse further discussion and development of ES technology development projects and proposals

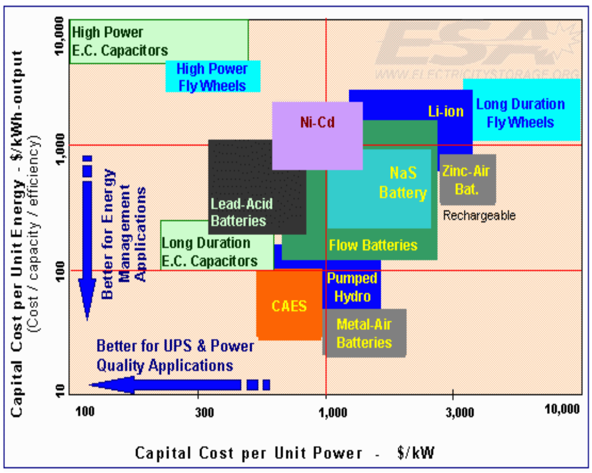
The ITI approach to foresighting considers key market trends and emerging business needs which may create market pull for new technology. This forms the basis for identifying and exploring specific technology development opportunities. The conclusions of this study are the result of a highly consultative approach engaging over 50 companies and organisations across the energy storage sector and involving around 100 individuals with a broad range of industry expertise and experience. This approach sought to leverage ideas and input from operators of storage systems, technology users, technology suppliers and researchers.

This study focused on a range of energy storage applications and associated technologies; it did not include consideration of the production and storage of conventional fuels such as gas, LPG and petrol. The following diagrams illustrate the applications and technologies "in scope".

MARKET APPLICATIONS



TECHNOLOGIES



Energy storage is already an established global market and despite the relative maturity of certain segments and associated technologies there are strong prospects for accelerated growth

- The energy storage market, although established for many decades through the adoption of battery and pumped storage systems, has potential for rapid growth and significant technological change
  - Total global market is currently well in excess of $40Bn per annum and is expected to grow at more than 10% p.a

- The two most significant markets already in existence are battery storage (worth in excess of $30Bn annually) and pumped storage (with an estimated value of $3Bn). The following areas are expected to see particularly strong growth:
  - Rechargeable batteries, currently ~$6Bn, projected growth in excess of 10% p.a
  - Uninterruptible Power Supply (UPS), currently $7.8Bn, projected growth in excess of 12% p.a

- The expected growth in demand will provide a range of opportunities including incremental improvements in existing commercially available technology and, in some instances, strong prospects for the introduction of wholly new systems and/or applications.
- There are three main energy storage market segments:
  1. **Utility / industrial** applications including: grid reinforcement, renewables integration and uninterruptible power supply (UPS) applications
  2. **Transport / mobile** applications including: on-board power for vehicles, new drive trains (electric and hybrid electric vehicles) and leisure applications (caravanning)
  3. **Portable applications** including: computing, cell-phones and cameras

- Each of this segments give rise to a diversity of requirements and demands on technology

- Most foreseeable technology opportunities are related to extensions of existing markets e.g. expanding the market for batteries through improvements in cost and performance

- However, there is some potential for fundamentally new market development if, for example, a low cost bulk power storage technology were available (as an alternative to pumped hydro storage)

A range of market drivers will influence the scale and pace of market growth across the three main energy storage segments

- There are five broad drivers of energy storage markets:

1. **Political and Regulatory** developments (e.g. power system de-regulation/regulation, green energy market assistance)
2. Energy **Supply Side** developments (e.g. emergence of large and small scale distributed generation systems such as commercial and domestic gas fired Combined Heat and Power)
3. Developments in **Power Delivery Systems** (e.g. weakened or ageing grid Transmission & Distribution systems)
4. Developments in **End Use Systems** (e.g. vehicles)
5. Developments in **End User Requirements** (e.g. increasing demand for portable power)

- A number of factors shape or influence each of these five areas as follows:

Political and Regulatory	▪ Efforts to reduce carbon emissions e.g. "clean" transport ▪ Ongoing effort to seek Environmentally benign / neutral technologies ▪ Increasing constraints on site / permitting constraints (e.g. for pumped storage) ▪ Initiatives to reduce energy consumption ▪ Incentives and support for renewable energy ▪ Spend restraints through regulated pricing mechanisms
Supply Side	▪ Generator / fuel diversification, including: renewables & distributed generation ▪ Increasingly complex interactions between generators and Transmission & Distribution (T&D) ▪ Increasing concern over reliability of supply in light of hi profile black-outs ▪ Utility companies face significant challenges relating to "reputation management" and protecting their "license to operate"
Power Delivery Systems	▪ Increasing number and complexity of islanded systems ▪ Dependency on powered/digital systems increases the impact of power failures (safety and financial) ▪ Ageing assets – asked to deliver or carry more power ▪ Increasing need to provide buffering between system elements
End Use Systems	▪ Portable computers requiring higher power and / or capacity ▪ Convergence of cell phones, PDAs and note-book computing increasing need for higher power ▪ Distributed networks and sensors e.g. telecoms ▪ Digital economy requires "premium" quality
End User Trends	▪ Price trends & regulation driving demand for efficiency with ES as part of potential system solution. ▪ Users demanding greater levels of mobility ▪ Device & end users demand cheaper, long duration portable power

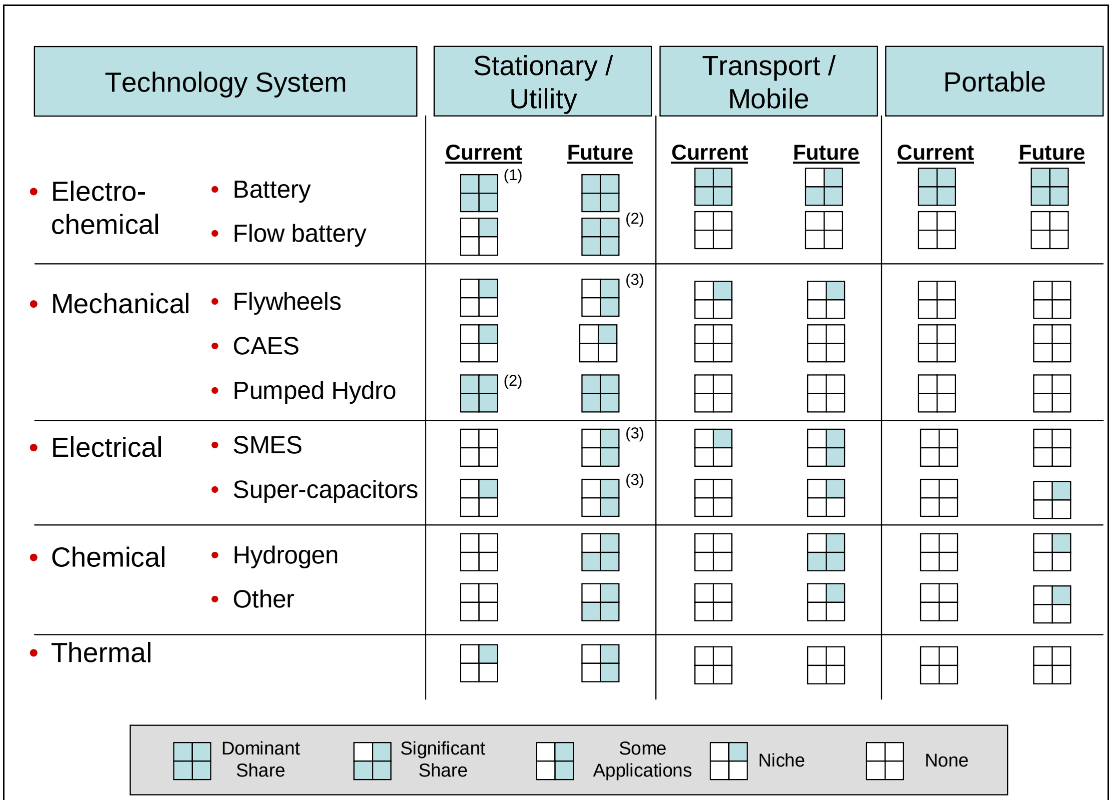
Future energy storage requirements will drive a range of technology developments centred around a number of distinct systems

Energy storage applications are served by a range of distinct technology systems each of which has a unique combination of strengths and weaknesses:

- Electrochemical systems e.g. batteries and flow cells
- Mechanical systems e.g. fly-wheels and compressed air energy storage (CAES)

- Electrical systems e.g. super-capacitors and super-conducting magnetic energy storage (SMES)
- Chemical systems e.g. hydrogen cycle (electrolysis -> storage -> power conversion)
- Thermal systems e.g. sensible heat (storage heaters) and phase change

As a result of the varying maturity, cost, performance and features of these technologies the market for each has developed in different ways. Certain technologies have already developed dominant positions in specific market segments. Batteries, for example, are dominant in power back-up and portable power applications. Other technologies, such as advanced fly-wheels, are still working through a stage of market proving and as yet have only secured a small number of niche or demonstrator applications. Looking ahead, the prospects for the different technology systems are likely to vary considerably – both in response to changes in market needs and as a result of developments in the technologies themselves. The following diagram summarises the current standing of technologies across the three main market segments and their likely prospects in the coming decade:



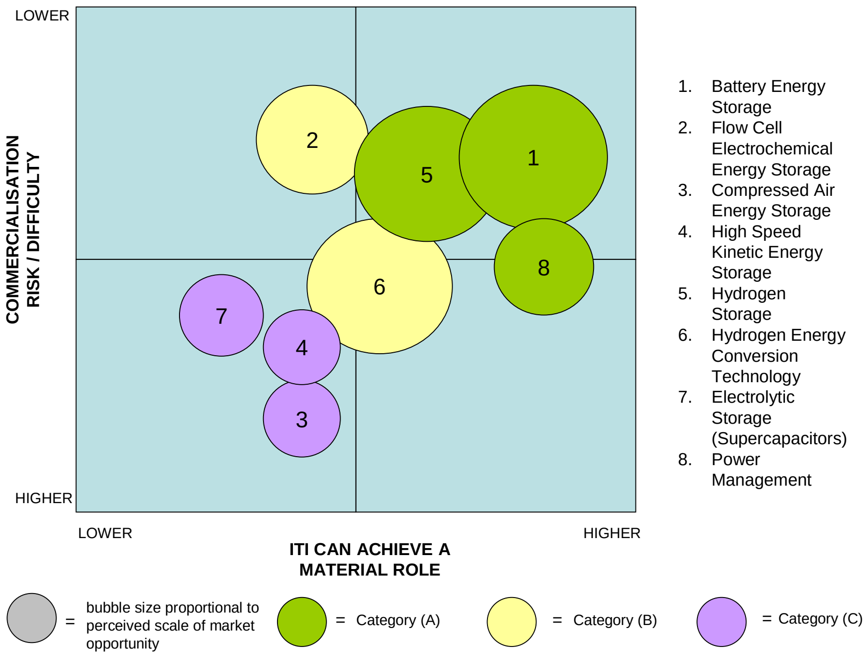
Notes: (1) UPS (2) Large scale (3) Power quality / reliability

Although energy storage technologies are at distinctly different stages of maturity, there is potential for improvements in most of the technology systems, as summarised below:

Electrochemical	- Reduced weight and volume - Higher energy density - Shorter charging times - Longer discharge time
Mechanical	- Reduced material costs - Super-conducting material & bearing developments - Improved system design, stability & component life
Electrical	- Reduced material costs - Super-conducting material & bearing developments - Improved specific energy density - Increased operational temperature range
Chemical	- Reduced weight & volume - Reduced costs - Reduced refuelling times - Improved durability - Increased efficiency - BoP & systems integration
Thermal	- Further development & demonstration of phase change materials - Improved efficiency & reliability

An emerging set of priorities for ITI Energy to focus on

A structured process of brain-storming sessions (workshops and one-to-one meetings) combined with desk-top research provided an initial long-list of around 60 technology opportunities. This long-list was then filtered and prioritised to create a short-list of 8 technology areas on which to focus. Further research and analysis generated short summaries for each of these areas (contained within the main report) and an initial prioritisation of how ITI Energy proposes moving forward to develop specific projects. The following diagram summarises how the 8 technologies have been prioritised:



The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The 8 technology areas have been, as indicated in the above diagram, allocated a prioritisation / categorisation as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 8 technology areas.

The prioritisation of these 8 areas – as discussed above – is only for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals i.e. categories A and B. The 8 areas have all been selected from the long-list as having significant potential for new technology development. Therefore, project proposals in any of the 8 technology areas will go through the same project screening and selection process i.e. the categorisation does not imply a pre-allocation of R&D project funding biased toward those areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 8 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

1. INTRODUCTION

1.1 Purpose, Scope and Objectives

This report concludes ITI Energy's Future Energy Storage foresighting study. The study has focused on a range of storage technologies with applications, or potential application, to a number of broad market segments. The following summarises the scope of the work:

Technology Scope	**Market Scope**
Focus: ➢ Electrochemical Systems ➢ Mechanical Systems ➢ Enabling (cross-cutting) technologies **Covered (but not in-depth):** ➢ Chemical (e.g.H2 cycle) ➢ Hydrogen production ➢ SMES **Not in Scope**: ➢ Thermal storage ➢ Conventional fuel storage (LPG etc.)	**Focus:** ➢ Utility / Industrial Applications o Load levelling o Renewables integration ➢ Mobile / Transport Applications o On-board power o Electric drive trains ➢ Portable Power Applications o Mobile phones o Portable computing

This report serves two broad purposes. Firstly, the document communicates the basis for ITI Energy's focus on certain areas of energy storage technology - allowing members to test and challenge this focus, as well as consider ideas and proposals they might wish to present to ITI Energy for consideration. Secondly, the report provides a collation of information which member companies and organisations might find useful in developing their own plans.

In particular, the document sets out to define the objectives of ITI Energy's market foresighting exercise, to detail the work activities carried out and to highlight the technology priorities identified and proposed next steps. The purpose of issuing this report to members is:

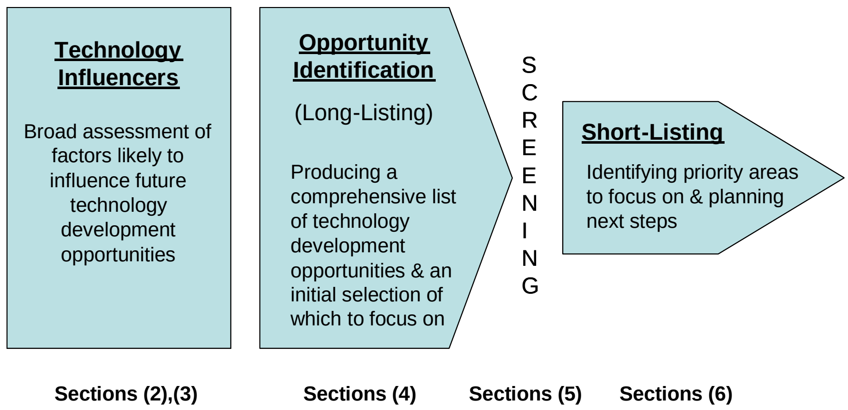
- To share with members a summary of the market and technology information gathered and analysed through the foresighting process
- To communicate to members what areas of technology emerged as priorities from the foresighting work
- To allow members to comment on the resulting technology priorities and to consider if they have particular project proposals or ideas they would like to bring forward for consideration

1.2 Report Structure and Foresighting Process

The report is structured into 6 sections (including this introduction) as follows:

(2) Storage Related Technologies
(3) Markets and Applications
(4) Opportunity Identification & Initial Selection
(5) Technology Screening
(6) Indepth Screening

The following diagram summarises the overall approach adopted during this foresighting study alongside the overall report structure:



The foresighting study harnessed a broad range of inputs and sources, including:

- Desk-top research
- Workshops
- Conference visits / networking
- One-to-one interviews
- Focus groups

Desk-top research formed a key element of this study. However, though there is a substantial volume of published material, most of this prior work has focused on either market/commercial topics or on more specific technical/technological issues - whereas the purpose of this activity was to investigate the interaction between both market/commercial factors and technological developments. Appendix(1) provides a summary of some of the key desk-top research material.

Two workshops were held, one on 'Mobile, Portable & Transport Applications' and one on "Utility / Industrial Applications". The workshops were designed to bring together a substantial cross section of expertise in numbers which would facilitate active discussion. The key objective was to "brainstorm" opportunities for investment for ITI Energy.

Conference visits and related networking included: Alistore, Electrical Energy Storage Workshop (DTI), H2Net 2004, Portable Power 2004 (as detailed in Appendix 2)

A number of one-to-one meetings were conducted to gather more in-depth, qualitative perspectives from a range of parties directly involved and influential in shaping technology developments. These meetings covered a range of topics as follows:

- Company perspectives on future markets and technologies
- The nature and extent of activities
- Drivers for investment and any anticipated risks
- R&D needs and any shortfall in provision of these
- Synergies with ITI Energy.

In total, the foresighting activities included contact with more than 100 individuals and ~50 companies / organisations (most of which are listed in Appendix 3) and synthesis of several previous research studies, conference / technical papers and market analysis.

2 STORAGE RELATED TECHNOLOGIES

Energy storage potentially embraces a huge spectrum of energies, technologies, scales, applications and markets. At the macro-level, the energy related conversion media may embrace potential, kinetic, chemical, thermal or electrical energy storage. The ultimate conversion interface to the end use application may either be directly in the form of the stored energy involved (e.g. via the extraction of heat from a thermal energy store) or indirectly, via an energy conversion system (e.g. electrical output from pumped hydro storage of potential energy). Table 2.1 provides an illustration of some of the principal storage related markets and technologies with an indication of the maturity of the respective subsets of technology and some high level comments on the challenges facing technology development in these areas.

