Battery Energy Storage

White paper

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Battery Energy Storage

White paper

SUSCHEM
European Technology Platform for Sustainable Chemistry

Throughout this white paper, several images are shown of people using or enjoying electric products with batteries. These are widely used in mobility: such as electric cars, bikes, buses and ferries. In addition, in electric storage and tools at home, care products or hand held power devices and many other products that make life pleasant all over Europe.

Contents

Introduction

Worldwide energy consumption has been increasing rapidly, reaching 160 000 TWh in 2016, driven by the increasing world population, as well as increasing per capita energy consumption. The impact of this growth in energy consumption on the environment and society is becoming more and more apparent. This has accelerated the development and deployment of Renewable Energy Sources (RES) harvesting technologies and facilities; RES accounted for 24.4% of global electricity production by the end of 2016.

The increase of RES has highlighted the next big challenge; storage of energy when demand is lower than the supply. Several energy storage technologies exist, many of which have been used for decades. Among the different technologies, **batteries have the highest cost reduction potential at the moment**[1].

This paper looks into the current state of battery storage technologies in Europe, the main challenges, and suggests actions for the future, representing the views of stakeholders in the European battery value chain and, in particular, the chemical industry and raw material suppliers.

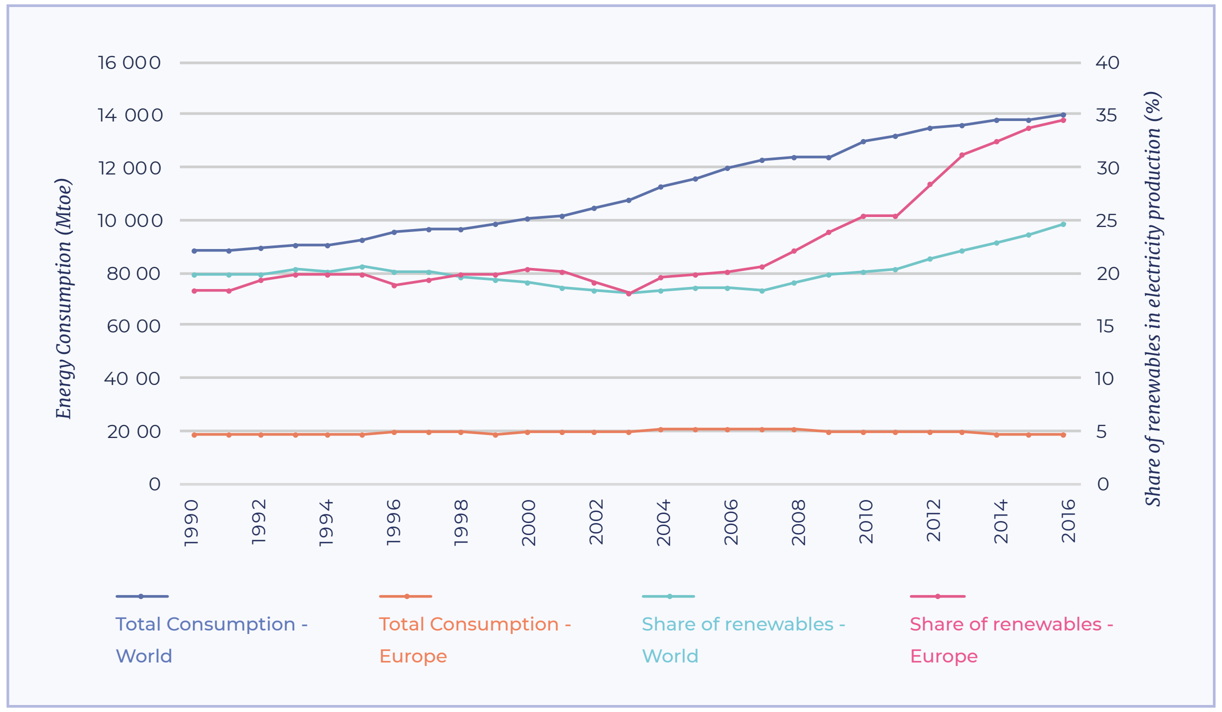


Figure 1. Energy Consumption and share of Renewables in Energy Production (Bax & Company, 2018, source: Enerdata Yearbook; The World Bank)

1: European Academies Science Advisory Council (2017). *Valuing dedicated storage in electricity grids*. EASAC policy report 33 (May 2014).

Battery energy storage technologies

As batteries serve a wide range of functions (from stationary to mobile applications and from powering consumer electronics to large industrial facilities), there is a wide variety of electrochemical energy storage technologies, each with different characteristics.
Below we provide an overview of the different technologies.

Lithium-ion (Li-ion) batteries

Li-ion Batteries make use of a cathode (positive electrode) which is metal oxide, an anode (negative electrode) which is porous carbon, and an electrolyte. When the circuit is closed, the ions flow from the anode to the cathode during discharge, generating electricity. Charging reverses the direction of the ion flow[2].

