# Lithium-ion battery

## Brief description of technology

Lithium (Li) has the lowest density of any metal, and the highest electrochemical potential. With the advent of consumer portable electronics in the 1980s lithium batteries were developed for their excellent power to weight ratio, and pioneering work was commercialised by Sony in the early 1990s [1]. Lithium batteries are available with a large number of different electrode chemistries, but the main focus for secondary (rechargeable) batteries has been on Li-ion and Li-ion polymer batteries, until the 1990s mostly for the consumer electronics industry but now also for large scale electric vehicle and grid 'battery energy storage systems' (BESS).

Lithium based battery technology is currently widely researched, and is also overlapping into development for use in both flow-battery [2] and metal-air battery [3] topologies; this fact sheet covers conventional rechargeable Li-ion batteries. For utility scale applications, arrays of 100s of thousands of battery cells are arranged in a parallel-series combination, as in figure 1, therefore figures presented here are scalable to larger applications.

**Figure 1: Parallel connection of small batteries within an EV battery pack**

## Technical/economic data

A123 systems, a Massachusetts start-up company, currently supply scalable, modular Li-ion battery systems which are claimed have performance characteristic capacities of 2 MW power and 500 kWh energy, together with a 20ms response time. Dependent on Wh throughput, they claim a cycle-life range from near 10,000 to 100,000's of cycles at a system round-trip efficiency of almost 90% [4], however, these figures have not been tested under independent review.

The costs of installing Li-ion grid storage is difficult to verify, but are of the order of $23million for a 20 MW plant installed by AES in Johnson City [5], indeed, a U.S. government white paper by the Electric Power Research Institute (EPRI) [6] estimates:

- Based on a 0.25 to 50 MWh plant,
- 1-100 MW Power capacity for a duration between 15 minutes to an hour,
- An efficiency of 75-90% over 100 000 cycles,
- Estimated cost $950-$1590/kW,
- Or $2770-$3800/kWh

These are aimed at utility frequency regulation and fast response applications, and are based on the average of currently installed systems; actual durability and life-cycle cost data is not yet available as the technology is in its infancy. Note that many of these systems are early stage demonstration systems, and therefore costs are not intended to be representative of a mature technology. Further data can be found in table 1.

## Application/markets

Li-ion BESS have already been deployed for frequency stabilisation and spinning reserves [4]. Like other BESS, their primary use is to aid with grid penetration of renewable generation sources, as they provide fast response services of the order of minutes. Given their relatively low self-discharge rate, Li-ion systems could if necessary provide effective energy storage of the order of tens of days at a discharge rate of 0.1 to 0.3% per day [7]. Their use in EV / HEV applications is also prompting research into 'second life' applications for used Li-ion battery packs in BESS scenarios. In this scenario, energy storage systems could be built from used EV / HEV battery packs and utilised as either large centralised BESS, or on a more distributed scales with BESS being installed locally alongside alternative energy generation.

## Advantages/disadvantages

Li-ion batteries have high specific energy (energy-to-weight ratio), are efficient, have long lifetimes, minimal memory effect and low self-discharge. While solutions for the consumer electronics market could be considered quite mature, there remain difficulties in scaling up the technology until safety, cost, and materials availability can be resolved [10].

| Energy Density | Rated Capacity (MW) | Duration (minutes) | Cycle Efficiency [%] | Energy Cost [$/kWh] | Power Capacity Capital Cost [$/kW] | Life |
|---|---|---|---|---|---|---|
| 75-200Wh/kg[7],<br>150-315W/kg[7] | 1-100[6]<br>0-0.1[7] | 15-60[6]<br>0-60+[7] | 75-90[6]<br>85[8] | 2770-3800[6]<br>600[8] | 950-1590[6]<br>400[8] | 5-15 years[9, 7]<br>100,000cycles[6]<br>4000 cycles[8]<br>300-10000+[9] |

**Table 1: Technical and economic data for Li-ion batteries**

While Li-ion cells have high current capacity, this must be limited in practice to prevent internal heating and early failure. Safety has been a significant issue in bringing the consumer battery technology to market and Li-ion cells can only be operated in conjunction with a battery management system (BMS) providing at minimum, overvoltage, undervoltage, overcurrent and overtemperature protection [11]. Larger utility scale systems will also require cell voltage balancing, as when cells are in series, the performance of the overall system can be limited by the performance of the weakest cell. Other drawbacks are high cost and the reduction in lifetime caused by deep discharging [12], along with a limited and strict safe operating temperature range.