Technology		Markets	Status of Technology	Challenges/Comments
Electrochemical	Batteries	Stationary/utility Mobile/transport Portable/transportable	Embryonic → INCREASING MATURITY → Mature LiS, $NaNiCl_2$, Li polymer, NaS, Li ion, NiMH, Pb Acid, NiCd	• Reduced weight and volume • Higher energy density • Shorter charging times • Longer discharge time
	Flow batteries	Stationary/utility Mobile/transport Portable/transportable	Embryonic → INCREASING MATURITY → Mature CeZn, PSB, ZnBr, VRB	• Improved energy density • Improved membranes to prevent electrolyte cross-mixing/imbalance • Reduced production costs
Mechanical	Flywheels	Stationary/utility Mobile/transport	Embryonic → INCREASING MATURITY → Mature Advanced (high speed), Conventional (low speed)	• Reduced material costs • Further development of superconducting materials for bearings
	CAES	Stationary/utility	Embryonic → INCREASING MATURITY → Mature Small scale (tanks), Large scale	• Large scale systems are geologically constrained • Small scale - improved system design, stability and life time of the components
	Pumped hydro	Stationary/utility	Mature	• Geologically and geographically constrained • Large scale & very high capital cost

Table 2.1: Overview of Energy Storage Technologies and Markets

Electrical	SMES	Stationary/utility	Embryonic → Mature INCREASING MATURITY SMES (> 6MW) → Micro SMES (up to 6 MW)	• Reduction in material costs • Further development of high temperature superconductors
	Supercapacitors	Stationary/utility Mobile/transport Portable/transportable	Embryonic → Mature INCREASING MATURITY Large (> 100 farads) → Small (< 100 farads)	• Improved specific energy density • Increased life time • Increased operational temperature range • Decreased production costs
Chemical	Hydrogen and other feedstocks	Stationary/utility Mobile/transport Portable/transportable	Embryonic → Mature INCREASING MATURITY Adsorption[3] Absorption[1] Chemical reaction[2] Compressed H_2 Liquid H_2	• Reduced weight and volume • Reduced costs • Reduced refuelling times • Improved durability • Increased efficiency • BoP and systems integration
Thermal		Stationary/utility	Embryonic → Mature INCREASING MATURITY Phase change → Sensible heat	• Further development & demonstration of phase change materials • Improved efficiency and reliability

Table 2.1: Overview of Energy Storage Technologies and Markets

[1] Absorption, e.g. simple metal hydrides

[2] Chemical reaction, e.g. complex metal hydrides and chemical hydrides

[3] Adsorption, e.g. carbon and zeolite materials

The emphasis of the present Foresighting assignment is principally on "electrical" energy storage markets and applications. The terminology electrical energy storage is essentially used in relation to those technologies and systems which, from the user's perspective, provide for the storage of electrical energy over some pre-defined time period and which may be replenished (re-charged) over multiple cycles, Table 2.2 goes some way to define the storage time period and the cycle life of energy storage technologies.

Storage Period	Time Period
Short Term	Milliseconds – seconds/minutes
Medium Term	Minutes – Hours
Long Term	Hours – Days

Cyclability	No. of Cycles
Low	10 - 1000
Medium	1000 – 10000
High	10000+

Table 2.2: Storage Period and Cyclability

The core energy conversion media may exist in a number of forms, including electrochemical, mechanical, electrolytic and chemical systems. The sub-sections below provide a brief resumé of some of the more important features of these technologies and their applications.

2.1 Electrochemical

2.1.1 Battery Systems

Battery systems represent the dominant form of electrochemical storage, in the form of arrays of individual cells. Battery systems are classified as either primary batteries (non-rechargeable) or secondary batteries (rechargeable); it is only the latter category that is considered here. Battery systems can range from small scale systems, at the Wh scale, for such applications as cell phones, through to multiple tens of MWh capacity systems, for power utility applications.

Lead Acid Technology

The Lead Acid battery is made up of plates, lead, and lead oxide (various other elements are used to change density, hardness, porosity, etc.) with a 35% sulfuric acid and 65% water solution. This solution is called an electrolyte and is directly involved in the electrode reactions and provides an excellent medium for ion conduction. The ubiquitous lead acid system continues to dominate battery storage, with it accounting for in excess of 50% of secondary battery sales, in a global market worth some $17 billion. Automotive SLI (starting, lighting and ignition), industrial traction and stand-by power/UPS (uninterruptible power supply) applications represent the principal outlets for lead acid battery system sales, with other applications including submarine propulsion and utility battery energy storage. The technology continues to be developed, particularly for partial state-of charge (S-o-C) applications, which include hybrid electric vehicles and remote area power supply (RAPS)/renewable energy systems (1, 2). Generally speaking lead acid battery technology may be defined as a long term storage solution with a medium cycle life.

Nickel Based Technology

Nickel cadmium systems have a pedigree almost as long as lead acid and capitalise on their low maintenance, high reliability and high power at low S-o-C characteristics, complemented by their overall robustness. NiCd batteries have a medium cyclability and a long storage period in any state of charge. Their applications base is diverse, including aircraft power systems, electric vehicles, power tools, portable devices, stand-by power and utility scale storage. The electrochemistry is however under the constant threat of its effective outlawing, due to concerns of cadmium toxicity (3).

It was this latter consideration that led to the development of the nickel metal hydride system, where "stored hydrogen" is utilised as the active material, as an alternative to cadmium. In the late 1960's scientists discovered that some metal alloys had the ability to store atomic hydrogen 1000 times their own volume. These metallic alloys are termed *hydrides* and typically are based on compounds such as $LiNi_5$ or $ZrNi_2$. In properly designed systems, hydrides can provide a storage sink of hydrogen that can reversibly react in battery cell chemistry. The most common cells that use hydride cathodes carry over the nickel anodes from NiCd cell designs. These cells typically have an electrolyte of a diluted solution of potassium hydroxide, which is alkaline in nature. Nickel metal hydride batteries are limited by a low cyclability and a limited storage period due to their high self discharge characteristics. Ideally NiMH should be stored in a cool place at about 40% state of charge.

The technology enjoyed a short-lived reign in the consumer electronics market in the mid-1990s, prior to itself being displaced by the lithium ion system.

Sodium Based Technology

As illustrated in Figure 2.1 NaS battery consists of liquid sulfur at the positive electrode and liquid sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte. The electrolyte allows only the positive sodium ions to go through it and combine with the sulfur to form sodium polysulfides. During discharge, as positive Na^+ ions flow through the electrolyte and electrons flow in the external circuit of the battery producing about 2 volts. This process is reversible as charging causes sodium polysulfides to release the positive sodium ions back through the electrolyte to recombine as elemental sodium. The battery is kept at about 300°C to facilitate the process.

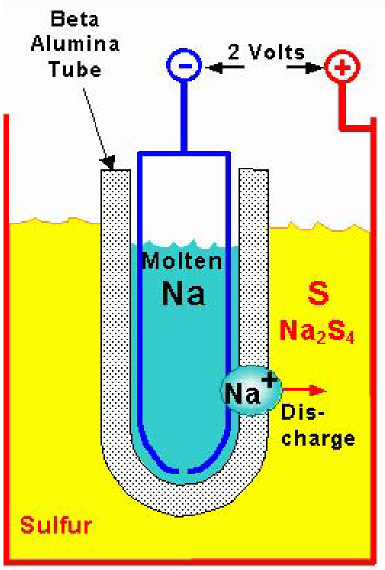


Figure 2.1 Overview of a 2V Sodium Sulfur Cell
(Source: Energy Storage Association, NaS)

The sodium sulphur technology is now in the early stages of commercialisation by NGK and TEPCO in Japan, with the latter finding niche electric vehicle and related traction applications.

Lithium Based Technology

The cathode in these batteries is a lithiated metal oxide and the anode is made of graphitic carbon with a layer structure as illustrated in Figure 2.2. The electrolyte is made up of lithium salts dissolved in organic carbonates. When the battery is being charged, the Lithium atoms in the cathode become ions and migrate through the electrolyte and separator toward the carbon anode where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge.

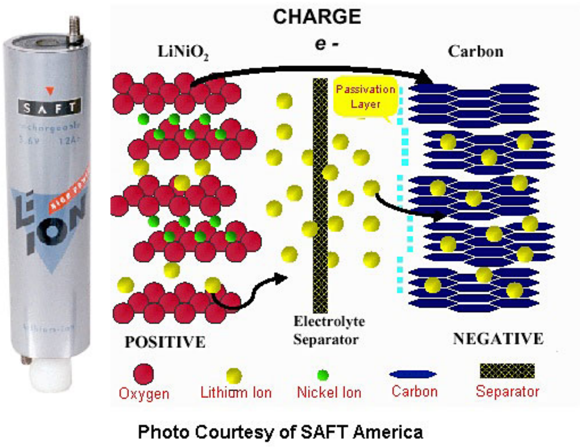


Figure 2.2 Sample Lithium Cell ElectroChemistry
(Source: Energy Storage Association, Li-Ion)

It is this technology that is now the technology of choice for the mainstream consumer electronics (3Cs; cameras, cell-phones and computers) markets, with cells being produced at a global scale of approaching one billion units per annum (4). Far Eastern suppliers dominate the market here, both in terms of the technology's development and its mass production. Many commentators believe that the Lithium ion system represents the zenith of battery technology, for all but some very specialist niche market applications. Such considerations are fundamentally based on Lithium's position in the periodic table and its electrochemical half cell potential of 3.04 volt. There is a consensus that a further 10 to 15% in energy density may be squeezed out of Lithium ion over the next ten years, by the elimination of weight and bulk from battery assemblies, with complementary cost reductions coming from the aggressive targeting of materials and components. Any further significant step change in performance may lie with variants on the basic lithium technology such as lithium sulphur. Lithium electrochemistries benefit from a relatively low self discharge thus suitable for long term storage however, the cells may be subject to aging and have a low cycleability, typically about 300 cycles subject to developments.

Important to note is that micro-fuel cells represent a significant potential challenger to the traditional battery solution for portable devices, provided challenging targets in relation to their fuel storage and handling, safety/regulatory aspects and cost can be met, fuel cells are discussed generally in section 2.4.

2.1.2 Flow Cells

Electrochemical, or Redox (Reduction/ Oxidation) flow cells are analogous to batteries in many respects, but with their chemical energy stored in electrolyte solutions, external to the flow cells (or modules) themselves, as shown in Figure 2.3. The electrolyte solutions are circulated through the flow cells, with electrochemical conversion taking place across an ion exchange membrane which separates the two electrolytes.

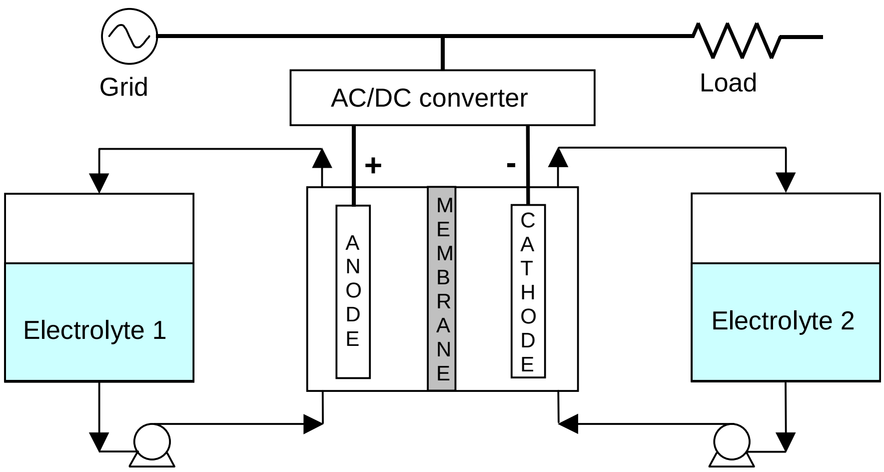


Figure 2.3: A Redox Flow Cell Energy Storage System

Power and energy then become independent variables, with system power rating being determined by the number of flow cells and their surface area, and energy capacity by the volume of the electrolyte solutions. Systems can therefore be designed to suit the requirements of particular applications, with the potential for the provision of medium/longer term storage capacity via the installation of an increased quantity and/or capacity of electrolyte storage tanks. This, coupled with a potentially excellent electrolyte cycle life and electrolyte exchange, makes flow cell systems generally quite attractive.

Developmental and demonstration activities have centred around three principal electrochemistries to date, namely the vanadium, zinc bromine and polysulphide/bromide systems, with a more recent development in terms of the zinc cerium electrochemistry (Plurion).

The vanadium redox battery (VRB) employs the V2/V3 and V4/V5 redox couples in sulphuric acid as the negative and positive electrolytes respectively. Vanadium redox batteries are potentially suitable for a wide range of energy storage applications, including power quality, uninterruptible power supplies, peak shaving, increased security of supply and integration with renewable energy systems.

The two principal developers and suppliers of vanadium redox systems to date have been VRB Power Systems Incorporated and Sumitomo, with extensive cross linkages between the two. These two companies have supplied circa eight installations to date, typically at the multiple tens of kW/multiple hours scale. Further developmental programmes are also being pursued by such parties as e-fuel Technology, HILTech Developments, Magnam Technologies and the Cellennium Company.

The zinc bromine system was first developed by Exxon in the early 1970s and comprises a zinc cathode and a bromine anode separated by a microporous separator. Zinc bromine batteries are suitable for a range of applications with discharge times ranging from seconds up to several hours. The primary focus of development and demonstration projects to date has been for grid connected utility applications for load levelling and renewable energy system optimisation. At the present time, the only company that is actively developing and supplying zinc bromine batteries is ZBB Energy Corporation (ZBB). ZBB's technology is now in the first stages of commercialisation, via the company's F2500 baseline turnkey product, a fully containerised 500 kWh (250 kW x 2 hours) grid-interactive storage system. In addition, it can supply individual 50 kWh modules for renewable energy applications. Circa half dozen units have either been supplied or projected to date.

The polysulphide/bromide system, better known as Regenesys™, has previously been developed over the past twelve years by RWE Innogy and its predecessor companies (Innogy and National Power). The system has been marketed as a grid-connected utility scale storage system, for power ratings in excess of 5MWe. Notwithstanding the significant scale-up of and commitment to Regenesys™ related activities, RWE Innogy announced in December 2003 that it would no longer be funding the technology's development and subsequent commercialisation. It has since announced (September 2004) the sale of an exclusive licence on the Regenesys™ intellectual property and related physical assets to VRB Power Systems, for the sum of $1.3M (6). The basis of this deal is thought to principally relate to the IP (Intellectual Property) associated with the module design, plus the acquisition of significant stocks of Nafion membrane material.

2.2 Mechanical

2.2.1 Kinetic Energy Storage (Flywheels)

Flywheel storage, more correctly referred to as kinetic energy storage, provides a high power rating storage medium for short term storage periods, typically sized to discharge over some 10 to 100 seconds, and virtually unlimited cycle life subject to the mechanical reliability of the components, Figure 2.4 shows a typical configuration.

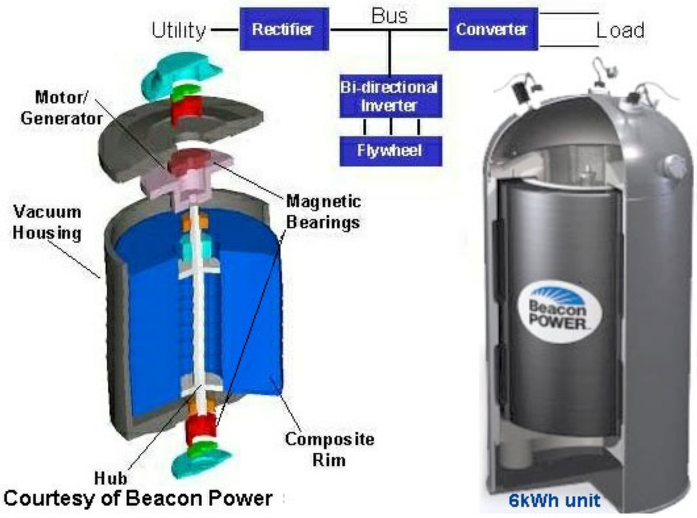


Figure 2.4 Typical High Speed Flywheel Configuration
(Source: Energy Storage Association, Flywheels)

Conventional steel rotor systems have been in place for many years and are often installed in combination with stand-by diesel generators, to provide extremely secure power supplies to such applications as primary broadcasting stations, financial processing centres and air traffic control hubs. Leading commercial suppliers include Piller, Active Power and Satcon.

Much of the current research and developmental effort in relation to kinetic energy storage is directed towards high speed machines, running at tens of thousands of RPM and utilising state-of-the-art composite materials technology. The high directional strength properties of such composites, in combination with their relatively low densities allows the designer considerable freedom in optimising the overall flywheel configuration and hence its specific energy and specific power. Units have already been supplied on a commercial basis by Urenco Power Technologies (UPT) and with further systems being developed by AFS-Trinity, Beacon Power, Piller and others. UPT, in particular, has implemented various systems providing railway trackside voltage support and has also demonstrated the application of a device providing a short-term power smoothing capability in relation to wind turbine output (8). However, the company's future is now far from certain, following the decision by its Urenco parent, May 2004, to cease funding the development of the technology (9).