Several types of Li-ion batteries exist. **Lithium Cobalt Oxide** *(LiCoO2)* batteries use a cobalt oxide cathode, and a graphite carbon anode. Its high specific energy makes it the popular choice for mobile applications such as phones, laptops and digital cameras. The typical operating range of Li-cobalt cells is between 3 - 4.2V. Specific energy density varies between 150 and 200 Wh/kg and can go up to 240 Wh/kg for specialty cells. These systems can typically reach up to 1 000 charge/discharge cycles before performance is significantly reduced.

The main disadvantages of Li-cobalt cells are their relatively short life-span, limited specific power capabilities, and low thermal stability, which causes overheating when the cell is charged at a current higher than its capacity, in mA.

2: Hesse, H. H. et al (2017). *Lithium-Ion Battery Storage for the Grid — A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids.* Energies 2017,10.

Lithium Manganese Oxide *(LiMnO2)* batteries make use of lithium manganese oxide as the cathode material. The design of the batteries creates a 3-dimensional spinel structure that enables better flow of ions on the electrode. This provides higher thermal stability, as well as better safety, which makes Li-manganese batteries highly suitable for applications with high loads, such as electric vehicles and power tools. Main disadvantages are their relatively low calendar and cycle life, as they can typically reach up to 700 cycles. Li-manganese batteries can provide between 3 - 4.2V, while their specific energy density varies between 100 and 150 Wh/kg.

Lithium Nickel Manganese Cobalt Oxide *(NMC)* batteries are one of the most successful systems as the combination of nickel-manganese-cobalt at the cathode gives them the flexibility to be tailored for energy (higher capacity, lower current) or power (lower capacity, higher current) applications. This flexibility makes the battery ideal for a variety of applications, from electric vehicles (EVs) to medical devices and industrial applications. Another advantage is the reduced cost (compared to other Li-ion technologies) due to the (partial) replacement of cobalt with nickel at the cathode, which is cheaper. Like other Li-ion technologies, NMC have a typical operating range between 3 and 4.2V. Specific energy density varies between 150 and 220 Wh/kg, and batteries can reach up to 2 000 cycles.

Lithium Iron Phosphate *(LFP - LiFePO4)* batteries make use of iron phosphate in the cathode, which provides good electrochemical performance, and low resistance. The main advantages of the technology are long cycle life, good thermal stability, high tolerance to full charge conditions, lower stress if kept at high voltage for long periods, and high current rating. This makes them useful in applications that need high load currents and endurance, e.g. as a starter battery in vehicles, replacing lead-acid batteries.

As a trade-off, the Li-phosphate batteries have a higher self-discharge compared to other Li technologies, and lower nominal voltage around 3.2V, which reduces their specific energy density to 90-120 kWh/kg. Li-phosphate batteries can reach up to 2 000 cycles.

Lithium Nickel Cobalt Aluminum Oxide *(LiNiCoAlO2, NCA)* batteries are similar to NMC. They have a high energy density of 200 - 260Wh/kg, operating range of 3 - 4.2V, and reach up to 500 cycles. They are typically costlier than the average Li technology, and are usually used in industrial applications, and electric powertrains.

Lithium Titanate batteries make use of titanate in the anode, instead of graphite in typical Li-ion batteries. Cathodes can be Li-manganese oxide, or NMC. Li-titanate has good performance at extreme temperatures, and does not form a solid electrolyte interface (SEI) film or lithium plating when charging in low temperatures, or fast charging. Typical applications are electric powertrains and uninterruptible power supplies (UPS). The main disadvantage of the system is its high cost, as well as its low specific energy density of 50 Wh/kg. Typical operating range is 1.8 - 2.85V. Li-titanate batteries can reach up to 7 000 cycles.

