Energy Storage - Underpinned by Materials Science

New opportunities in materials development driven by a growth market

Chris Richardson

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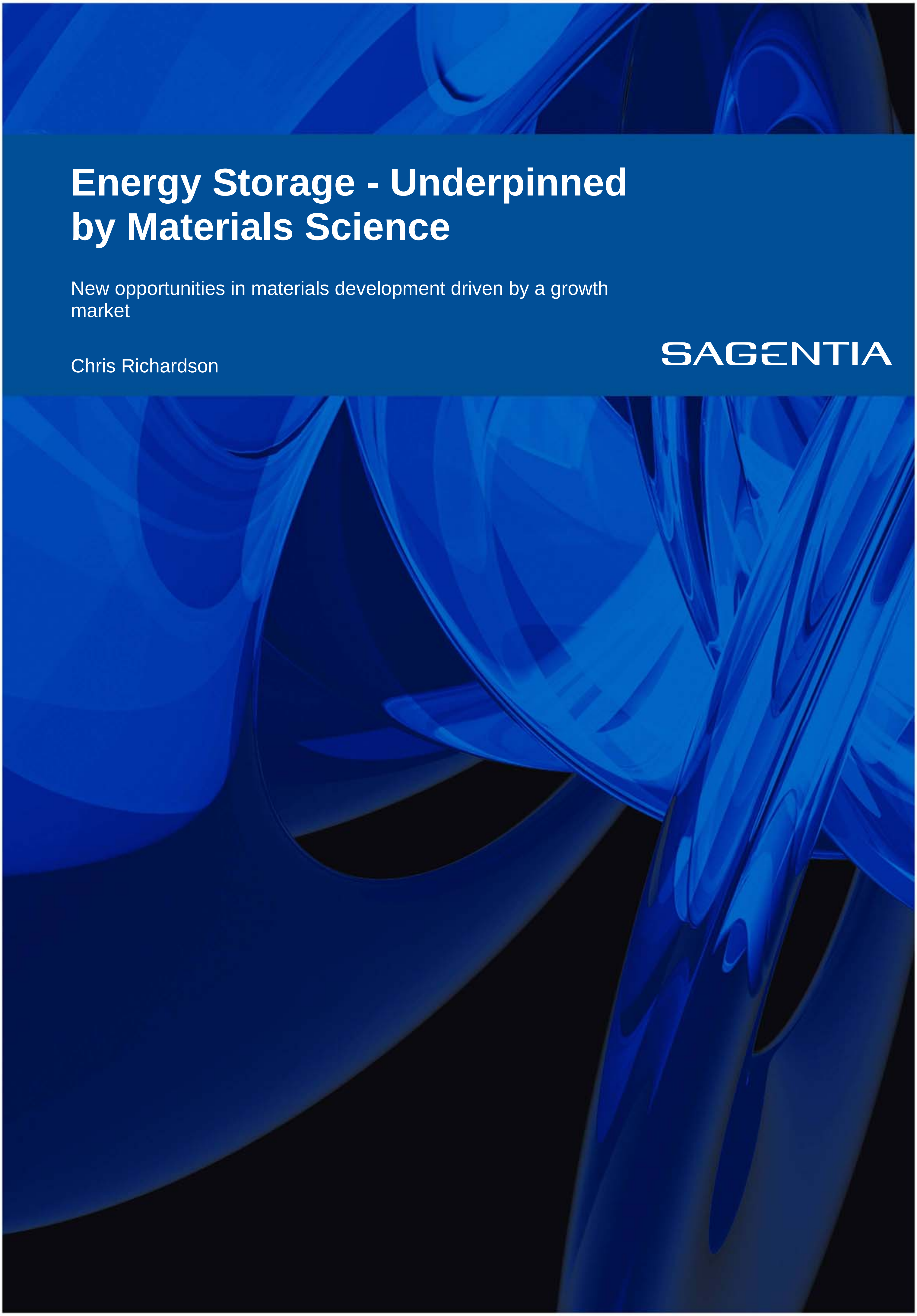

Access to electrical energy has been a fact of life in the industrialised world for more than 50 years. However, for much of this time our dominant electrical energy supply experience has been via large utility grids. We have been able to tap directly into the real-time generation of power from large centralised power plants. Times are changing and people demand more flexible access to power. This in turn is driving developments in energy storage technology, underpinned by materials science.