2.2.2 Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) complements pumped hydro as a larger scale (100 MW class), medium/longer term (hours) storage option and unlimited cyclability. Input power, storage capacity and output power are independent variables, which provide for a great degree of design flexibility, Figure 2.5 illustrates a typical system configuration.

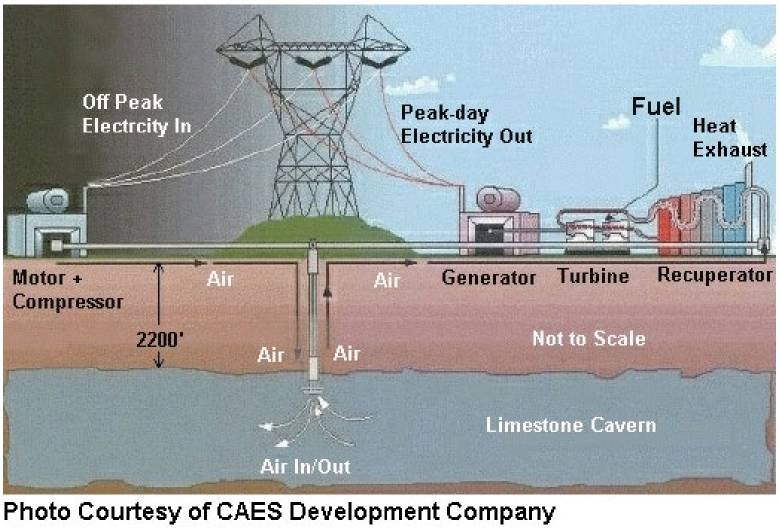


Figure 2.5 Typical CAES System
(Source: Energy Storage Association, CAES)

Only two CAES plant have been constructed and commissioned to date, namely the 290 MW Huntdorf plant in Germany (1978) and the 110 MW McIntosh plant in Alabama (1991) (10, 11). Operating experience on both plants is extremely favourable, with the former having completed some 7,000 starts to date, with 90% availability and 99% start reliability.

Such large scale implementations rely on the availability of favourable geological conditions, for their underground storage reservoirs. More recently, attention has focussed on the possibility of small scale CAES, utilising fabricated pressure vessel/piping storage and able to provide some 3 to 5 hours storage capacity, at ratings of 5 to 10 MW. Such small scale CAES systems are of particular interest in the US, in the context of buffering wind resources in several states. It is these smaller scale systems and the opportunities they create that are of particular interest (in the present exercise, to ITI Energy).

2.3 Electrical

2.3.1 Electrolytic (Supercapacitors)

Electrolytic storage, in the form of capacitor banks, has been established as a recognised part of electrical systems design for a century or more, albeit principally for smoothing purposes and for selected short duration, high discharge applications.

The past two decades have however seen the advent of a new generation of electrolytic devices, known as supercapacitors, or electrochemical double layer capacitors (EDLCs), which offer a step change in performance over their more conventional counterparts. They offer a significantly higher energy level than conventional capacitors (on a similar size and weight basis), and can deliver that charge either quickly or more slowly depending upon the application and have a high cycle lifetime. Thus, in essence, supercapacitors combine the energy storage features of batteries with the power discharge characteristics of capacitors. Figure 2.6 illustrates a typical supercapacitor configuration.

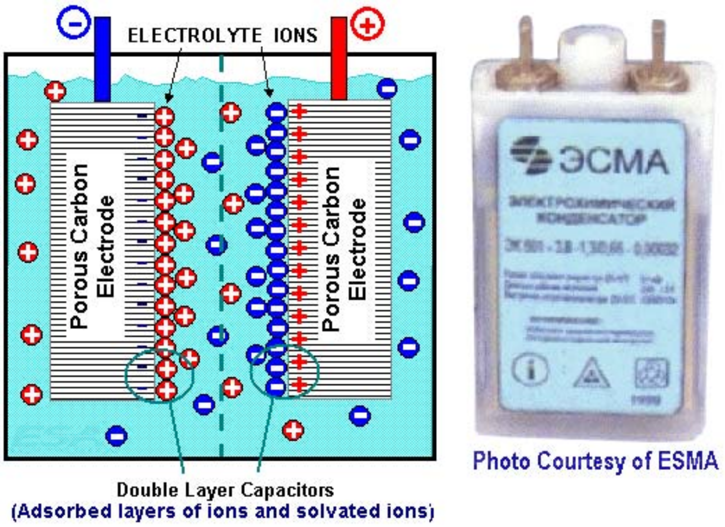


Figure 2.6 Typical Supercapacitor Construction
(Source: Energy Storage Association, Supercapacitors)

Supercapacitors can be divided into two broad groups, namely those using carbon-based materials and those using various metal oxide materials, with the former being the material of choice for both low and high voltage applications. The porous structure of the carbon-based electrode material allows its surface area to approach 2000 square metres per gram, much greater than can be accomplished using flat or textured films and plates. The charge separation distance is determined by the size of the ions in the electrolyte, which are attracted to the charged electrode. This charge separation (less than 10 angstroms) is much smaller than can be accomplished using conventional dielectric materials and it is this combination of extremely small charge separation and enormous surface area that leads to the significantly higher energy density of supercapacitors relative to conventional capacitors.

The mechanisms by which EDLCs store and release energy are completely reversible, making them extremely efficient and able to withstand a large number of charge / discharge cycles. They can store or release energy quickly, and they can operate over a wide range of temperatures and require no maintenance. Supercapacitors come in a wide range of sizes ranging from small cell devices of a few farads capacitance and roughly the size of a postage stamp up to medium and large cell devices which are roughly the size of a soda can and can have a capacitance of several kilo-farads. They can be implemented in standard modules or be custom designed to a specific application.

Supercapacitors were first used in military projects for cranking the engines of battle tanks and submarines, and as replacements for batteries in missiles. Since then, they have been used in a range of applications including;

- enhanced power quality and uninterruptible power supply for industrial applications
- diesel engine starting
- transient load levelling and regenerating the energy of braking in electric/hybrid-electric vehicles
- voltage stabilisation and regenerative braking for trains.

Worldwide, there are several organisations currently developing and producing supercapacitors on a commercial basis, but with in excess of 70% of the world market supplied by Maxwell Technologies (USA) (7).

2.4 Chemical Storage

2.4.1 Fuel Cell

Fuel cell power plant is increasingly recognised as the potential power generation technology of the future, with the past decade in particular having seen a vast increase in underlying funding, developmental activities, systems demonstrations and early stage commercialisation activities. Fuel cells themselves are an electrochemical energy conversion medium, which convert the chemical energy contained in an external fuel source to electrical energy. They offer the potential for clean, quiet operation at high conversion efficiencies, with minimal or even zero noxious emissions. Furthermore, systems can be designed and deployed across a range of sizes, ranging from individual cells through to multiple series/parallel arrays for various traction and utility power applications. Figure 2.7 illustrates a typical fuel cell construction and operation.

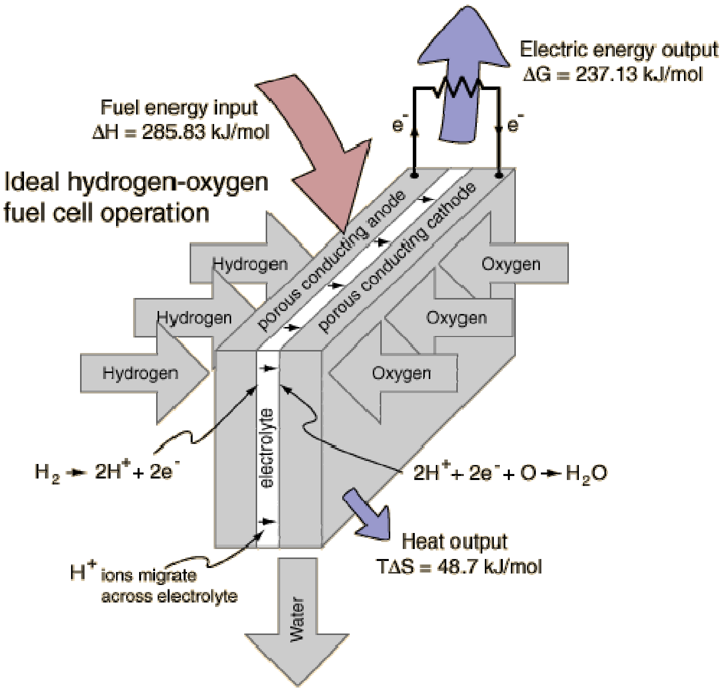


Figure 2.7 Typical Fuel Cell Construction and Operation

Fuel cell technologies themselves disaggregate into six principal categories, according to their make up and electrolyte composition. The origins of the alkaline fuel cell (AFC) date back to the original Bacon cells of the 1930s, with the technology achieving international recognition in the NASA space programme, from the 1960s onward. The technology is capable of achieving very high power densities, although it does require extremely high levels of purity in its fuel and oxidant streams. The phosphoric acid system (PAFC) has been available in the form of packaged CHP power plant for more than a decade and has accumulated in excess of 2.5 million fleet hours of operation, at sustained high levels of availability. The proton exchange membrane (PEM) system is distinguished by the solid state nature of its electrolyte. It is under active development on an international basis, particularly in terms of its small scale portable power, residential scale CHP and automotive applications potential, with early fleet demonstrations in passenger cars and buses already in hand in relation to the latter applications sector. The direct methanol fuel cell (DMFC) is a recent offshoot of PEMFC technology and utilises liquid methanol without the need for reformation to hydrogen. The molten carbonate fuel cell (MCFC) is a high temperature device and employs a carbonate salt mixture as its electrolyte. Early pre-commercial, demonstration units are in place in a number of countries. The solid oxide (SOFC) system employs a solid state ceramic electrolyte and is characterised by its high operating temperature, of between 800^{o}C and 1000^{o}C. Early demonstration units have been placed in various applications, ranging from residential scale CHP through to multiple hundreds of kW power generation systems.

The PEM, alkaline and PAFC systems all represent low temperature technologies and rely for their operation on the supply of hydrogen fuel. It is the PEM and alkaline systems in particular that most closely relate to the present energy storage brief, when utilised in conjunction with appropriate hydrogen storage and production facilities. Such systems can be engineered at sizes ranging from the micro-scale (e.g. just a few Watts output) through to systems in the tens and hundreds of kW range. The former find potential applications in the portable power sources domain, whereas the latter relate more to the transport and stationary power generation sectors.

2.4.2 Hydrogen as a Vector

Hydrogen can be used for many purposes, as an intermediate in the production of electricity, as an additive to natural gas or as a fuel to replace fossil fuels for transportation either through combustion in an internal combustion engine or through the use of fuel cells to produce electricity. Hydrogen production and storage are therefore potentially key enabling technologies for such pseudo-storage related fuel cell applications. Hydrogen storage permeates a wide range of applications domains and remains one of the principal challenges facing the broader "hydrogen economy" concept. Potential storage solutions include compressed gas, cryogenic storage, hydrides and absorbent materials.

Potential cyclic chemical production techniques for hydrogen include, water splitting, or hydrocarbon cracking from either biomass or conventional fossil fuels. Each technique has its respective advantages, disadvantages and level of maturity. Discussion of these chemical production processes and storage solutions is not within the scope of this report however in the context of the hydrogen economy is important to understand the alternative means for producing, storing and handling hydrogen particularly as it may represent a significant energy storage medium in the future. Figure 2.8 shows a schematic of future fuel cells and hydrogen economy strategies.

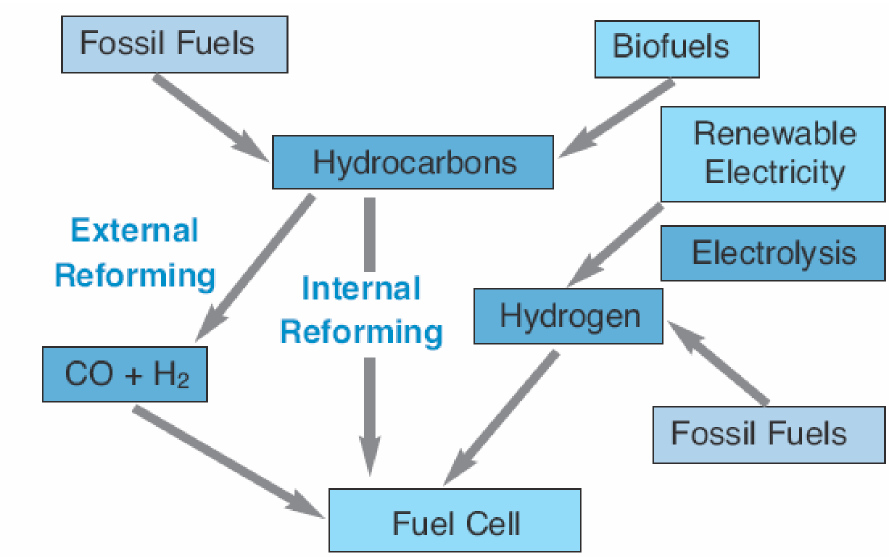


Figure 2.8 Fuel Cell/Hydrogen Economy Strategies
(Source: Fuelling a Greener Economy, Institute of Materials, Minerals and Mining)

Electrolysis is relevant to discuss in more detail as it may be viewed as the reversal of the fuel cell process, Consider Figure 2.9. By providing electrical energy, water can be dissociated into the diatomic molecules of hydrogen and oxygen. The electrolysis of one mole of water produces a mole of hydrogen gas and a half-mole of oxygen gas in their normal diatomic forms.

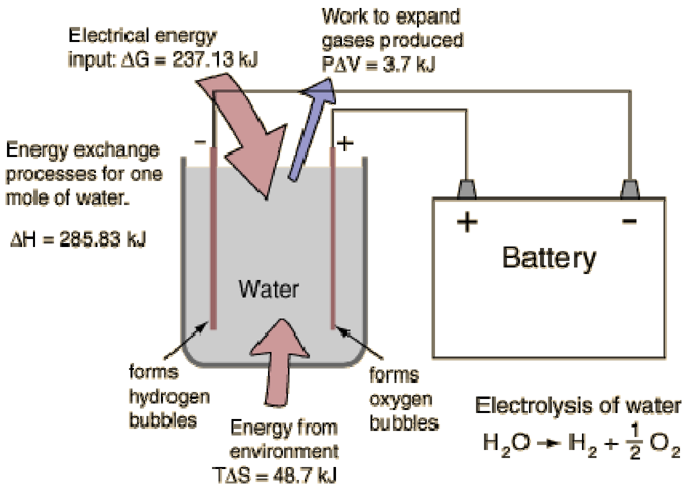


Figure 2.9 Basic Electrolysis Configuration

Electrolysis is a key component in many renewables related fuel cell/hydrogen related developments, with the performance of the electrolyser under a variable input loading pattern being a key design requirement.

2.4.3 Alternative Fuel Vectors

As well as hydrogen, other fuel vectors are emerging as potential strong chemical energy storage media. Consider Table 2.3 of alternative vectors each with different properties, applications and production techniques, again detailed discussion of these vector is not within the scope of this report but it is useful to understand that hydrogen is not the only potential ‘fuel of the future’.