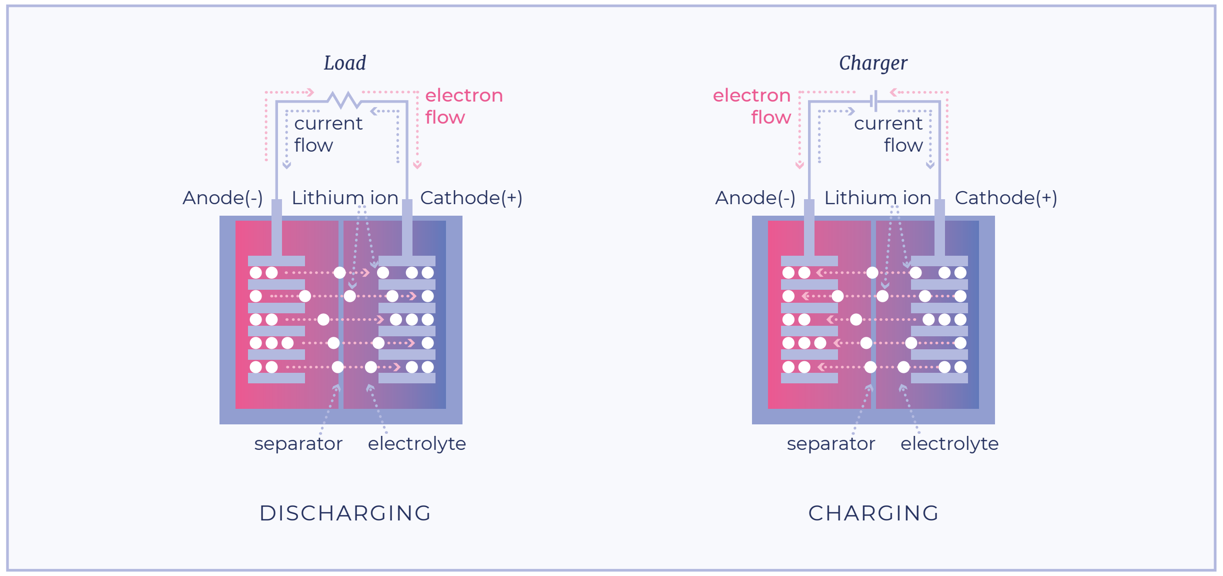


Figure 2. Charging and discharging of Li-ion cells

Flow batteries

Flow Batteries are a type of electrochemical cell which is a cross between a conventional battery and a fuel cell. The energy is provided when two liquid electrolytes (metallic salts dissolved in liquids) are circulated through a common core (with the help of a pump) that consists of a negative and a positive electrode and separated by a membrane. This circulation generates an ion exchange between the catholyte and anolyte, which generates a flow current, and hence, electricity. Similarly, the reverse process is used to charge the battery[3]. The biggest difference between conventional and flow batteries is that the energy is stored in the electrolyte (compared to the electrodes in conventional batteries). Hence, the volume of the battery dictates the battery's capacity.

There are several types of flow batteries. **Redox flow batteries** *(reduction-oxidation)* are the most commonly used flow batteries, where electricity is generated due to the difference in potential of the two tanks. When discharged, both tanks hold the same electrolyte solution – a mixture of positively and negatively charged ions. Materials commonly used in redox flow batteries are Vanadium-Polyhalide, Vanadium-Vanadium, Bromine-Polysulfide, Iron-Chromium, and Hydrogen-Bromium[4].

In **hybrid flow batteries**, one or more electro-active components are stored as a solid layer. The electrochemical cell contains one battery electrode and one fuel cell electrode. Typical materials used are Zinc-Bromine, Zinc-Cerium, and Lead-Acid.

Membraneless flow batteries make use of a laminar flow to ensure separation of the two electrolytes in the common core, eliminating the need for a membrane.

3: Davies, J. T.; Tummino, J. (2018). *High-Performance Vanadium Redox Flow Batteries with Graphite Felt Electrodes.* Journal of Carbon Research, 4 (1).
4: Leung, P. et al. (2012). *Progress in redox flow batteries, remainingchallenges and their applications in energy storage.* The Royal Society of Chemistry Advances (Issue 27).

Cell voltage for flow batteries ranges between 0.5V and 2.4V, depending on the specific technology, and materials used. Power density can vary from some 800 W/m3 for vanadium-vanadium to >1 000 W/m3 for zinc-bromine and lead-acid systems and can go up to 15 000 W/m3 for hydrogen-lithium systems. Energy density for flow systems is typically around 50 Wh/L for vanadium-vanadium systems, but can go up to ~1 400 Wh/kg for hydrogen-lithium chlorate systems.

One key advantage of flow batteries is the separation of power and energy requirements. As the electrodes are not part of the electrochemical "fuel", they can be designed for optimal power acceptance without the need to maximise the energy storage density. In addition, the fact that electrodes do not contain active material, leads to more durable and stable performance, and longer lifetimes. The separation of active materials ensures increased safety of the whole system. In addition, flow batteries can reach deep discharges without any impact on cycle life, and can reach near unlimited charging cycles, with little to no impact on nominal capacity. The main disadvantage of flow systems is their size – which limits their applications to large stationary industrial applications – as well as the complex system of pumps, sensors, vessels etc. required, even though the mechanics of each individual component are fairly simple.

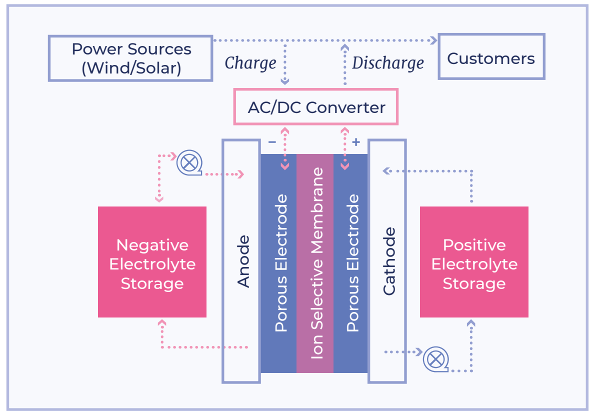


Figure 3. Generation of electricity in a flow battery

Nickel-based batteries

Ni-based batteries make use of a porous nickel electrode for the deposit of active materials. Since their invention at the end of the 19th century, several enhancements have been introduced.

Nickel Cadmium *(NiCd)* was the first type of Ni-based battery. It is highly durable, and can reach more than 1 000 cycles with proper maintenance. In addition, it can be charged fast, performs well in low temperatures, and has among the lower costs per cycle. This has made it the technology of choice for many years in the aviation industry, and it has also been used for stabilising wind energy systems.