The drivers for storage

Mobile device energy storage

Consumers have an ever-increasing appetite for devices that offer mobile functionality. These range from laptops to biological implants, and from portable instruments to mobile phones.

Such devices typically require a power source, and consumers are moving away from expendable primary cells for reasons of both cost and environmental concerns. For this reason, secondary or rechargeable batteries are becoming increasingly popular. Demand for improved battery performance continues as users seek to combine both higher levels of performance with greater lifetime and lighter weight.

Transportation energy storage

Transportation, primarily domestic, makes up approximately 25 percent of a typical industrialised nation’s power consumption. The demand for more sustainable solutions to satisfy this transportation need is a key driver for worldwide development programmes into electric powertrain systems. Such drive systems, whether for domestic electric/hybrid electric automobiles or industrial forklifts, have created a new set of demands for high performance, medium sized batteries.

Grid level storage

Demand for electric power has been steadily increasing, but unfortunately as it increases, the variance in consumer demand has also been widening. Sometimes this ratio between peak and off-peak may be greater than 2:1.

Generation capacity must be matched to peak demand, therefore this situation is driving the construction of additional generation, transmission, and distribution infrastructure. This can result in an infrastructure that is only lightly utilised for the bulk of the day. Despite sophisticated management systems, utility companies find themselves struggling to strike the right balance: an increased cost of electricity and increased carbon emission weighed against the potential for ‘brown-outs’.

Diurnal or daily load levelling at a grid level, where power can be stored during the night and fed back into the grid during the day, can play an important role in reducing the additional generation infrastructure required. In addition, daily load levelling can also be applied at local or plant level, enabling connected customers to reduce their reliance on high cost, peak rate energy.

Typically any smoothing energy storage systems need to be low cost, but also need to have the capability to be scaled to large sizes. Energy storage systems working at a regional or national level will have total energy storage requirements far in excess of what could be achieved simply by upscaling traditional battery technologies.

Technologies that can be deployed

The diverse range of applications available place great demands on energy storage technologies, with major differences in key performance criteria. Important criteria for these applications may include cost per watthour, energy or power density, total energy capacity, and many others. Such differences require a range of technology solutions to meet the application requirements:

- Electrochemical
- Electrostatic
- Mechanical

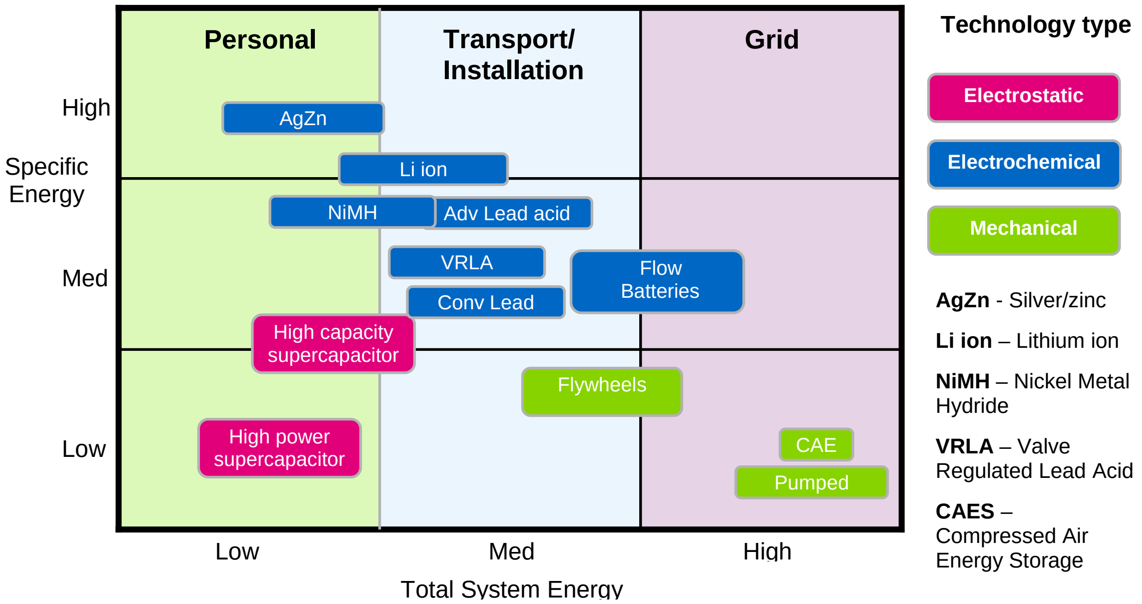

Fig 1 Energy Storage Technologies

Electrochemical

Electrochemical technologies provide the basis for the dominant type of electrical energy storage device. Such an electrochemical cell consists of two active electrodes, and an electrolyte to facilitate ion movement between the two. In addition, a separator is inserted between the electrodes to prevent direct contact.