Fuel Vector	**Typical Chemical Energy Density**
Hydrogen	142.0 MJ/kg
Ethanol	29.7 MJ/kg
Ammonia	17.0 MJ/kg
Automotive Gasoline	45.8 MJ/kg
Methane	55.5 MJ/kg
Methanol	22.7 MJ/kg

Table 2.3 Alternative Fuel Vectors
(Source: Chemical Energy, The Physics Hyper text Book)

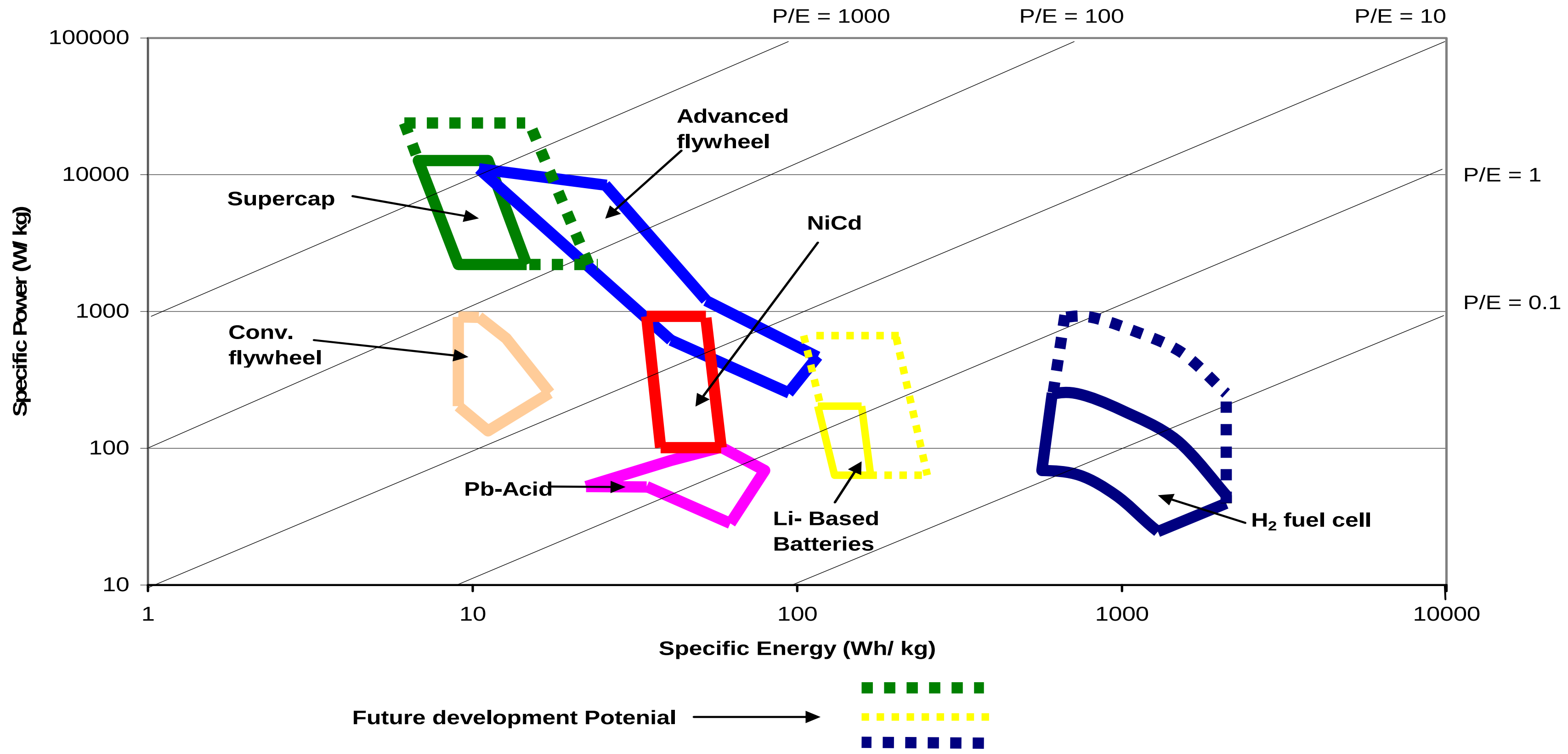
2.5 Technology Comparison Summary

The previous sections (2.1 to 2.4) have presented a wide range of information and data, in relation to the various storage technology options available. Table 2.4 summarises the principal advantages and disadvantages of these technologies, in a single tabular format, with Figure 2.10 providing a graphical illustration of their energy and power ratings, in the form of a Ragone plot, superimposed on this plot is the anticipated improvements in power and energy performance of selected technologies. Significant developments are foreseen in supercapacitors, lithium based batteries and H2 fuel cell related technologies. The other technologies, flywheels, NiCd and lead acid, may experience certain incremental improvements.

	Batteries	Flow Cells	Electrolytic	KESS	CAES	Hydrogen/Chemical
Pros ….	• widely understood, accepted & available • low/zero maintenance • reasonable storage capacities • acceptable cost levels • reasonable cycle life • suitable for range of applications and sizes • good round trip efficiencies • absence of moving parts	• modular construction • power & energy ratings as independent variables • able to configure for applications • siting flexibility • suitability for larger scale/longer term applications • high cycle life expectancy	• suitability for high power/short duration discharge applications • high cycle life expectancies • ability to configure into larger scale/higher power systems • very high power densities • beginning to challenge batteries in selected appns.	• high cycle life expectancies • suitability for deep discharge operations • high power, multiple tens of seconds application domain • environmental tolerance • low maintenance • quantifiable S-o-C • high round trip efficiencies	• storage capacity, charge rating and discharge power rating as independent variables • suitability to service longer term/larger scale storage requirements • turbo machinery aspects well understood • low visual intrusion • high reliability • low standing losses	• ability to configure for applications • energy & power ratings as independent variables • possible linkages between stationary and renewable applications bases • ability to scale-up, to larger scale applications
Cons….	• self discharge/ parasitic losses • performance degradation at low/high temperatures • requirement for battery management system/cell balancing	• limited applications/ experience base • cost • low energy density/large footprint • limited number of suppliers	• low energy density • cost • requirement for systems integration	• capital cost • size/weight • limited supply base • containment • mounting (for mobile appn) • ancillaries • parasitic losses	• requirement for favourable geological matches (large scale) • planning/permitting • unproven technology (mini-CAES) • fired combustion plant	• safety & licensing • low round trip efficiencies • unproven technologies • capital cost • limited experience base

Table 2.4:- Summary of Principal Technology Advantages and Disadvantages

Figure 2.10: A Ragone Plot



2.6 Storage Technology Cost Comparisons

A direct comparison of storage systems costs in any exercise such as this is somewhat problematical, both due to the extremely wide range of technologies considered and their equally wide ranging applications domains. The presentation of costing information and data is also very much a function of the application and systems make-up, with relatively short duration/high discharge rate media being more appropriately costed in terms of their power ratings, whereas longer duration, multiple hour duration systems are more appropriately costs in terms of their energy capacities. Figure 2.11 attempts to illustrate a range of technology costs in terms of specific power and energy.

It is worth noting from Figure 2.11 that although metal air batteries appear to outperform other technologies for energy management applications (due to high energy density and low cost) they are essentially primary cells exhibiting inefficient electrical recharging. The rechargeability of these batteries needs to be developed further before they can compete with other rechargeable technologies.

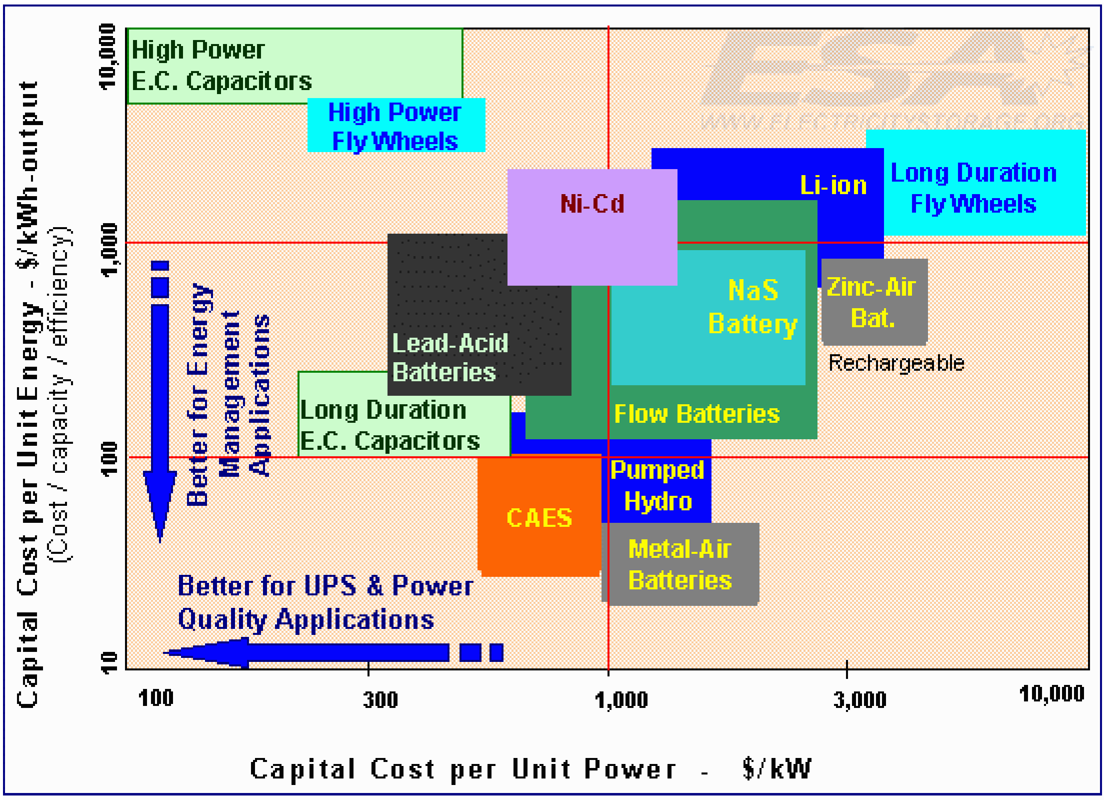


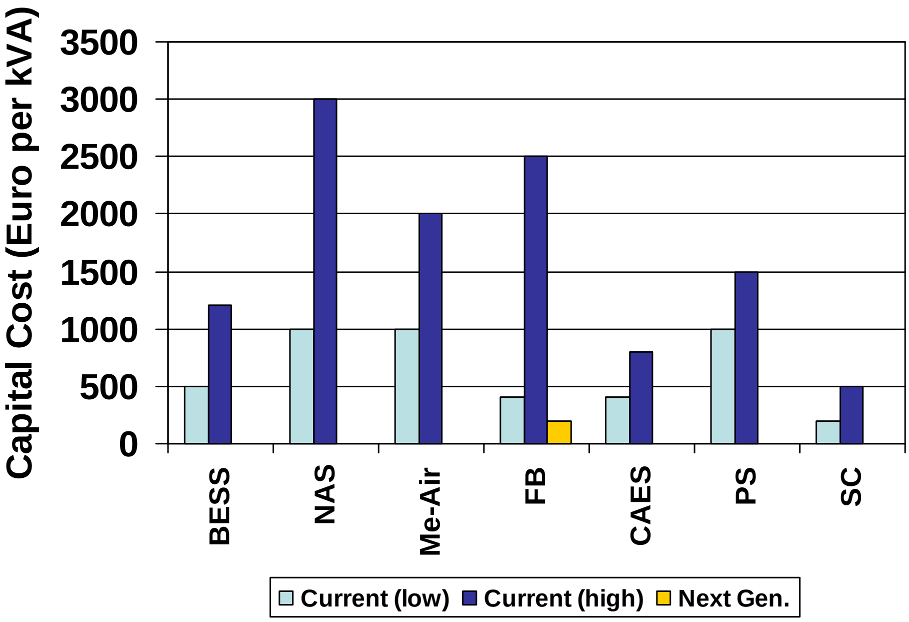
Figure 2.11 Technology Comparative Costs
Source: Energy Storage Association, Capital Cost

Table 2.5 below attempts to provide a first pass summary of such information; for the range of technologies considered.

	Batteries	Flow Cells	Electrolytic	KESS	CAES	H_2 / chemical
$/kWh	160 - 1600	1000 -2000			50 - 100	‡
$/kW			50 - 200	50 - 500		‡

Table 2.5: Summary of Storage System Costs

In addition to this data the following Figure represents a similar analysis comparing capital costs (Euro per kVA) of different storage types:



BESS	NAS	Me-Air	FB	CAES	PS	SC
Battery Energy Storage System	Sodium Sulfur Batteries	Metal Air Batteries	Flow Batteries	Compressed Air Energy Storage	Pumped Storage	SuperCapacitor

Figure 2.12 Energy Storage Capital Cost Comparison

As is seen from Table 2.5 and Figure 2.12, costs can vary significantly, even within a single systems category. For a number of flow cells, CAES and hydrogen systems, the complete systems costs are obtained from a summation of the principal sub-assemblies and associated Balance-of-Plant. The ability to configure these latter systems according to the application, with power and energy being completely independent variables, further compounds the difficulties associated with any like-for-like cost comparisons.

The cost make-up of the more discrete storage technologies, such as batteries and capacitor systems, is an amalgam of their raw materials costs, component fabrication, labour, plant depreciation and underlying R&D expenditure, amortised

‡ Limited commercial applications and data available, and dependent upon fuel and conversion process

across the technology development. Such information and data are highly proprietary in nature although with materials costs generally equating to some 25% to 50% of battery costs, for the principal battery technologies. Direct labour costs can also be a significant part of the overall cost equation, as exemplified by the progressive move of battery manufacturing to low labour cost economies, particularly in the Far East.

3 MARKETS AND APPLICATIONS

This section of the report focuses on the range of market applications for energy storage and a consideration of how these applications are changing and developing over time.

Electrical energy storage related applications permeate virtually every aspect of life as we know it today, with yet further and more demanding requirements coming on stream, each successive year.

The total energy storage market, as defined for the purpose of this foresighting work, has annual sales far in excess of $40Bn and annual growth rates of more than 10%. Storage solutions appear in a wide variety of applications ranging from batteries for mobile phones to pumped hydro storage for large scale electricity supply-demand balancing; and from hydrogen storage to batteries for (hybrid) electric vehicles. Figure 3.1 depicts a number of energy storage applications as a function of power capacity requirement and storage time.

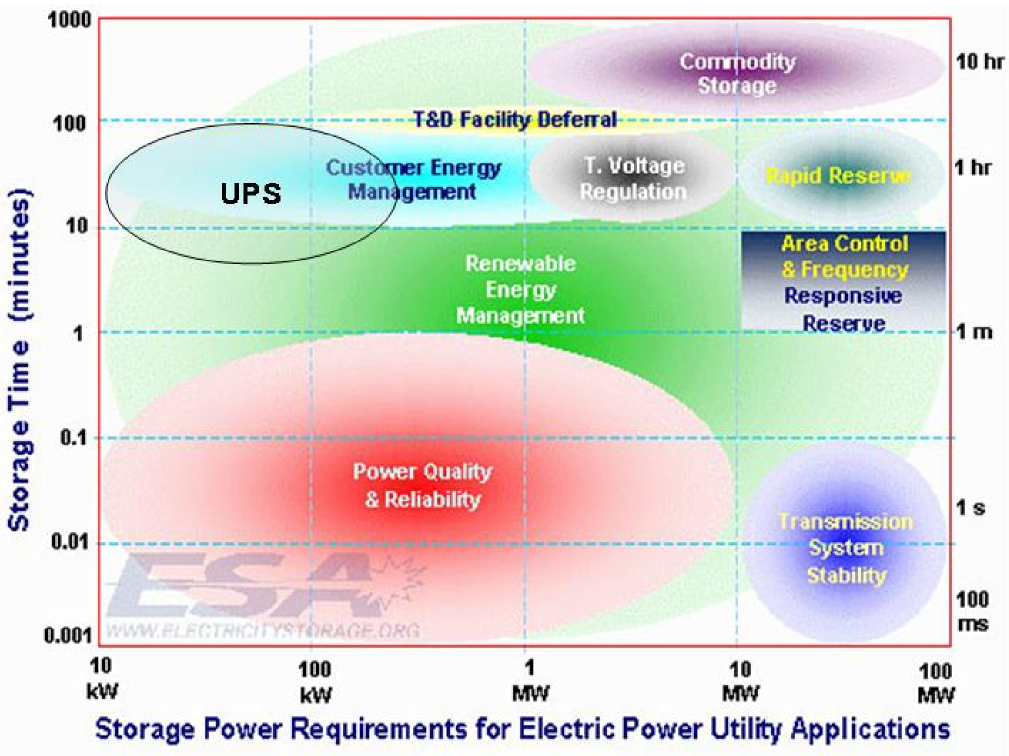


Figure 3.1 – Energy storage applications

The range of storage applications may be loosely categorised into 3 sectors:

1. Utility & Industrial
2. Mobile and Transport (Back-up)
3. Portable

There is a high degree of interaction and crossover between these sectors, as is summarised in Figures 3.2 and 3.3. For instance, UPS has applications in utility networks as well as in the transport sector.

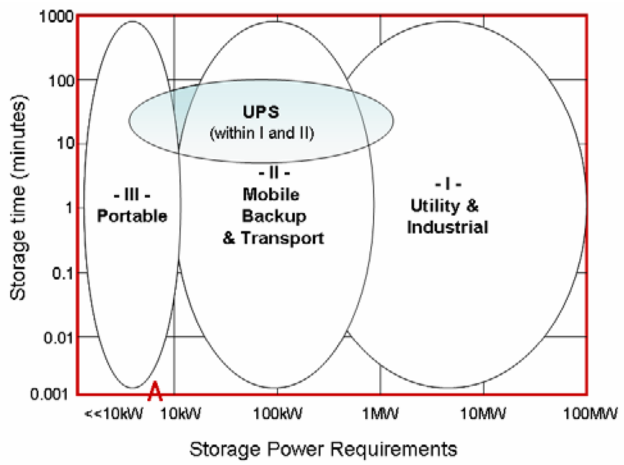


Figure 3.2:- Applications & Markets

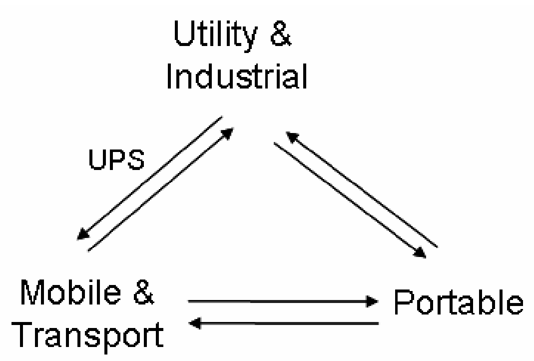


Figure 3.3:- Applications & Markets

The following sections aim to provide an overview of the salient characteristics of each of these 3 market sectors, prior to identifying and reviewing the technology related opportunities in each.