The most important downside is that Cadmium is a toxic material which can not be disposed in landfills due to soil pollution, so it is gradually being replaced by other technologies. NiCd also has a relatively low specific energy density of 45 – 80 Wh/kg and has a memory effect (so needs periodic full discharge and charge cycles).

Nickel-metal-hydride *(NiMH)* is a newer Ni-based technology, and provides ~40% higher energy density than typical NiCd systems. It is mainly used as rechargeable batteries (typically in AA and AAA sizes) for consumer electronics. Main advantages are good performance in a wide range of temperatures, and ease of recycling.

On the downsides, NiMH has a high discharge rate (20% in the first 24 hours, 10% each subsequent month), and is sensitive to overcharge, requiring complex charging algorithms. Specific energy density is typically between 60 to 120 Wh/kg and cells can reach up to 500 cycles.

Nickel-iron *(NiFe)* makes use of an iron anode, an oxide-hydroxide cathode, and potassium hydroxide electrolyte. It is resilient to over-discharge and overcharge, and resistant to vibrations and high temperatures. For this reason, it is mainly used in mines, railroad signaling, and trucks/forklifts. Disadvantages include high discharge rates (up to 40% per month), poor performance in low temperatures, and relatively low energy density, of up to 50 Wh/kg. Cost of the system is not low either; at about four times the cost of lead acid systems, and comparable to Li-ion.

Nickel-zinc (NiZn) are similar to NiCd, as it uses an alkaline electrolyte, but has a higher cell voltage (1.65V compared to 1.2V for NiCd), but does not include highly toxic materials. Energy density can go up to 100 Wh/kg and can reach up to 300 cycles.

Nickel-hydrogen *(NiH)* batteries were developed to address the issues with metal instabilities in NiMH batteries. NiH has solid nickel and hydrogen electrodes, and the electrolyte, electrodes and screen are encapsulated in a high pressure steel canister (8270 kPa). It has a long service life, low self-discharge and good performance in a wide range of temperatures (-28 °C to +54 °C). NiH batteries are mainly used in satellites. Specific energy density is 40 – 75 Wh/kg.

Metal-air batteries

Metal-Air batteries comprise a pure metal anode, an air cathode, a separator, and the electrolyte. The separator is an insulator which only allows the transformation of ions. During the discharge process, oxidation reactions occur to the metal anode with metal dissolved in the liquid electrolyte and an oxygen reduction reaction is induced in the air cathode. Due to the open battery configuration that uses air as the reactant, **metal–air batteries have much higher energy capacity** (up to ~12 000 Wh/kg, which is comparable to that of petrol), which has made it very attractive to the automotive industry. Nevertheless, metal-air batteries have not yet been put into commercial use, as there are **several challenges that need to be overcome.**

Several alternative metal-air technologies exist, with that of *Li-air* being one of the most promising. Other technologies include *Al-air, Iron-air, Zinc-air, Mg-air, Sodium-air, Na-air*, and *K-air* among others.

Lead-acid batteries

Lead-Acid batteries consist of flat lead plates which are immersed in a pool of electrolyte. One of the plates is covered with a paste of lead dioxide, serving as the positive, and the other is made of sponge lead, serving as the negative. A separator is placed between the two plates. A key difference for lead-acid systems compared to other batteries is their very long charging times, compared to discharge, which is connected to the formation of lead sulphate on the negative electrode. Lead-acid batteries also often require addition of water to the electrolyte, as excess electrons lead to hydrogen generation and hence, water loss.

Apart from this, lead-acid batteries require low maintenance. Typical applications are back-up for emergency power, UPS, and automotive and traction. Energy density varies between 30 to 50 Wh/kg, cell voltage is 2V, and systems can go up to 300 cycles.

Sodium sulfur (NaS) batteries

NaS batteries are a type of molten-salt battery technology which use molten sulfur as the positive electrode, and molten sodium as the negative. The two electrodes are separated by a solid ceramic sodium alumina, which acts as the electrolyte as well. During discharge, electrons are released from the sodium metal atoms, leading to the formation of sodium ions which move through the electrolyte to the positive electrode, generating electricity. NaS batteries operate at high temperatures, typically >300°C, so in many cases external heaters are required. They have a high round-trip efficiency of ~90%, and specific energy is 150 Wh/kg or higher. They are often used for peak shaving and generally for stabilising renewable energy output and providing ancillary services.