NB: Primary cells use non reversible electrochemical reactions and are outside the scope of this discussion.

Lithium ion cells, widely found in laptops or mobile phones, and conventional flooded lead acid batteries, ubiquitous in cars for starting, lighting and ignition (SLI) functions, are the most commonly encountered secondary batteries. However, many other types of secondary cell exist. These can be products optimised for specific performance niches, or those representing more fundamental developments in battery technology. Some of these step-change developments have the potential to create new applications or displace existing technologies. Leading edge examples include:

- Development of massive flow batteries for load levelling, such as VRB's 12MWh Sorne Hill wind farm installation
- Step change improvements in lead acid and nickel metal hydrid technologies via advanced electrodes and bipolar cell assemblies by Firefly, Nilar and others. Lead acid and nickel metal hydrid chemistries have been widely expected to be displaced by newer technologies, but developments such as these raise the prospect of these chemistries remaining important for years to come
- New alternative chemistries to lithium ion with the potential for increased safety and performance, such as silver/zinc from ZPower

The diverse range of performance capability achievable from electrochemical technologies will ensure that this group continues to provide the basis for many energy storage devices in the future.

Electrostatic

Electrostatic devices rely on capacitance to store energy. Traditional capacitors have the capability to supply power much faster than a battery, but the energy storage density of such devices is tiny compared to a conventional battery. However, in 1957, General Electric engineers demonstrated that a capacitance much higher than that found in traditional capacitors could be created in devices with porous carbon electrodes. These devices relied on the creation of an electric double-layer in a thin electrolyte coating and had energy storage capacity far greater than that of a conventional capacitor, while having a power capability superior to an electrochemical battery.

These devices, known as supercapacitors or ultracapacitors are now found in peak power applications such as mobile phone camera flashes. In the near term supercapacitors are also being promoted as an alternative to batteries for certain hybrid electric vehicle configurations.

Mechanical

Mechanical storage devices are used primarily in very large scale storage facilities. For example, pumping water back against gravity into a reservoir is a form of reversible hydroelectric plant. This provides a convenient way of levelling medium time-constant power demands on the grid, such as the well-known midday demand peak. Of course, this is only applicable if you have access to a suitable hydro site.

An alternate technology for areas with no suitable hydro site could be Compressed Air Energy Storage (CAES). Here, using off-peak energy, air is compressed into vast confined spaces and then, during peak times, this air is used to return energy to the grid. The air is either run through turbines to generate power directly or, preferably, used in its compressed form in the burning of fossil fuels to improve the efficiency of a power plant. This technology is most cost effective where there are natural underground caverns or depleted aquifers that can provide the storage space without the need for excavation, thus requiring the power station site to be near them.

Finally, mechanical flywheels are already commercially viable and are used in some forms of Uninterruptible Power Supply (UPS). Prototypes have also been evaluated in certain transport applications including railway locomotives.

Flywheels have good energy density capacity, and are particularly valuable where high peak current is required. A high value niche for flywheels is where very high current transients are required – such as circuit breaker testing at 10,000 to 1,000,000A. In these cases, localised brown-outs would occur if power was taken directly from the grid.

The challenge for materials manufacturers

Evolution of these energy storage technologies has been critically dependant on parallel evolution in materials and related technologies. Many different parameters are important in one or more of these storage technologies, including the following:

Stability

A challenge for all of these energy storage technologies is the storage of a maximum quantity of energy in the smallest mass and volume. Such an energy density is potentially hazardous, therefore stability is a common requirement for the choice of materials in such devices.

The key stability parameter may be thermal, electrical or mechanical, dependant on the type of device and the material's role within it. The development of composite materials for use in flywheels provides an example. Here, moving to materials with a higher strength per unit mass than conventional steel alloys enables a greater energy density to be safely stored in the device.