3.1 Utility and Industrial Applications

The stationary and utility sector embraces a wide range of applications, all with the objective to either balance supply and demand of large quantities of energy over time, or to ensure the quality of the electricity wave signal. The applications are mainly found in the energy supply side and are therefore sold into a business-to-business market. They can be summarised as follows:

- Power utility related applications
  - Load levelling
  - Renewables integration (unpredictable generation, signal quality)
  - Asset deferral (capacity constraints)
  - Power quality management (frequency, voltage regulation)
  - Network stability and spinning reserve
  - Arbitrage
- Uninterruptible Power Supply (UPS) for high risk / value applications:
  - Industrial process / plant
  - Health care
  - IT and other high end business services
- Other “Off Grid” industrial or commercial applications:
  - Telecoms remote infrastructure
  - Remote sensing, measurement & control systems
  - Oil and Gas (e.g. downhole, subsea)

3.1.1 Power Utility and Related Applications

The established power utilities sector is presently operating in a period of unprecedented change, driven by the challenges of deregulation, competition, moves towards distributed generation and the ascendancy of renewable power sources. Renewables in particular bring with them the challenge of intermittency, which becomes an increasingly more significant issue, as their penetration increases. [4]

Distributed generation, whether through renewables or other prime movers, presents a whole series of challenges, associated with multiple hundreds, if not thousands of connections at the low and medium voltage distribution network levels. Active distribution network management is one possible scenario and, again, presents opportunities for such technologies as storage.

The concept of the broader “hydrogen economy” is also under consideration for the medium/longer term, which will require an effective interface with the electricity network as it exists today.

The role for innovative thinking and design solutions is increasingly recognised if such top level objectives are to be met, with regulatory considerations already moving towards the incentivisation of such measures (12). Storage systems represent a multi-faceted technology, potentially able to extract value from multiple revenue streams and thereby form an integral part of any utility’s design and engineering solutions portfolio.

The penetration of storage into the mainstream power utilities sector to date has been limited almost entirely to large scale pumped hydro schemes, with total global installed capacity equating to circa 90 GWe, as summarised in Table 3.1 (13, 14, and 15).

[4] See ITI Energy Report on Low-Cost Renewables

Country	Pumped Hydro Capacity (MWe)
Japan	20,910
United States	19,500
Italy	5,244
Russia	5,068
France	4,280
China	4,200
United Kingdom	2,800
Taiwan	2,620
Germany	2,110
Poland	1,738
South Korea	1,700
Australia	1,740
Belgium	1,200
Luxembourg	1,000
Ireland	290
Other	15,600
Total:	**90,000**

Table 3.1:- Principal Pumped Hydro Storage Capacity by Country

This equates to a historical market penetration of circa 3% of the installed global generating base of some 3,270 GWe, Table 3.2 (16). Storage penetrations vary considerably and reflect both the topographical conditions in particular countries and their electricity supply/demand characteristics. Some 32 GWe of pumped storage exists within the European Union, accounting for 5.5% of the total installed power generation capacity base. In countries such as Austria and Switzerland, with a favourable Alpine topography, pumped storage approaches 20% of the capacity base and this Figure is 80% for Luxembourg. In Japan, which suffers from seasonal and daily demand peaks, storage accounts for some 10% of the installed capacity base.

Region	Capacity Base (GWe)
North America	936
Asia & Oceania	898
Western Europe	634
Eastern Europe & Former Soviet Union	425
Central & South America	180
Africa	100
Middle East	96
Total:	**3,269**

Table 3.2:- Year 2000 Global Installed Generating Capacity Base

Various analyses (17), supported by the available anecdotal evidence, indicate that storage penetrations of circa 20% to 25% can be accommodated into integrated electrical power systems. Iannuci (18) predicts that storage will take 10% of the US market for new generation capacity over the next 10 years, equivalent to 24 GW of storage systems.

Market Potential Estimate

If an average achievable penetration level of 10% is assumed (e.g. as in Japan), this would indicate a potential global market of some 330 GWe of storage capacity. Furthermore, it is worth noting that the global generating capacity base has grown at an average rate of 3.5% pa over the last 20 years, indicating that storage has the potential both to penetrate the existing capacity base and also take a proportionally larger share of the new capacity. On top of the existing 90 GWe this would equate to a potential new large scale power storage capacity of 10 GWe per annum over the next 20 years. If we assume a system capital cost of $500-$1000 per kWe, this leads to a $5-10 Bn annual spend in this market.

The other side of the equation consists of an estimate of the value of 10 GWe of energy storage capacity in the market. If we assume the price for 1 kWH storage is $0.05 (based on the difference in peak and off-peak electricity price[5] and we further assume that all storage capacity will be used for 2 hours every day of the year and at 100% conversion efficiency, it follows that 10 GWe storage capacity can generate revenues in the order of $350M per annum or a total market of ~$11Bn per annum if storage were to achieve a full 10% penetration relative to generation capacity. On this basis the current market (of 90GW) is worth in the region of $3Bn per annum, not including the market for new or replacement equipment and maintenance / repair services.

Given a capital cost of $5-10 Bn for this amount of storage capacity, this leads to at least a 15 to 20 year payback time at current cost of technology. The most promising technologies to date for large scale energy storage are:

- Pumped hydro (limited by topography)
- CAES ($500-$1000 per kWe – also limited by topography and by HSE risks)
- Flow Cells ($500 - $1000 per kWe level, estimated by manufacturers)

The above considerations essentially relate to the determination of the potential for the implementation of storage, at the macro-level. The placement of storage within the electricity sector will be a function of the evolution of the electricity industry itself, the associated regulatory and legislative regimes and the characteristics and performance of the different storage systems available. The current trend in favour of renewables and distributed generation is likely to favour medium scale (1-10 MW) distributed storage systems. Any return to larger scale central generation and/or nuclear, will shift the balance towards large scale storage, analogous to the existing pumped storage capacity. Various statements in recent months[6] indicate at least a re-examination of the nuclear option in the UK as well as in other countries.

[5] Source: Essent website consumer prices www.essent.nl

[6] Expert sales Five Year Deadline for Nuclear Decision. Times online, www.timesonline.co.uk, 4th October 2004

Smaller scale micro-grids, community energy systems and other 'islanded' power distribution networks represent another potential high growth area, where storage becomes increasingly important, in the absence of any larger integrated networks which traditionally provide for load buffering and security of supply. It is worth noting that many of the Scottish islands potentially fall into this category, with the high costs of fuel shipments to the isles bringing alternative renewables based schemes forward for more active consideration. The principal beneficiaries here may well be the energy scheme stakeholders themselves, rather than the more mainstream utilities, which may serve to accelerate the uptake of technologies such as storage.

3.1.2 Uninterruptible Power Supply (UPS)

UPS solutions are required where power failure or interruptions can cause:

- Safety and/or environmental damage
- Significant losses in business down-time or equipment damage

UPS applications represent a clear established market for small/medium scale energy storage, with market growth being driven by demand for ever more secure power supplies for computers, IT, telecoms and associated systems. The computer and telecoms sectors account for 60% of global UPS sales. As concerns over grid stability increase due to network aging and adoption of distributed generation at scale, so too will the market potential for UPS increase. Table 3.3 provides a breakdown of the global UPS market, together with indicative growth rates (21).

Region	**Market value ($million pa)**	**Average annual growth rate (%)**
North America	2,300	8.5
Europe	1,500	5.0
Pacific Rim	1,400	16.0
World	7,700	12.0

Table 3.3: Global UPS Market Values

Typical ratings of UPS devices are:

- 1 to 2.9 kVA for systems used to protect PCs and workstations
- 3 to 10 kVA for systems used to protect telecoms systems
- above 10 kVA for industrial end-use applications

Power utilities have extensive use for UPS to manage balance swings and unplanned outages. Their requirements vary from milliseconds to hours and from a few kWs to many MWs. Technologies that are used for utility UPS include batteries, flywheels and super-capacitors.

UPS systems vary considerably in price, depending on their specification. Off-line power protection devices for stand-alone PCs retail at around the $150 level, with high specification systems for servers, networks, telecoms and industrial process control applications costing typically between $1,000 and $3,500.

Sealed lead-acid batteries remain the technology of choice for UPS systems, although there are competing technologies in flywheels, supercapacitors and flow cells, particularly in niche applications.

3.1.3 Other "Off Grid" Industrial and Commercial Applications

There are a number of specific requirements for energy storage in remote locations, where there is no connection to the electricity grid and which are difficult to access for refuelling. Mobile phone network operators require signalling stations in remote locations in order to guarantee high degrees of geographical network coverage. These stations are unmanned and for their power supply they often have a combination of small scale power generation and storage devices. Typical power requirements are in the 5-50 kW range and refuelling takes place every 3 to 6 months.

Other remote storage applications can be found in condition based monitoring of assets of infrastructure operators, like utilities, and in measurement and control systems for organisations that operate in remote areas, like forestry, weather stations, etc.

A third category of applications can be identified in providing power into remote (and often severe) environments, like down-hole or subsea in the oil & gas, or mining sectors. These are applications where umbilical and local power generation cause limitations in flexibility or performance.

These are just some examples of a vast amount of applications for specific storage solutions. Although the markets for each of these solutions is relatively small, the added value can be significant and therefore the obtainable price premium can be considerable.

3.1.4 Utility & Industrial Supply Chain Considerations

Large scale storage

Key benefits of large scale storage are reduction of and more efficient use of generation capacity and improved power quality and reliability. These benefits will be captured by a number of players along the value chain (generators, network operators, suppliers, traders, etc.). Maximum financial advantage is gained where an uninterrupted value flow can be demonstrated (e.g. from generation, through transmission, distribution and to supply). Such a scenario principally exists in vertically integrated utilities, which are increasingly threatened as governments worldwide undertake programmes of utility reform. The role of governments and their complementary regulatory regimes may represent a key facilitation mechanism and market driver, in the introduction of energy storage technologies. Although conversely introduction of new systems may be constrained in regulated markets where spend must be focused on core business.

The underlying technologies for pumped hydro and for CAES are well known and can be delivered by many companies. However, for CAES, only 2 organisations have experience with operational plants. Flow Cell technologies are only now emerging as commercial options and there are only a few manufacturers.

UPS

Utilities (generators and network operators) are in the first place responsible for delivery of uninterrupted, high quality power supply to consumers. As such, they will be the primary customers for large scale UPS solutions. They are mainly driven by the standards that are set by governments and regulators and by the ability of their assets to deliver against these standards.

When industrial or private consumers require power supply quality above the regulated standards, they will have to pay a premium for this, in the form of the smaller scale UPS solutions. Solution manufacturers will sell into a business as well as into a consumer market.

3.2 Mobile and Transport Applications

In contrast to the utility applications sector discussed above, which represents a large potential market for energy storage, the mobile and transport applications sectors represents a mixture of both significant established markets and potential emerging markets, summarised below:

- Transport
  - On-board power for conventional vehicles; starting, lighting and ignition (SLI)
  - Alternative drive trains to ICE -> Electric Vehicles e.g. LGVs, Bikes, military vehicles, leisure
  - Hybrid vehicles e.g. ICE+battery, Fuel Cell + battery
  - Aerospace e.g. all electric planes (expect for propulsion)
  - Marine e.g. all electric ships with generators plus electric propulsion system
- Mobile (e.g. moveable power delivery systems)
  - Emergency power and light
  - Signalling
  - Military
  - Leisure (e.g. caravans, yachts)
  - Industrial applications (e.g. mobile robotics, AUVs/ROVs)

3.2.1 Transport Market

Most of the existing market is for battery systems, principally for starting, lighting and ignition (SLI). This market segment is $17Bn in its own right, consisting predominantly of lead acid battery technologies (Figure 3.4).

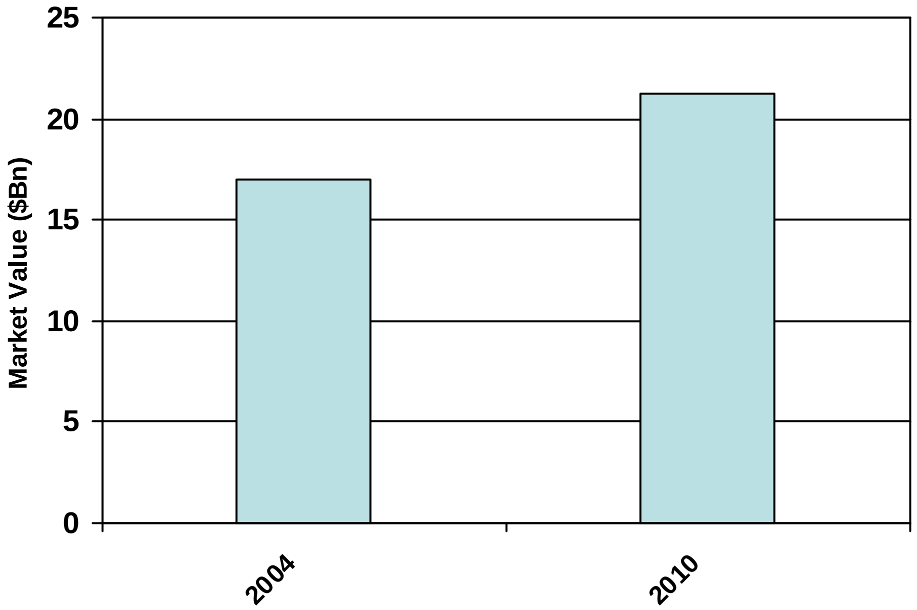


Figure 3.4 – Global SLI Battery Market Size ($17Bn)

Most of the growth in the Transport market segment will come from Electric Vehicles (EV) and Hybrid EV (HEV). These market segments are still small, but we expect significant growth. Although there will be competition from fuel cells and other technologies, a significant role is expected for battery technologies, including Nickel Metal Hydrates (NiMH) and Lithium-Ion. This could become a billion $ market in its own right (see Figure 3.5).

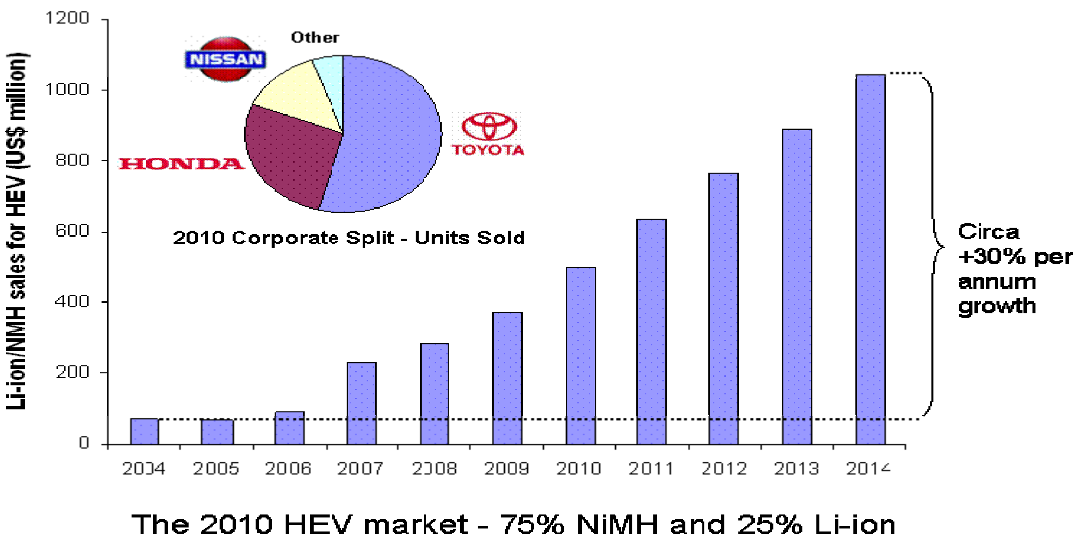


Figure 3.5 – Global Li-ion and NMH HEV market growth forecast ($M) [7]

There are also UPS applications in Transport, including railway power supply systems (i.e. effectively extended power supply networks) and also the electric ship concept, where the ship's propulsion and service loads migrate to an electric design solution (22). Although each of these sub-sectors provides a series of potentially high added value applications, they are relatively small, in comparison to the mainstream power utilities and UPS sectors discussed in Section 3.1.

3.2.2 Mobile Power Market

The Mobile power market size is already significant, but it is fragmented into various unrelated sub-segments (see Figure 3.6)

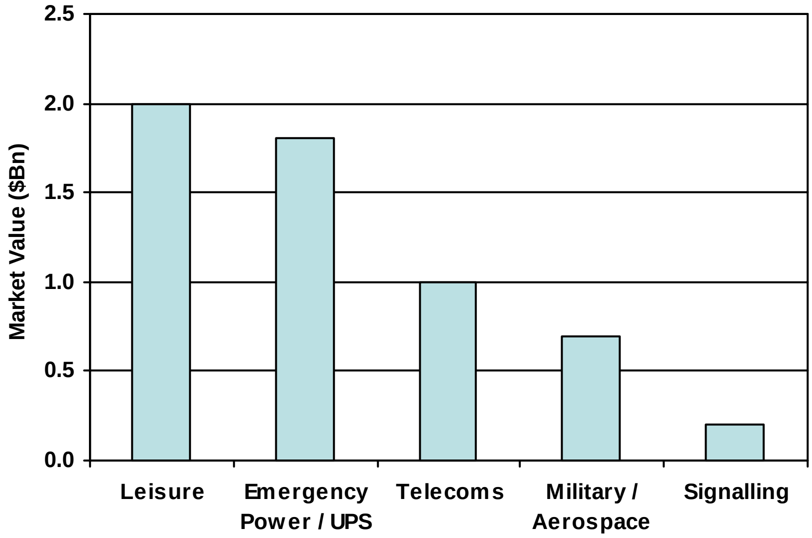


Figure 3.6 – Mobile Power Market Sub-Segments (size in $Bn)

3.2.3 Supply Chain Considerations for Mobile & Transport Power

When observing the adoption of new technologies in the Mobile & Transport Power market, one has to take into account the following considerations:

- Long lead times in design of new car models
- Strength of car manufacturers and existing players to control technology development
- Significant sums of technology investment already in place
- Geographic location of key players may hinder collaboration
- Other geographical differences: Japanese HEV manufacturers want to keep all battery and battery management systems (BMS) development in house,

[7] Electric car market only, does not account for commercial, utility or specialised vehicles

whereas most European and US manufacturers support development by third parties

As a result, ITI Energy will need to look for niche solutions at a smaller scale in EV and specialist HEV markets, rather than approaching the mass passenger HEV market e.g. Toyota Prius.