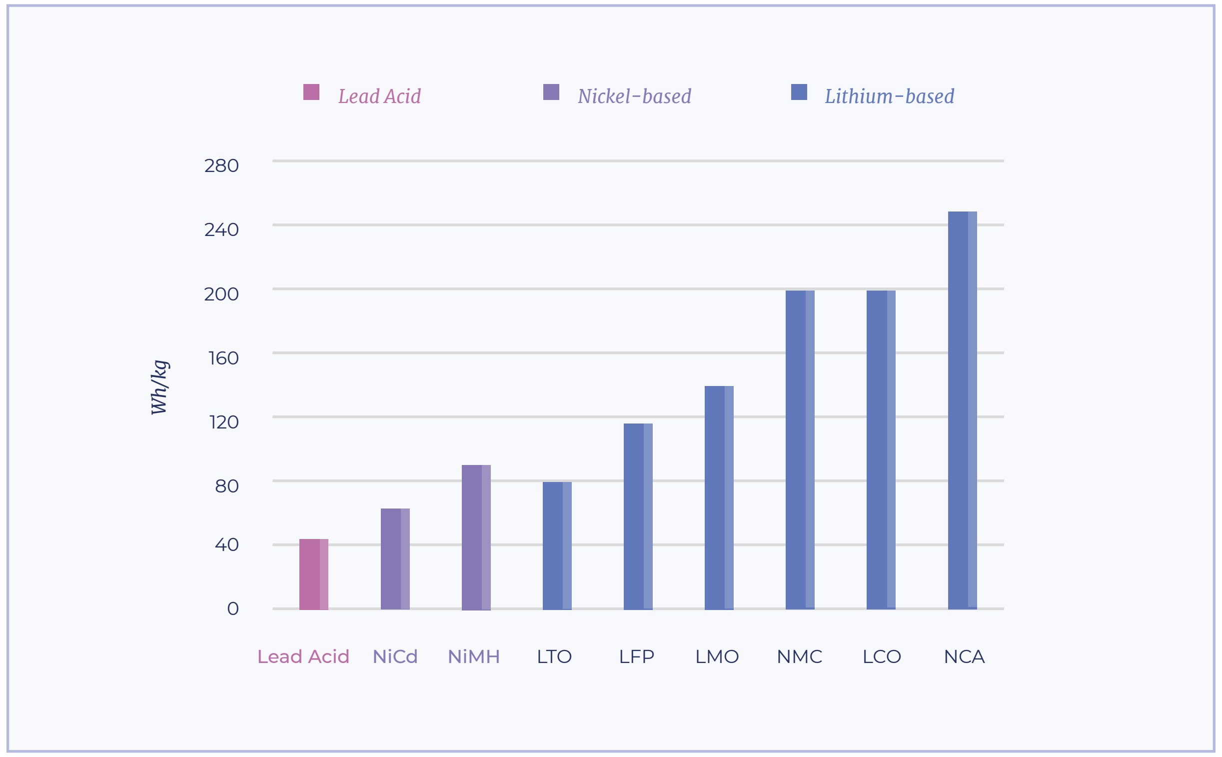


Figure 4. Specific energy for different batteries[5]

5: http://batteryuniversity.com/learn/article/types_of_lithium_ion

Current state

Main challenges

The various technologies have different advantages and disadvantages. Below we list the key challenges identified by experts in the industry that need to be tackled.

Technical challenges

General

One of the major challenges for all mature technologies in the market is insufficient energy density for specific applications, and notably for EVs. When it comes to stationary applications where battery volume (and hence energy density) is not a primary issue, there are still challenges in cost, as the Levelised Cost of Storage (LCOS, measured in €/kWh) would still have to drop below €0.05 per kWh to sufficiently increase the attractiveness of batteries.

Lithium-ion

Although at the moment Li-ion is the most promising technology – particularly for mobile applications – there are still some challenges that need to be overcome.

Conventional Li-ion still need improvements in energy density, fast charge capabilities, and cost. Moreover, the technology uses Cobalt oxides in the cathode that are expensive and unstable; in comparison, LFP based compositions are safer but lack energy density and have lower voltage. There is a trend to reduce Cobalt at the cathode while keeping the benefit of higher density and voltage.

Performance of Li-ion is also sensitive to external conditions, and can be significantly reduced when exposed to high or low temperatures, which in the long term negatively affects battery life.

Furthermore, the operating cell voltage is partly limited due to the conventional materials used in cathodes, although alternatives are being investigated. When it comes to the anode, promising materials are being investigated as well (e.g. Silicon-based), which show potential for significant increase in energy density, but still lack cyclability due to morphological changes.

Flow batteries

Flow batteries have been receiving growing attention, as they offer a cost-effective energy solution, although suitable primarily for stationary applications, due to the size of the system. Key challenges that still need to be addressed include the high price of complexing agents (bromide-ions) which are used to stabilise the free iodine forming iodine-bromide ions as a means to free up iodide ions for charge storage. In addition, the overall performance of the electrolytes could be further improved.

Current electrode material (typically graphite felt) also results in a relatively large cell ohmic resistance and limited power density. Furthermore, the design of the electrode can be further improved to allow better flow of the electrolyte, as well as better cyclic performance[6].

Nickel-based

The main challenge for nickel-based systems is the high toxicity of Cadmium, which needs to gradually be replaced with other materials. European directives to restrict the use of Cadmium have already been put in place.

Metal-air

Practical applications of metal-air batteries are still challenging, particularly for highly promising technologies, e.g. Li-air, which are subject to severe capacity fade after ~50 cycles. In addition, in Li-air batteries, the electrolyte accounts for ~70% of the mass, which is a limitation to increasing specific energy[7].

In general, metal-air batteries face issues with slow reaction of oxygen chemistry due to high overpotentials for the oxygen reduction and oxygen evolution reactions. Furthermore, electrical recharging is difficult and inefficient; secondary (rechargeable) batteries under development currently have a lifetime of a few hundred cycles and typically attain only 50% cycle efficiency.