While the capability of a material to withstand elevated loading for prolonged periods is a key factor for longevity, the safety of the device is often determined by its tendency to fail-safe under peak load conditions. One particular example is the case of lithium batteries, where faults in usage or manufacture can cause local temperature spikes in a battery. Unfortunately, many current cathode materials show instability at high temperatures and this can cause exothermic degradation of the cathode. The electrolytes used in lithium cells are typically flammable, and this cathode failure provides an ignition source. Such catastrophic failures have been a significant factor in reducing the speed of uptake of lithium ion technology.

Surface area

The key energy storage reactions for all electrochemical cells and supercapacitors are surface limited, and optimisation of surface area is a key theme for materials development.

It is not simply a question of maximising the surface area, but also considering the accessibility of this area to specific reactants. This has been a critical factor in the development of electrodes for supercapacitors, where carbon materials from a number of sources, both synthetic and natural, have been evaluated in an attempt to achieve the optimum in price and performance balance. In this technology, the minimum size of pore that can be considered for contribution to effective surface area is determined by the size of the bulky electrolyte molecule. This electrolyte must be able to enter the pore opening and wet out the surface of the electrode for a double layer to form on the surface. The result of this constraint is that high surface area mesoporous carbons are much more effective than ultra-high surface nanoporous materials.

Other non-carbon based nanomaterials are demonstrating promise, particularly for battery electrodes, for example, Altairnano's lithium ion anode technology. Such nanoparticulate routes allow the use of otherwise unprocessable material, as well as controlling surface area and chemistry to maximise power while minimising the risk of thermal instabilities.

Conductivity

Electrical conductivity determines the efficiency of moving charge in and out of the storage device and so is a key requirement for many of these technologies. Traditionally metals have been the material of choice for conduction of electrical energy in and out of a device.

However, some of these energy storage devices under development impose additional constraints. An example is the requirement of many thin film batteries for low temperature processing. Thin metal track printing technologies, under development for organic electronics provide some interesting new technologies here, but compromises made in conduction and power-carrying capability leave significant room for further development.

Heat management is also often an important element in energy storage systems – typically any energy efficiency less than 100 percent implies the loss of some energy via heat. Thermal properties such as conductivity, emissivity and capacity can become important parameters for materials choice, enabling careful control of the movement of heat out of the active areas of the system. Such thermal management by conduction, convection or radiation can provide significant increases in product longevity or inherent safety.

Processability

Development and selection of the correct materials processing technology can also be important in device design, particularly in ensuring that the desired functionality can be provided at the required price point. The earlier case of nanoparticulate lithium ion battery electrodes is a good example – this material's chemistry could not be constructed economically by other means.

A related example in a parallel industry is that of turbine blades for wind farms. Here, our work with industry leaders identified a discontinuity in the economy of ever-increasing installation scale when the turbine blade became too big. This jump in cost occurred when the blade length exceeded the threshold for safe road transport. Construction of the blade in pieces was not viable as this adversely affected strength and modulus per unit mass. This resulted in manufacturing processes, which might not be economically viable in stand-alone environments, becoming more interesting if they have the potential to be run on-site.

In summary

The energy storage devices market will become increasingly attractive as our demand increases for energy at specific times, specific places and from renewable sources. This development trend can only be sustained on the back of significant and novel developments in the underlying materials. The enabling nature of many of these materials ensures that they can capture a significant part of the value created by these technologies.

Some of the unmet needs can only be met by the development of very specific products, but for the materials manufacturer looking to mitigate their risk, there are underlying materials issues that can provide opportunities across a range of technologies. Membrane technology is an example of such an enabler: some form of separator is required in all electrochemical cells. Hence membrane providers that are able to tailor products to work with a variety of chemistries and environments will have a bright future

Sagentia has significant experience in identifying materials development strategies based on enabling platform approaches. We have successfully run projects in areas ranging from household chemicals to organic electronics. These have led to the establishment of multiple significant research programmes for our clients, targeted at opportunities valued in aggregate at over $1B.

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www.sagentia.com
info@sagentia.com

Sagentia Ltd
Harston Mill
Harston
Cambridge
CB22 7GG
UK

T. +44 1223 875200

Sagentia Inc
One Broadway
14th Floor
Cambridge, MA 02142
USA

T. +1 617 401 3170

Sagentia SGAI Ltd
Unit 6-7, 13/F
Wah Wai Industrial Centre
38-40 Au Pui Wan Street
Fotan
Hong Kong

T. +852 2866 8701

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