3.3 Portable Applications

3.3.1. Portable Market Size

The portable power market contains a number of sizeable and growing segments and focuses mainly on consumer electronics:

- 3Cs: Cameras, Cell phones (mobile phones) and Computers (mainly laptops)
- Toys
- Other electronics, e.g. torches, hand-held scanners, remote controls, camcorder, PDA, games, headsets and audio.
- Power tools, e.g. hand drills / saws / screw-drivers

Almost all applications use (rechargeable) batteries. The market size is in the order of $10 Bn, as is depicted in Figure 3.7.

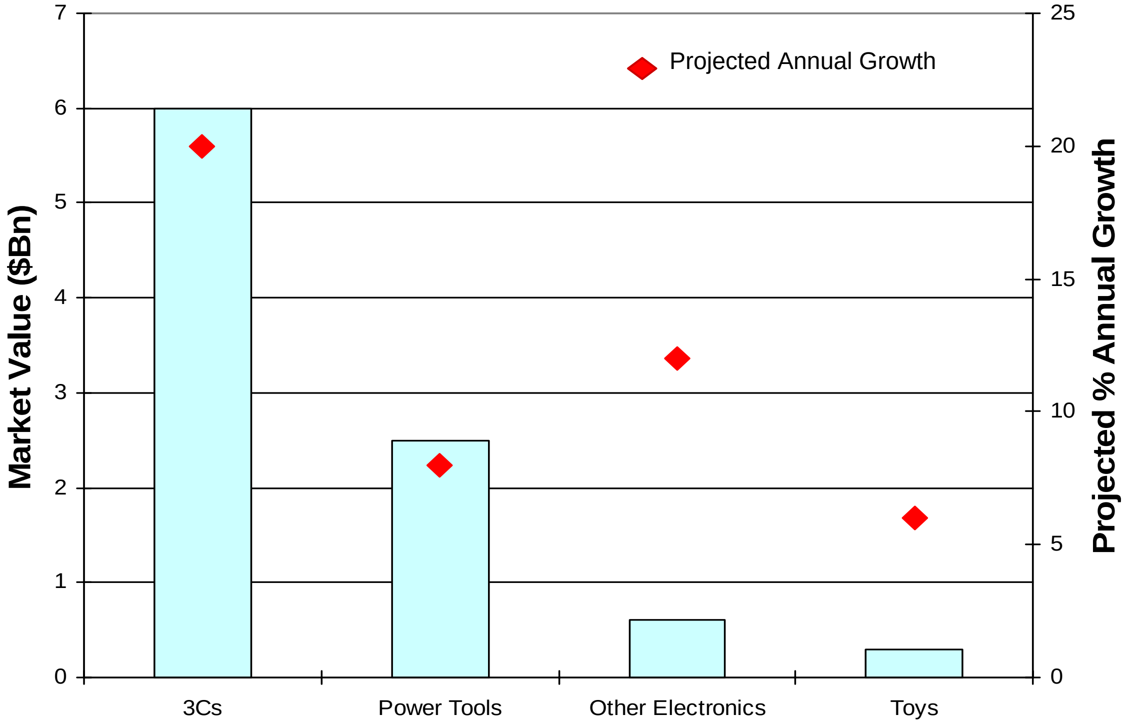


Figure 3.7 – Portable Market Segment (size in $Bn)

The 3Cs portable electronics market (cameras, cell phones and computers) alone represents a $6 billion market for rechargeable batteries, forecast to grow to $9 billion by 2010 (23). The 3Cs market is driven to a very large extent by straight commercial competitive market forces, with every potential for genuinely disruptive technologies to radically affect overall market developments and direction. Safety, licensing and certification issues are also very evident in this sector, in view of the direct access, if not contact, of such systems with members of the general public, outside of any controlled or regulated industrial safety environment.

This market segment is able to adopt new technology very quickly as can be seen from Figure 3.8, showing the displacement of NiCd batteries by Li-Ion. The strong correlation between these cell/battery sales and the rapid consumer product trends can also be seen from the down-turn in 2001, in the Figure below.

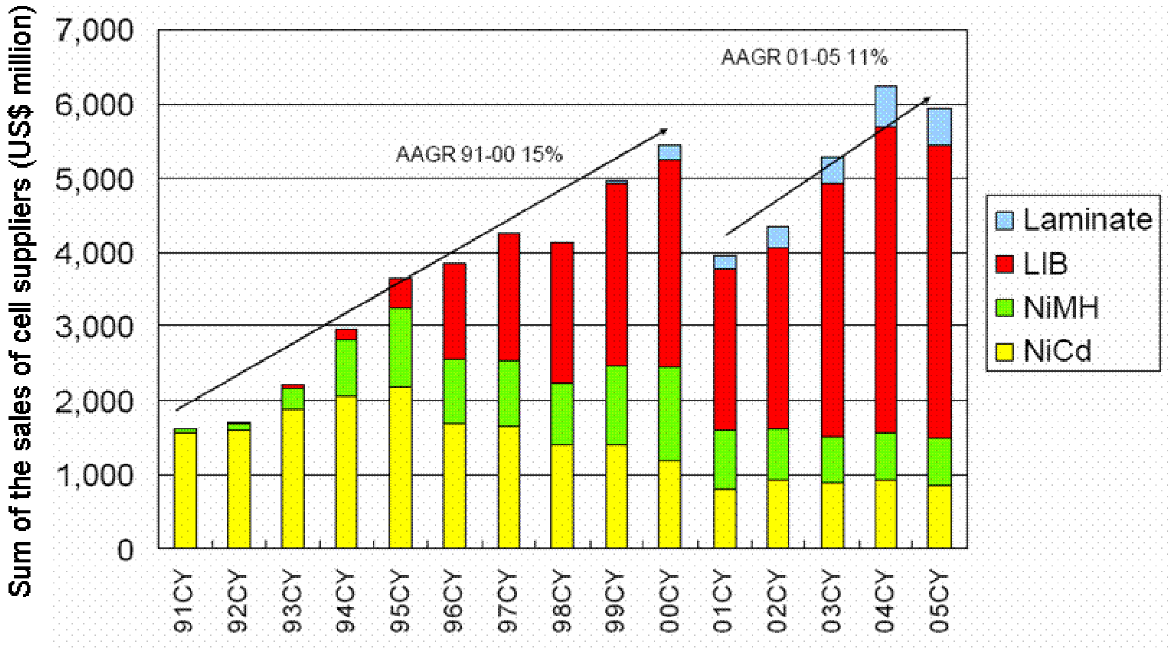


Figure 3.8 – Cell Sales (size in $Bn)

Key requirements of storage systems in 3C applications may often relate to volumetric and gravimetric energy and power densities, with the former directly relating to the potential for the extended operation of portable devices. Re-charging and re-fuelling times can also be a significant consideration, with price points more related to whole product and performance costs, rather than $ per kWh or $ per kW per se. Whilst batteries may be well established in all these principal sub-sectors, the ever increasing performance demands could see a step change to alternative power solutions, such as micro-fuel cells/hydride storage, if and when such systems can demonstrate their viability and practicability. Environmental considerations relate principally to end of life and re-cycling issues, rather than primary energy usage per se, although the latter is of greater concern in the automotive traction sector.

3.3.2. Supply Chain Considerations for Portable

The cell manufacturing market has historically been dominated by Japanese companies. Now that technology is commoditising, Chinese and South Korean companies are gaining market share fast. The Japanese companies are increasingly focusing on 'value added' solutions. US and European large scale cell manufacturing capability has virtually diminished since the 1980s. And only smaller, niche players remain.

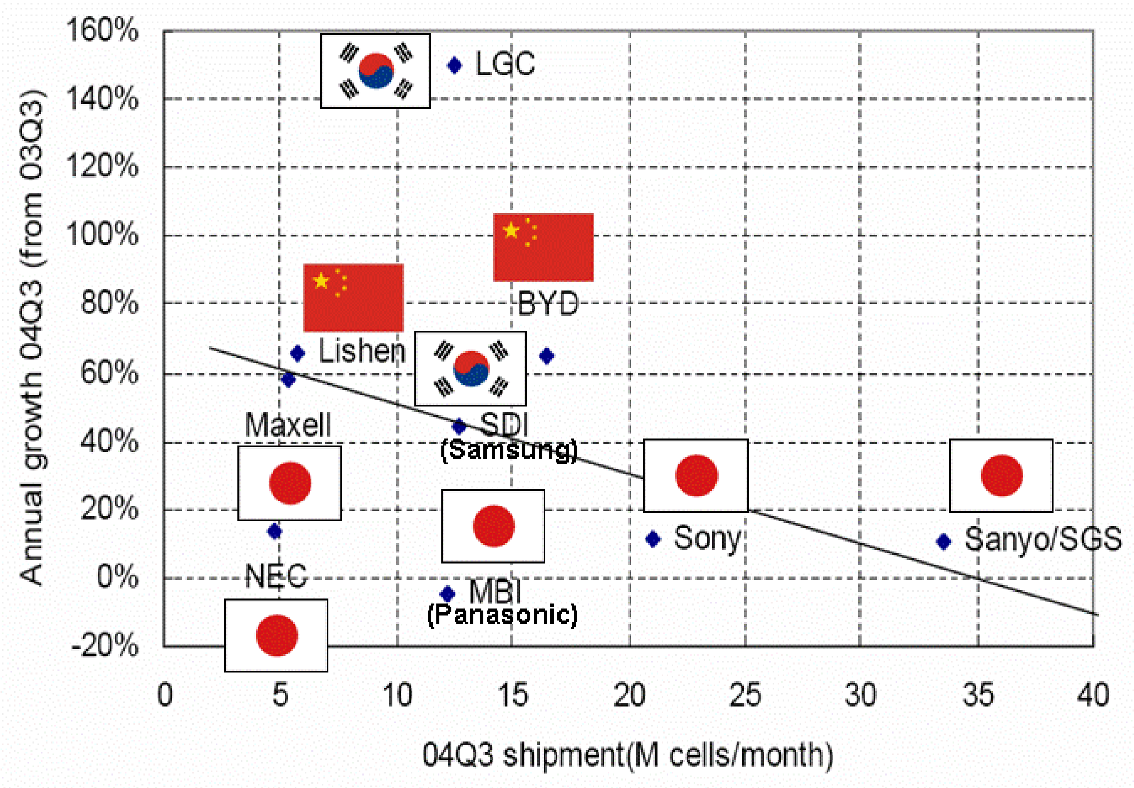


Figure 3.9 – Leading Cell Manufacturers

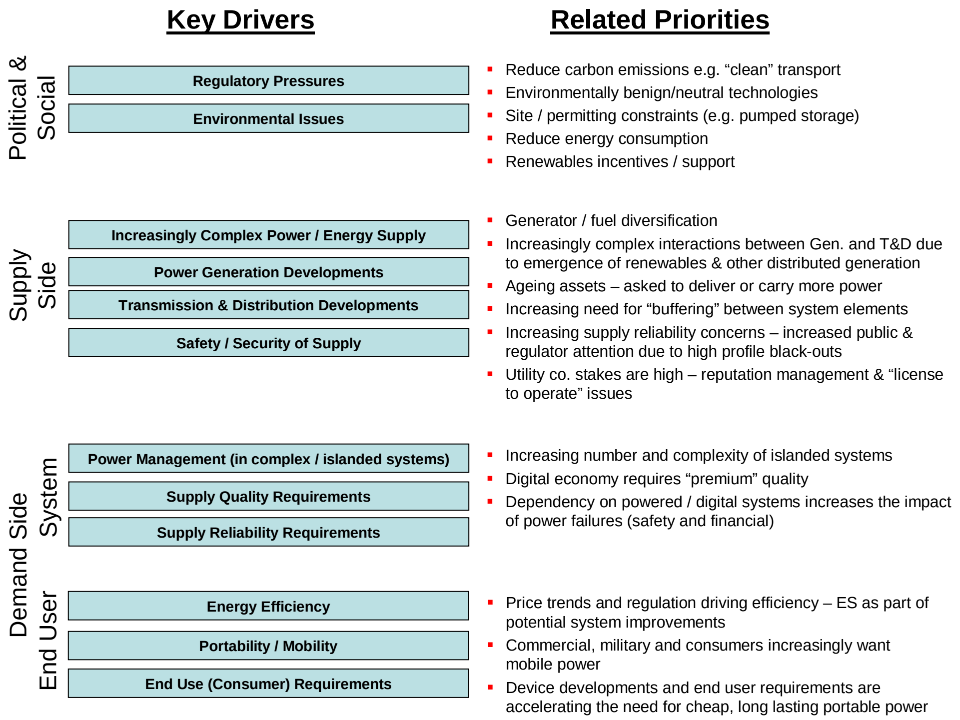
Cell manufacturers are trying to integrate vertically along the value chain, leading to companies with different offerings:

- Cell manufacturing only (e.g. Thundersky)
- Cell and battery manufacturing (e.g. Saft, DiaCell)
- Cell, battery and electric devices manufacturing (e.g. Sony, Sanyo, Samsung)
- Battery wholesalers (e.g. Philips)

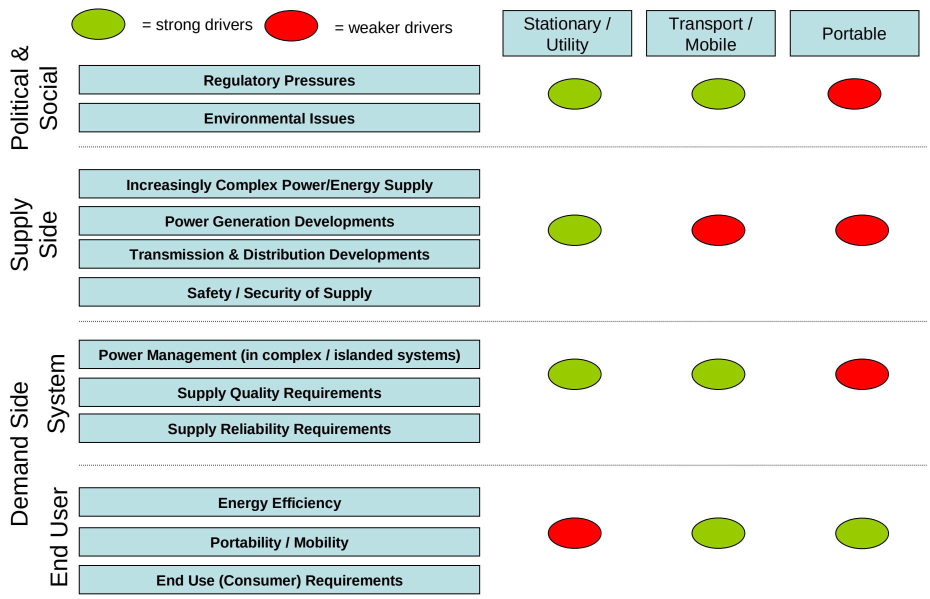
Most laptop and phone manufacturers are quite specific about battery safety and standards for their devices. In some cases this may lead to close involvement in development of the battery technology, but others are more hands-off.

3.4 Market Drivers and Developments

The following provides an overview of the key drivers affecting energy storage requirements in general:



However, not all these drivers are equally significant across all segments of the energy storage market. The table below summarises the key drivers relative to each of the 3 main market segments:



As each of the segments again consists of a number of sub-segments with quite different application requirements, ITI will need to address technology drivers for each of these sub-segments.

	Stationary / Utility			Mobile / Transport		Portable	
	UPS	Utility: Bulk Storage	Utility: Quality Reliability	HEV	Mobile	Laptop	Cellphone
Environmentally benign	✓	✓	✓	✓	✓	✓	✓
Foot-print				✓	✓		
Weight				✓	✓	✓	✓
Volume						✓	✓
Cost	✓	✓	✓	✓	✓	✓	✓
Response time	✓		✓	✓			
High capacity		✓					
High power	✓		✓	✓		✓	✓
Cycling		✓	✓	✓	✓	✓	✓
Product Life	✓	✓	✓	✓	✓	✓	✓
Ruggedness				✓	✓		
Fast Charge Capability			✓	✓	✓		

During interviews, we furthermore identified the following top priorities in the HEV, Computers (laptops) and Mobile phone market segments.

HEVs

- Battery must last life time of vehicle
- Performance must be at least as good as conventional ICE vehicle
- Fuel cost savings need to provide payback to compensate premium paid in short time

Laptops

- Runtime is key metric in premium models (corporate market)
- Cost is key in low end models (laptops rarely unplugged, home computing market)
- Environment not a key issue

Mobile Phones

- Reduction in size, making it slimmer
- Runtime currently adequate
- Increasing functionality as phones become PDAs then micro computer
- Environment not a key issue

4 OPPORTUNITY IDENTIFICATION & INITIAL SELECTION

Section 4 essentially draws on the outputs from the structured program of consultation and desk research, to present a series of value creation and technology opportunities. This program of work principally comprised:-

- the performance of a structured programme of desk research, relative to specific trade journals, websites and bought in publications and proceedings, as summarised in Appendix 1
- the attendance and participation in selected meetings, workshops and conferences, as summarised in Appendix 2
- the organisation and delivery of a targeted programme of dialogue with key storage related stakeholders, as summarised in Appendix 3
- the organisation and delivery of two storage related workshops in Glasgow, 2nd and 3rd September 2004

Output from the above was used as the basis for several internal brainstorming activities involving ITI Energy and EA Technology's team and subsequent discussions with external contacts.