Lead-acid

Simple flat plate designs (automotive) have low prices but short lifetime and relatively poor performance in stationary applications; in contrast, deep discharge tubular plate designs have longer lifetimes but are expensive due to lower production volumes, lack of standardisation, and higher material usage. Future regulations are expected to prohibit lead batteries in vehicles.

Sodium sulfur

Operating temperatures of over 300°C imply they're only viable in large scale applications with dedicated infrastructure and high utilisation rates.

Policy challenges

One of the biggest challenges for uptake of energy storage technologies in Europe is the fragmented regulatory environment, which creates barriers for public or private national companies to upscale operations and expand beyond borders, making investment decisions even more difficult. This reduces the "market pull" element[8].

In addition, the lack of definition of energy storage in the grid and its ownership further prevents private investments. This issue is currently being addressed with the Revision to the "Electricity Market Directive".

Financial and market challenges

Even though there have been some discussions on the creation of a pan-European battery consortium, the main weaknesses of the European battery landscape are still the gaps in the value chain, and particularly the **lack of large scale cell production** in Europe. In addition to that, scarcity of raw materials makes Europe dependent on other countries. The pricing and availability of such raw materials is highly sensitive to geopolitical events, as many of the raw materials are sourced from "unstable" countries (e.g. 80% of global Cobalt production comes from Congo). Nevertheless, it is worth mentioning that there are several European raw material suppliers.

Another challenge is that currently **the European market is not in urgent need of additional energy storage capacity**. Considering current energy storage grid applications (serving flexibility needs) and a moderate growth scenario, no additional energy storage deployment would be necessary for the next 5 - 10 years, although this evolution is highly unpredictable.

The price of raw materials (e.g. electrolytes) is still high, partly due to technological developments, and partly due to the smaller market size, especially for less "popular" technologies.

Finally, the cost of transactions in the network (e.g. double taxation for individuals that produce locally and sell to the grid) discourage private investments.

Other

One other challenge in Europe is that although significant breakthroughs are achieved in European and national collaborative projects, results are not exploited (or at least not in Europe); several experts point out that this is either because they are not applied to real-life cases, or because dissemination is very limited.

6: Nguyen, T.; Savinell, R. T. (2010). *Flow batteries*. The Electrochemical Society Interface, Fall 2010.

7: Zhang, X. et al. (2016). *Recent progress in rechargeable alkali metal–air batteries*. Green Energy & Environment, 1 (1).

8: EUROBAT (2016). *Battery energy storage in the EU – Barriers, opportunities, services and benefits.*

Opportunities

Besides the challenges described above, there are several opportunities for European battery stakeholders.

Foremost, **Europe has significant knowledge** on fundamental materials technology and engineering in the field of battery management systems, systems integration, manufacturing machinery development, and commercialisation. In the area of Li-ion, Europe possesses the necessary knowledge to be well positioned in the race for the next generation of Li-based batteries, which could provide the solution to the EV range issue. Similarly, European organisations possess significant knowledge in flow batteries, which are promising for stationary applications[9].

Another opportunity that could materialise into a strength is the possibility to use **blockchain technology** to reduce transaction costs between actors in the network.

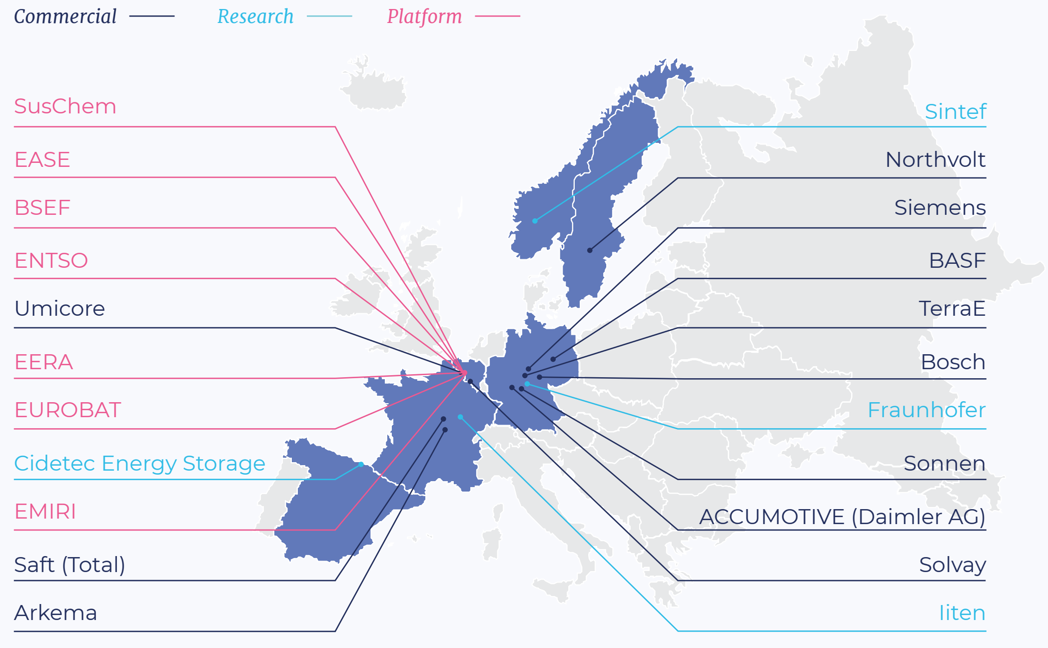
Furthermore, a number of European power-plants built in the 60s and 70s (especially nuclear power plants) are now reaching their end of life, presenting an opportunity to be substituted by RES coupled with battery energy storage.