## Current status

The first demonstration of a multi-megawatt scale Li-ion installation for grid ancillary services was built by AES energy storage in Indianapolis, Indiana[1]. The 2MW plant was completed early 2008 and performs effectively providing frequency regulation while maintaining a state of charge. Since then a number of Li-ion battery plants have been built, from 2 MW up to a 32 MW installation at Laurel Mountain wind farm in West Virginia, with proposals for up to a 400 MW capacity plant being considered for the Long Island Power Authority [5]. An estimate of installed Li-ion based BESS capacity on the U.S. grid was approximately 54 MW in 2011 [13]. In June 2011 the successful commissioning of the first Li-ion energy storage system on the UK grid was announced, a 200 kWh capacity system installed by ABB[2]. The system is an adaptation of the company's existing reactive power compensation systems and works in conjunction with a supercapacitor bank to provide both reactive and active power compensation, aiding grid penetration of a local windfarm [14].

## Time to commercialisation and R&D needs

In a major review of Li-ion batteries for the Journal of Power Sources, Scrosati et al [10], insist that a radical change in the internal lithium battery structure is required, and that a complete change in chemical process is required away from the current, and restrictive, insertion electrodes mechanism, which is limited to one electrode per formula unit, to conversion processes which instead allow two to six electrodes per formula unit [10]. The authors point out that this step has already been made in lithium-air and lithium-sulphur technology, and that rapid success will be dependent upon the efficient exchange of information between interdisciplinary studies. Smaller improvements are constantly being reported and research into cathode, electrolyte and anode materials continues to bring advancement [15].

Research until the early 2000s was concentrated on macroscopic changes to cell structure, when increasing electrode surfaces brought increased risk of secondary reactions involving electrolyte decomposition. When this problem was solved with new electrode coatings, it cleared the path for the current trend in nano-scale research and vastly increased electrode surface areas, with nanotechnology providing improvements in power, capacity, cost, materials and sustainability, and promising more still [16]. Polymer electrolyte batteries are being developed that alleviate such issues as internal shorting, electrolyte leakage, and having combustible reaction products at the electrode surfaces – all of which are problems in liquid electrolyte designs [17]. However, these recent developments will take time to filter through into commercial products, and the added safety requirements for such energy dense and potentially volatile units can only extend the testing and time to commercialisation of any academic advance.

[1] www.aesenergystorage.com
[2] www.abb.co.uk

## Safety, security, environmental and public perception issues

Active safeguards have been designed to prevent some failure modes in multi-cell Li-ion batteries, but the batteries are prone to thermal runaway under short circuit conditions with highly explosive results. Thermal stability at high temperatures remains a major challenge to the advancement of the technology [18]. Safety is therefore a significant concern, and while there is a great effort underway to address it, the solutions are all expected to result in a reduction of specific energy [10].

Lithium batteries are generally not considered an environmental hazard, except where they contain other toxic (heavy) metals and are disposed of in large quantities. According to a recent literature review for Ecotoxicology and Environmental Safety, lithium is not expected to bio-accumulate and its human and environmental toxicity are low [19]. However, there is currently a large research effort underway investigating the use of both hazardous and non-hazardous materials in novel electrode and electrolyte types, therefore each battery chemistry must be evaluated individually. According to the U.S. geographical survey[3] the largest reserves of Lithium in the world lie in South America, in Chile and Bolivia. While Chile is already a major exporter, Bolivia has yet to exploit their resource, and therefore may affect price as their production capability comes online.

Currently there is no commercially viable recycling process for used Li-ion batteries, although significant research is being carried out in this area, mainly prompted by the presence of Cobalt in some of the Li-ion battery chemistries.

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