These various activities resulted in the identification and listing of in excess of sixty basic "ideas"; as shown in Appendix 4, as well as additional lower level ideas (e.g. focused on specific pieces of enabling technology). In many cases these ideas were merely statements of a particular requirement or of a system/technology permeating multiple applications (e.g. low cost power electronics).

This raw list of "ideas" was then used as an initial long list of technology opportunities as shown in Table 4.1. A first cut was then made to identify the 9 technology themes to take forward for further investigation. This was based upon qualitative consideration of; market opportunity, technology opportunity, IP opportunity and Scottish/Strategic Fit. These top 9 themes were then expanded further into a list of thirty five specific technology opportunities shown in Table 4.2.

No.	Opportunity
1.	Battery storage
2.	Chemical energy storage (e.g. NH_3, tri-methyl cyclohexane)
3.	Compressed Air Energy Storage (CAES)
4.	Electrolysers
5.	Flow cells
6.	Flywheel storage
7.	Fuel Cells & Micro Fuel Cells
8.	Hydrogen storage (matrices, hydrides and others)
9.	Supercapacitors
10.	Demand management (addressed in ITI's Future Power Networks foresighting)
11.	Energy carrier materials (e.g. Aluminium)
12.	Hydraulic storage
13.	Invertors and interfaces
14.	Load management
15.	Low cost power electronics
16.	Materials
17.	Open cycle gas turbines(OCGTs)
18.	Portable battery charging systems
19.	Pumped hydro
20.	Solar, as portable power solution
21.	Spinning reserve
22.	Superconducting Magnetic Energy Storage (SMES)
23.	Uninterruptible power supplies (UPS)
24.	Wave/water column storage

Past First Cut
Rejected at First Cut

Table 4.1: Long list of Technology Opportunities

Those technologies that passed this first cut were then carried forward and expanded into a longer list of opportunities grouped around these top 9 areas of opportunity, as summarised in Table 4.2.

Technology Theme	**Related Technology Opportunities**
1	Battery storage
1.1	Lead acid
1.2	Nickel cadmium
1.3	Nickel metal hydride
1.4	Lithium based
1.5	Sodium Sulphur
1.6	Sodium nickel chloride
1.7	Specialist/niche electrochemistries (including zinc, silver, iron & magnesium electrochemistries)
2	Chemical energy storage
2.1	Ammonia
2.2	Tri-methyl cyclohexane
2.3	Adsorption/Absorption
2.4	Chemical reaction
3	Compressed Air Energy Storage (CAES)
3.1	Large scale CAES
3.2	Mini-CAES
3.3	Power cycles
3.4	Pressure vessels and piping
4	Electrolysers
4.1	Low temperature (e.g. alkaline, proton exchange membrane)
4.2	High temperature
4.3	Transient response
5	Flow cells
5.1	Vanadium based
5.2	Zinc bromine
5.3	Polysulphide bromide
5.4	Zinc cerium
6	Flywheel storage
6.1	Conventional steel rotor
6.2	Advanced high speed machines
6.3	Supporting technologies (e.g. bearings, materials etc)

7	Fuel cells
7.1	Systems technologies, including PAFC, PEM, alkaline, direct methanol, MCFC and SOFC
7.2	Fuel sources, handling & storage
7.3	Size/scale, ranging from micro-scale to large-scale, multi-MW systems
7.4	Micro-fuel cells (PEM and direct methanol)
8	Hydrogen storage
8.1	Hydrides
8.2	Nano-materials
8.3	Cryogenics
8.4	Pressurised systems
9	Supercapacitors
9.1	Carbon based
9.2	Metal oxide based

Table 4.2: First Cut Technology Opportunities (Long-List)

The overall process for long-listing and the subsequent screening and short-listing is summarised below in Figure 4.1

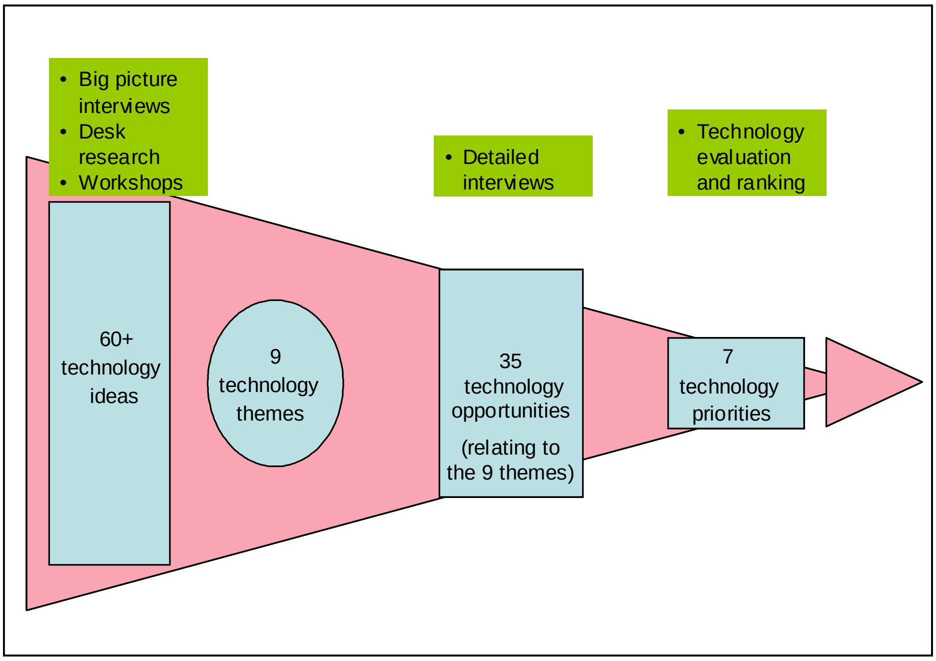


Figure 4.1 Technology identification and screening process

These thirty five technology opportunities were subjected to an initial screening against three principal criteria:

Technology	Assessment of the scope, scale and viability of technology development opportunities
IP position	Strength and defensibility of the achievable IP position
Market	Assessment of the potential market value of a particular technology development

The results of this initial screening analysis are shown in Table 4.3 below, with the various opportunity categorisations being ranked as high (green), medium (yellow) or low (red) against each of the four criteria.

Opportunity	**Technology**	**IP**	**Market**
Battery storage			
Lead acid	High	Low	High
Nickel cadmium	High	Low	Medium
Nickel metal hydride	High	Low	Medium
Lithium based	High	Medium	High
Sodium Sulphur	High	Low	Medium
Sodium nickel chloride	High	Medium	Medium
Specialist/niche	High	Medium	Low
Chemical energy storage			
Ammonia	Medium	Medium	Medium
Tri-methyl cyclohexane	Medium	Medium	Medium
Adsorption/Absorption	Medium	Medium	Medium
Chemical reaction	Medium	Medium	Medium
Compressed Air Energy Storage			
Large scale CAES	High	Low	High
Mini-CAES	Medium	Medium	High
Power cycles	Medium	Medium	High
Pressure vessels and piping	Medium	Low	Low
Electrolysers			
Low temperature	High	Low	Medium
High temperature	Medium	Low	Medium
Transient response	Medium	Medium	High
Flow cells			
Vanadium based	High	Medium	High
Zinc bromine	High	Low	High
Polysulphide bromide	Medium	Low	High
Zinc cerium	Medium	High	High
Flywheel storage			
Conventional steel rotor	High	Low	Low
Advanced high speed machines	Medium	Medium	Medium
Supporting technologies	Medium	Medium	Medium
Fuel cells			
Fuel cell technologies	Medium	Medium	High (1)
Fuel sources, handling & storage	Medium	Medium	High (1)
Micro-scale systems	Medium	Medium	Medium
Hydrogen storage			
Hydrides	Medium	Low	High
Nano-materials	Low	Low	High
Cryogenics	Medium	Low	High
Pressurised systems	Medium	Low	High
Supercapacitors			
Carbon based	High	Medium	Medium
Metal oxide based	High	Medium	Medium

High   Medium   Low

Notes: (1) Strong market potential but only in the longer term

Table 4.3: Top Level Screening Evaluation Matrix

Although such a high level screening inevitably carries a strong degree of subjectivity and does not necessarily recognise specific proprietary technology developments, it does nevertheless present a useful initial overview of the technology landscape. Table 4.3 therefore provides a simple graphical representation of the most likely favoured areas for future attention in the present project, namely those with a preponderance of high/medium rankings.

The required functions and features of a storage technology can also be ranked against the principal market segment requirements, as in Figure 4.4. This analysis aims to highlight which particular features are most critical to each of the major market segments. Of course, all applications require a threshold level of performance across all these, particularly, environmental, product life and cost performance. The analysis aims to focus on those features or characteristics regarded as the most critical for a specific market segment.

Obviously cost is of critical concern and many considerations are to be born in mind when assessing the cost of technology for a particular application e.g. Capex, Opex, Decommissioning all of which contribute to the cost of power and energy. High value applications (UPS) will tolerate a higher cost whereas low value applications (bulk storage) will require a much lower cost threshold. The cost threshold is very much a function of the application related to the value of the associated energy/power.

	Stationary / Utility			Mobile / Transport		Portable	
	UPS	Bulk Storage (Utility)	Quality Reliability (Utility)	HEV	Mobile	Laptop	Cellphone
Environmentally benign	✓	✓	✓	✓	✓	✓	✓
Foot-print				✓	✓		
Weight				✓	✓	✓	✓
Volume						✓	✓
Cost	✓	✓	✓	✓	✓	✓	✓
Response time	✓		✓	✓			
High capacity		✓					
High power	✓		✓	✓		✓	✓
Cycling		✓	✓	✓	✓	✓	✓
Product Life	✓	✓	✓	✓	✓	✓	✓
Ruggedness				✓	✓		
Fast Charge Capability			✓	✓	✓		

Figure 4.4: Market Segments Versus Characteristics / Features

Figure 4.5 takes the same listing of features / characteristics but this time plotted against the various technology systems. This allows us to infer how the different technologies might suit different applications. For example, from Figure 4.4 we can see that bulk power storage requires a combination of low cost and high capacity. From Figure 4.5 we can see that flow batteries, CAES and pumped hydro look most favourable with respect to this combination of features.

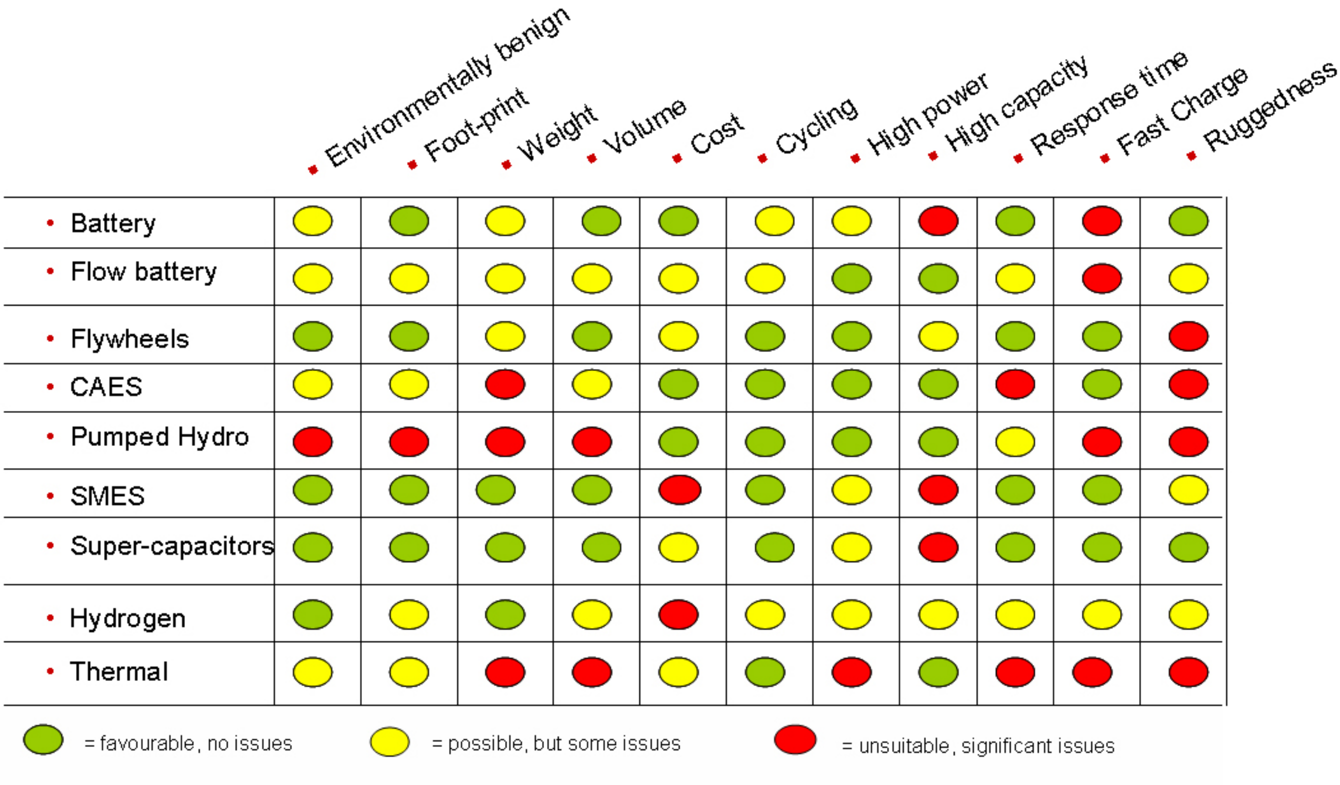
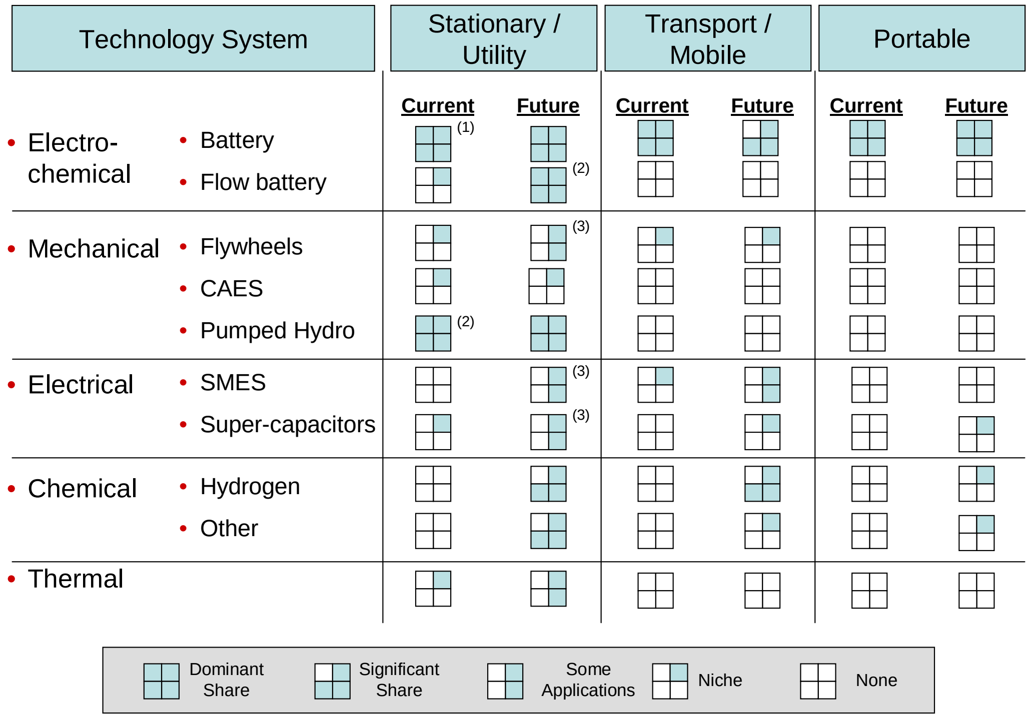


Figure 4.5: Systems/Functionalities Matrix

Figure 4.5 also addresses the functionality of SMES which appears reasonably favourable across most functionalities even though this particular technology was rejected at the first cut (as seen from Table 4.1). Note however that significant issues with cost and high capacity are perceived with SMES for energy storage applications. This technology is however viewed as a strong candidate for developments in power control applications surrounding generators and motors.

Figure 4.6 combines these two analyses with a view of the current market share of each technology across the range of market applications. The "future" column indicates the potential for each technology to achieve some share of each particular application in the longer term - assuming a reasonable level of technology development and improvement.



Notes: (1) UPS (2) Large scale (3) Power quality / reliability

Figure 4.6: Technologies/Applications Matrix

The results of these various considerations therefore lead to the identification and prioritisation of seven broad technology platform opportunities, for further and more detailed investigation and analysis:

- battery storage
- flow cells
- compressed air energy storage
- kinetic energy storage
- hydrogen storage
- hydrogen energy conversion technologies
- super-capacitors

These are now the subject of more detailed analyses in Section 5 onwards.