Finally, the increasing interest in RES, and its utilisation presents a growing opportunity for deployment of batteries.

9: European Commission (2017). The Strategic Energy Technology (SET) Plan.

Key players

Figures 5 and 6 illustrates the main industrial and academic players in Europe, selected based on their knowledge and expertise, production capacity, and their level of activity in the field (either as a Research and Technology Organisation (RTO), supplier, or end-user) and their positions in the European Battery Value Chain.



China
- ATL
- BAK
- BYD
- CATL
- Lishen

Japan
- Maxwell
- Sanyo
- Sony
- Panasonic

South Korea
- LG Chem
- Samsung SDI

USA
- Tesla
- Sakti3 (Dyson)

Australia
- Redflow

Figure 5. Geographical location of the main players in the European Battery Energy Storage Value Chain

Figure 6: The European Battery Energy Storage Value Chain and the key players in each segment

Project name	Objective	Funding	Partners
eCAIMAN 2015-2018	Development of higher density automotive batteries	H2020	• Austrian Institute of Technology • Ethniko Kentro Erevnas Kai Technologikis Anaptyxis • Arkema France • Commissariat A L Energie Atomique Et Aux Energies Alternatives • Centro Ricerche Fiat Scpa • Eutema GmbH • Fundacion Cidetec • Imerys Graphite & Carbon Switzerland SA • Lithops Srl • Samsung Sdi Battery Systems GmbH • Magna Steyr Battery Systems GmbH & Co Og • Pe Cee Nachhaltigkeitsberatung & Software Vertriebs GmbH • Piaggio & C S.P.A. • Politecnico Di Torino • Rise Research Institutes of Sweden AB • Volvo Technology AB
GREENLION 2011-2015	Result in the manufacturing of greener and cheaper Li-ion batteries for EVs	FP7	• Fundacion Cidetec • Österreichisches Forschungs- Und Prüfzentrum Arsenal GmbH • Westfaelische Wilhelms-Universitaet Muenster • Polytype Converting AG • Arcotronics • Politecnico Di Milano • Agenzia Nazionale Per Le Nuove Tecnologie, L'energia E Lo Sviluppo Economico Sostenibile • Celaya, Emparanza y Galdos Internacional, S.A. • Mondragon Assembly SA • AIT Austrian Institute of Technology GmbH • Rescoll • Tecnicas Reunidas SA • Centro Tecnico De Seat SA • Volkswagen AG • Karlsruher Institut Fuer Technologie • Manz Italy Srl

Project name	Objective	Funding	Partners
ALION 2015-2019	Development of an aluminium-ion battery technology for energy storage application in decentralised electricity generation sources	H2020	• Acondicionamiento Tarrasense Associacion Torrecid SA • Varta Microbattery GmbH • Albufera Energy Storage Sl • Dechema-Forschungsinstitut Stiftung • University of Southampton • Technische Universitaet Berlin • Solvionic • Norges Teknisk-Naturvitenskapelige Universitet Ntnu • Accurec-Recycling GmbH • Acciona Construccion SA • Ceg Elettronica Industriale Spa • Commissariat A L Energie Atomique et Aux Energies Alternatives
FiveVB 2015-2018	Development of a new cell technology based on innovative materials such as high capacity anodes, high voltage cathodes and stable, safe and environmentally friendly electrolytes	H2020	• AVL List GmbH • 3M Deutschland GmbH • Arkema France • Robert Bosch GmbH • Umicore • Kompetenzzentrum - Das Virtuelle Fahrzeug, Forschungsgesellschaft Mbh • Vrije Universiteit Brussel • Zentrum Fur Sonnenenergie- Und Wasserstoff-Forschung Baden-Wurttemberg • Bayerische Motoren Werke Aktiengesellschaft • JRC -Joint Research Centre- European Commission
ZAS 2015-2018	Improve the performance of rechargeable zinc-air batteries as a promising option for stationary energy storage	H2020	• Sintef • Fundacion Cidetec • Deutsches Zentrum Fuer Luft - Und Raumfahrt Ev • Danmarks Tekniske Universitet • Institute of Electrochemistry and Energy Systems • Ceramic Powder Technology As • Varta Microbattery GmbH • Instalaciones Inabensa SA • Reactive Metal Particles As • Abengoa Innovacion Sociedad Anonima