5 TECHNOLOGY SCREENING

The discussion and preliminary assessments contained in Section 4 succeeded in identifying seven broad technology platform opportunities, suitable for further investigation, analysis and screening. Notwithstanding the somewhat disparate nature of these opportunities, both in terms of the base technologies, their markets/applications and scale, there are potentially a number of common enabling technologies, which permeate multiple applications and storage technologies. Although the primary thrust of the present assignment is in relation to the latter, the identification and recognition of such key enabling technologies does potentially allow for the extraction of further "added value". For example the support of enabling R&D initially for one particular technology platform could then find multiple applications across other platforms. Table 5.1 below summarises some of the more important relationships here, a green square representing strong relationship, yellow representing some relationship.

Consider the columns enclosed by the dashed box in Table 5.1 entitled Power Conversion and Control & Instrumentation. Note that these enabling technologies are important across all the (platform) technologies considered and as such are worth breaking out into an interest area in their own right. In terms of ITI Energy interest this enabling technology will be known as 'Power Management' and further discussion of its relevance is provided in section 5.2.

Enabling technology Storage technology platform	Electrodes	Electrolytes	Membranes	Polymers	Seals	Materials	Control & instrumentation	Power conversion	Composites	Pressure systems	Catalysts	Nano-technology	Ceramics	Turbomachinery	Bearings	Vacuum technology	Magnetics
Battery energy storage	green	green		yellow	yellow	yellow	yellow	yellow					yellow				
Flow cells	green	green	green	yellow	yellow		yellow	green		yellow							
CAES					green	green	yellow	yellow		green				yellow	yellow		
Kinetic energy storage					yellow	green	yellow	yellow	yellow						green	yellow	green
Hydrogen storage					yellow	green	yellow	yellow	yellow	yellow		green					
Hydrogen energy conversion	green	green	green	yellow	yellow	yellow	yellow	green			green		yellow				
Supercapacitors	green	green	green		yellow	yellow		green				yellow					

Table 5.1:- Enabling Technologies Comparison Matrix

The identification of such common enabling technologies, both with respect to the present assignment and also the other Foresighting themes will serve to assist in ITI Energy's future strategy development and implementation.

5.1 Technology Platform Opportunity Summary Descriptions

Following the short-listing of the seven technology platforms, a final phase of more detailed background research and consultation was performed. This provided the basis for developing greater clarity on the specific technology development opportunities in each of the seven areas, a deeper investigation of market, IP and technology issues and a more refined ranking and prioritisation.

Sections 5.3.1 to 5.3.7 provide short descriptions for each of the seven identified technology platform opportunities. More detailed summaries of each platform opportunity are provided as a separate appendix, which provide a greater level of detail covering; full description of the platform and discussion of related market, technology and IP issues and opportunities.

Table 5.2 provides a summary of the final ranking and prioritisation of each of the seven opportunities.

Opportunity Number	Title	Technology Feasibility	IP Position	Market Opportunity	Strategic Fit
5.1.1	Battery Energy Storage	High	Medium	High	High
5.1.2	Flow Cell Electrochemistry Energy Storage	High	High	Medium	Medium
5.1.3	Compressed Air Energy Storage	Low	Low	Low	Medium
5.1.4	High Speed Kinetic Energy Storage (Flywheel Storage)	Medium	Medium	Low	Medium
5.1.5	Hydrogen Storage	High	High	High	Low
5.1.6	Hydrogen Energy Conversion Technologies	Medium	Medium	High	Low
5.1.7	Electrolytic Storage (Supercapacitors)	Low	High	Medium	Low

Table 5.2 Opportunity Summary

High	Medium	Low
● (green)	● (amber)	● (red)

5.2 Power Management

In addition to the seven technology platforms discussed previously, power management emerged as an eighth, high priority aspect to consider. In particular, and as highlighted in Table 5.1, the area of power management emerged as a critical area of enabling technology development with broad applicability across all energy storage technologies. Indeed power management has also emerged as a key area of development opportunity from other ITI Energy foresighting themes such as “Future Power Networks” and “Low-Cost Renewable Energy”.

The power management area describes opportunities related to control software solutions acting through a power electronic interface. This combination of software and hardware operates as an interface between various devices to achieve a specified primary objective. In the context of energy storage this essentially means managing the interface and power flow between energy storage devices (e.g. the battery, flow cell, flywheel, etc…), the primary energy source, the load and the dump load. The primary objective of the power management system will almost certainly be to make best use of the available primary energy. Other objectives specific to the individual application may also be accommodated, e.g. to maximise the life of a battery or minimise recharge time without damaging the storage device. Applications may include but are not limited to:

- Integration of renewable power storage with a power distribution network
- Vehicle applications such as managing the various components of a hybrid electric vehicle (e.g. power train supply, recharge, regenerative braking and onboard power requirements)
- Backup to the grid to minimize spinning reserve requirements

Power management, through instrumentation, control and power conversion, enables the optimization of complex electrical flow systems. When considered in the broader context the potential of such systems are vast, in terms of both the application and the scale of the system, from micro fuel cell systems (of the order of 10's of Watts) through mobile electric vehicle applications, to stationary grid interaction systems (on a multimegawatt scale). Power management plays a key role as an enabler for integration of energy storage (and renewables) into the wider energy network.

5.3 Summary Opportunities

The following sub-section provides a short descriptive summary of each of the 8 technology areas

5.3.1 Battery Storage

Battery storage opportunities are attractive in view of their large overall global markets, their multiple applications potential, existing indigenous resource base and the potential to achieve step change improvements in their energy/power densities, via the uptake of such technologies as lithium sulphur. Specific opportunities are therefore available for ITI Energy's consideration, although the pricing of the various IP portfolios is likely to be very much an increasing function of their near market applications potential. Further niche opportunities are also likely to be available via other electrochemistries and although these could well provide viable business streams in their own right, the magnitude of the returns, relative to any investment by ITI Energy, would have to be very carefully assessed.

Further battery storage opportunities are available via battery packaging and assembly, which can relate to one or more electrochemistries and are not therefore reliant on the securing of a satisfactory IP deal with any one particular cell developer or supplier. If the present dominance of the Far Eastern suppliers continues in relation to the manufacture and supply of cell technologies, battery packaging may well represent the most effective way for ITI Energy to secure a significant part of the overall value chain, with a direct return back to the Scottish economy. Indeed, there may be particular opportunities for ITI Energy to make an early impact here, via the facilitation of the (regional) packaging rights for some of the emerging lithium cell and high temperature sodium based technologies, ahead of the competition. There is already a small, although significant level of indigenous expertise in this area, notwithstanding that battery packaging IP is principally in the form of know how, as opposed to Patent protection.

5.3.2 Hydrogen Storage and Energy Conversion Technologies

The hydrogen storage and energy conversion opportunities form part of an overall “hydrogen economy” sub-set. Noting in particular the vast global expenditures on fuel cell technologies, it is unlikely that ITI Energy will be able to make a material impact in this area, unless specific business related opportunities can be identified and which are available at an affordable price. However, it is in the associated areas of hydrogen production/electrolysis and storage that the greater opportunities are likely to exist for ITI Energy; they offer clear multiple applications potentials, with direct links to the Scottish economy.

5.3.3 Flow Cells

Flow cell technologies are an increasingly attractive solution to the potential problems of intermittency associated with renewables resources and offer significant advantages over battery storage via their potentially lower cost and their ability to provide longer term solutions, via the provision of enhanced electrolyte storage capacity. Although only a relatively small number of electrochemistries are available, specific opportunities have been identified here where ITI Energy could make a material impact.

5.3.4 Supercapacitors

Considered a developed and mature technology that is dominated by the Maxwell Corporation the market is expected to grow significantly in the years to come largely based on new application bases. The associated IP is likely to become more incremental in nature with the prior art being well established and defined. The Scottish fit here is difficult without an established manufacturing base. The best opportunity is in developing and sustaining relevant R&D activities.

5.3.5 Compressed Air Energy Storage

Well established in the large scale, developments are likely to be incremental and benefit the smaller scale, fabricated storage vessel applications and their integration with renewables to act as a buffer for associated intermittency. Improvements in technology, and associated IP, are viewed as incremental in nature and centre around power plant cycles, turbo machinery and powerplant cycles. Growth is dependant upon small scale systems being accepted in the market. Fit in the

Scottish economy is limited to local, onsite fabrication, assembly, commissioning and operation.

5.3.6 Kinetic Energy Storage

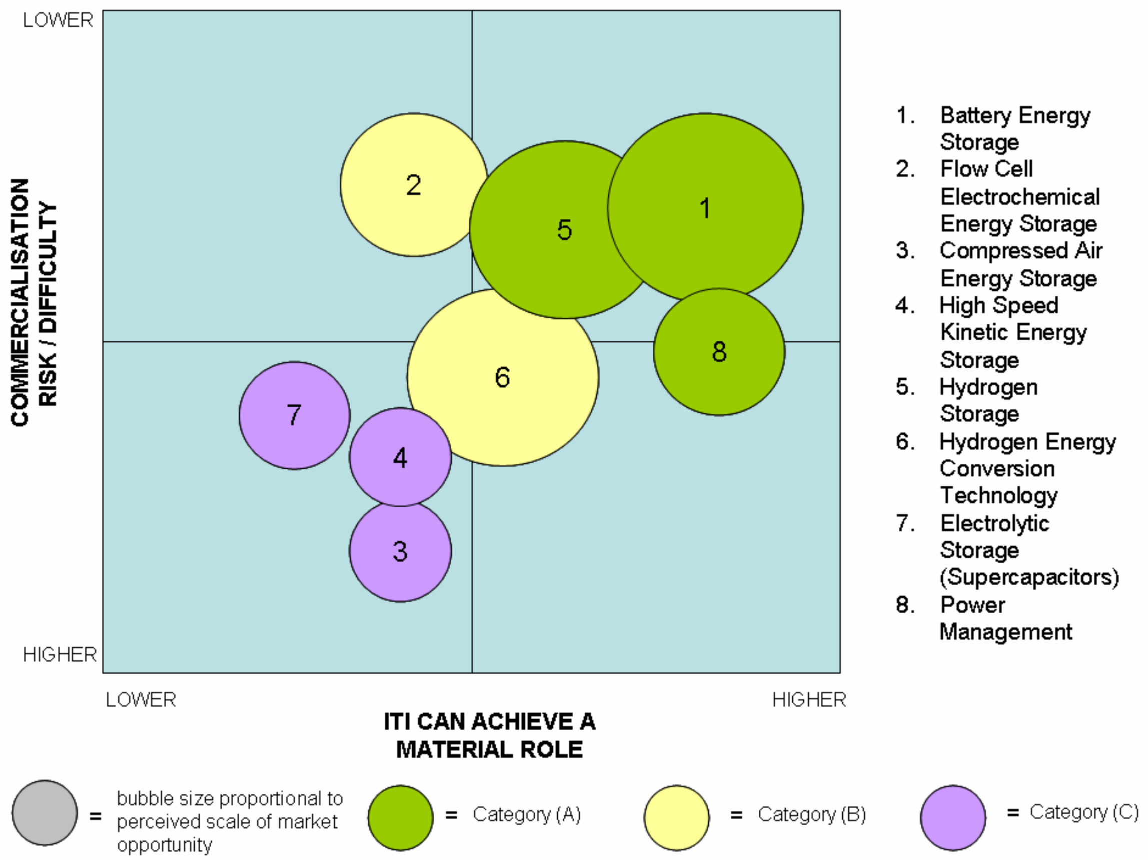
With a highly mature technology base, much of the current R&D effort is directed into high speed machines running at tens of thousands of RPM and utilising state of the art composite materials technology. Historically a niche market, there is potential for growth by placing the associated high speed bearing technology into other high added value niche markets and applications. The applications are expected to remain niche. IP will be incremental in nature and focus on particular aspects of machine design and operation. Scottish fit in this area is limited to potential high technology manufacturing jobs complementing a limited academic base.

5.3.7 Power Management

Though strictly not an energy storage technology power management is relevant due to its ability to act as a software controlled power electronics interface between the load and the primary energy source. Technically a highly feasible solution it is currently implemented on a case by case basis for individual systems designs and requires detailed knowledge of the system components and software engineering skills. In terms of market a suitable solution may be applied across a whole range of products of varying scale and the opportunity here is for development of a general solution, the 'MS Dos' of power management. ITI Energy could have a key role to play in developing this general power management solution in association with academic expertise and leveraging input across a range of Scottish based power systems providers.

6 IN-DEPTH SCREENING

Given ITI Energy's limited resources, there is a need to further prioritise within the eight short-listed technology areas. The ranking summarised in Table 5.2 and the more detailed analysis of each of the eight areas provided the basis for this more in-depth screening phase. The following diagram highlights how the conclusions drawn from this final stage of prioritisation:



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The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The size of the bubbles are a qualitative representation of the scale of market opportunity. The 8 technology areas have been, as indicated in the above diagram, allocated a prioritisation / categorisation as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 8 technology areas.

The prioritisation of these 8 areas – as discussed above – is only for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals. The 8 technology areas have all been selected from the long-list as having significant potential for new technology development. Therefore, project proposals in any of the 8 technology areas will go through the same project screening and selection process. The categorization here does not imply a pre-allocation of R&D project funding biased toward those areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 8 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

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iti Energy

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8 APPENDICES

Appendix 1

Principal Reference Publications, Proceedings and Related

- Batteries and Energy Storage Technology, Issues Summer 2003 to date
- EESAT 2003, San Francisco, October 2003
- Electricity Storage Association, Spring Meeting, May 2004
- Battery Industry Guide 2004
- EPRI-DoE Storage Handbook
- Power Sources 19, 2003
- Proceedings of Advanced Automotive Battery Conference 2004, San Francisco
- Institute of Information Technology, Japan, Secondary Lithium Battery Market Review 2004
- European Market for Full and Mild Hybrid Electric Vehicles, Frost & Sullivan, Mar 2003
- Batteries International, Issues Summer 2000 to present

Appendix 2

Principal Seminars, Workshops and Conferences Attended

- Electrical Energy Storage Workshop, Department of Trade and Industry, London, 13th July 2004
- H2NET Annual General Meeting, Rutherford Appleton Laboratory, 14th July 2004
- Portable Power, San Francisco, 12th to 14th September 2004

Appendix 3 - Organisations Involved in Foresighting

ABB
AEA Technology Batteries
Aggreko UK
Alstom
AREVA T&D
Azure Dynamics
Batteries & Energy Storage Technologies
Beta R&D
BRE
Carbon Trust
Core Technology Ventures
Dell
DSTL
e-Fuel Technology
Energy for Sustainable Development
EON UK
FDT Solutions
Gerry Woolf & Associates
Heriot-Watt University
HILtech Developments
HP
IBM
Ionotec
Johnson Matthey
Luichart Technology
Motorola
M Power Batteries
NaRec
Nokia
Orange
Philips
Plurion Systems Inc
PSI
Robert Marshall & Associates
Rolls-Royce
Ricardo
SAFT
Scottish & Southern Energy
Scottish Enterprise
Scottish Hydrogen & Fuel Cell Assoc.
ScottishPower
Sendo
SiGen
Sinclair Knight Merz Ltd
Swanbarton
Tokyo Electric Power Company
TVA

University of Edinburgh
University of Loughborough
University of Salford
University of Southampton
University of St Andrews
University of Strathclyde
Unst Partnership
UPT
Urenco Power Technologies
Voller Energy
WaveGen
Zytek

Appendix 4 – Technology Ideas Identified During Foresighting

anodes/cathodes
battery storage
bearings
biofuels
bladders
carbon fuel cells
carbon trading
catalysts
ceramics
chemical energy storage
composites
compressed air energy storage (CAES)
compressors
cost
demand (side) management
demand management
electrolysers
energy carrier materials
energy density
environment
fault management
flow cells
flywheel storage
fuel cells
grid interface
grid reinforcement
hydraulic storage
hydrogen storage
invertors
invertors and interfaces
load control
load management
low cost power electronics
materials
membranes
micro-fuel cells
modelling
open cycle gas turbines (OCGTs)
plates
polymers
portable battery charging systems
power electronics
pumped hydro
pumped storage
quality of supply
regulation
reliability & maintenance

Appendix 5 - GLOSSARY

AFC	Alkaline fuel cell
BoP	Balance of plant
CAES	Compressed air energy storage
CHP	Combined heat and power
DC	Direct current
EDLC	Electrochemical double layer capacitor
EV	Electric Vehicle
GW	Gigawatt
GWe	Gigawatts Electric
i/c	Internal combustion
IFI	Innovation Funding Incentive
IP	Intellectual property
IT	Information technology
KESS	Kinetic energy storage system
KWE	Kilo-Watt-Electric
KWH	Kilo-Watt-Hour
MCFC	Molten carbonate fuel cell
OEM	Original equipment manufacturer
OFGEM	Office of the Gas and Electricity Markets
PAFC	Phosphoric acid fuel cell
PEM	Proton exchange membrane
R&D	Research & development
RAPS	Remote area power supplies
RPM	Revolutions per minute
RPZ	Registered Power Zone
SLI	Starting, lighting and ignition
SoC	State of charge
SOFC	Solid oxide fuel cell
SMES	Superconducting Magnetic Energy Storage
UPS	Uninterruptible power supply
UPT	Urenco Power Technologies
USP	Unique selling point
VIU	Vertically integrated utility
VRLA	Valve regulated lead acid

Abbreviations	(for Tables 5.1.1 to 5.1.7)
H	High
M	Medium
L	Low