Project name	Objective	Funding	Partners
SPICY 2015-2018	Multi-disciplinary development of a new generation of Li-ion batteries meeting the expectations of electrical vehicle end-users, including performance, safety, cost, recyclability and lifetime	H2020	• Commissariat A L Energie Atomique Et Aux Energies Alternatives • Tekna Plasma Europe • Karlsruher Institut Fuer Technologie • Wavestone Luxembourg S.A. • Technische Universitaet Muenchen • Belife • Eidgenossische Materialprufungs- Und Forschungsanstalt • Fundacion Cidetec • Prollion SAS • Centre Technique Industriel De La Plasturgie Et Des Composites • Hahn-Schickard-Gesellschaft Fuer Angewandte Forschung E.V. • Vlaamse Instelling Voor Technologisch Onderzoek N.V. • Recupyl SAS • Forschungszentrum Julich GmbH • Prayon S.A.
ELIBAMA 2011-2014	Enhance and accelerate the creation of a strong European automotive battery industry structured around industrial companies already committed to mass production of Li-ion cells and batteries for EVs	FP7	• Renault SAS • Commissariat A L Energie Atomique Et Aux Energies Alternatives • Daimler AG • Entegris Cleaning Process (Ecp) SAS • Euro Dieuze Industrie SAS • Fraunhofer Gesellschaft Zur Foerderung der Angewandten Forschung E.V. • In-Core Systemes Sarl • Ingecal SA University of Limerick • Solvay Fluor GmbH • Imerys Graphite & Carbon Switzerland SA • Maschinenfabrik Max Kroenert GmbH & Co Kg • Thinkstep AG • Prayon S.A • Rhodia Operations • Saft • Societe Nouvelle D'affinage des Metaux-Snam • Solvay Specialty Polymers Italy Spa • Umicore • University of Newcastle Upon Tyne

Future outlook

A highly flexible electricity system would have very limited requirements for energy storage, as energy could be produced almost "on-demand". Until we reach that point though, **energy storage deployment is necessary**. The main trends that will lead this change, as well as the strategy to move forward are outlined below.

Main trends

One of the main trends that drive battery storage development is the **electrification of mobility**, which – at least partly – derives from the need for cleaner vehicles. This has partly driven the developments in Li-ion technologies towards higher energy density and lower costs and is expected to continue doing so.

Another influencing factor is the **decreasing cost of batteries** – due to developments in material technologies – which is increasing the attractiveness of battery applications.

Next to this, **growing public awareness** about environmental issues contributes to an increasing share of RES in the electricity mix, and as a result of this rising RES contribution, a rising volume of battery storage applications.

In terms of where energy is produced, the **decentralisation of energy production and storage** (already piloted in several locations in Europe) will eventually increase the need for deployment of smaller scale battery installations.

What is more, the **increasing load on existing electricity grids** due to increasing energy production will push for more (battery) energy storage to balance loads.

On a political level, the **increasing need for European energy independence and security** pushes for more 'in-house' developments and installation. Similarly, market and political developments such as the rise of Tesla and the Dieselgate scandal have already accelerated the development of battery technologies.

Besides stationary and EV applications, the rise of the Internet of Things (IoT), device electrification (e.g. e-books, smart watches, smart phones, smart keys etc.) is rapidly increasing the **need for higher density batteries.**

Finally, **new alternative ways for financing innovation projects** (e.g. crowdfunding, PPPs, corporate innovation competitions) can eventually lead to further development and deployment of battery technologies.

Strategy for moving forward

Below we list the main suggestions for addressing the challenges described above.

Technical

General

The implementation of **eco-design practices** in the development and manufacturing of batteries would make recycling easier and allow for the retrieval of raw materials and re-incorporation in the value chain. This would address (at least partly) the raw materials independence challenge mentioned above. In parallel, technological solutions to enable second-life applications for batteries (particularly from the automotive sector) should be developed.

Aiming to **increase market acceptance,** stakeholders should develop battery management systems and electric architectures aiming at increasing battery safety, reliability and lifetime.

In addition, **a better understanding of batteries** – from individual materials, to components, to systems – should be achieved through multi-scale and multi-physics modelling. As a result, new solutions for improving reliability, safety and performance should be proposed.

Finally, the **development and adjustment of standards** for battery performance and safety would greatly accelerate communication – both within and outside the industry – and wider public acceptance.

Lithium-ion

One of the main milestones for Li-ion and related applications is to develop large format (> 150 Ah) cells with high energy density (> 400 Wh/kg and 800 Wh/L) by 2030 (existing Li energy densities go up to ~265 Wh/kg). In order to achieve this milestone, it is of key importance to develop advanced materials (covering anode, cathode, binders, separators, electrolyte collectors, packaging materials) to increase performance and decrease costs. This could include the use of **composite or silicon based anode materials**, for stress absorption and boosting capacity respectively, such as carbon and silicon/tin to avoid pulverisation; high voltage cathodes for better energy density, and related new electrolytes to withstand higher voltages and minimise degradation; and solid state electrolytes. In addition, more suitable active materials that can be used in these components should be identified and tested.

Smart combination of high energy density active materials (cathode and anode) operated under challenging conditions (e.g. charging at > 4.5 V) will enable significant gains in driving range for EVs. This would require a full Li-ion battery cell system approach to optimise all material components.

Finally, **a better understanding of battery electro-chemistry and physicochemical properties** of the material interfaces should be obtained. This will contribute to creating batteries with higher energy density.

Flow batteries

With the aim of increasing overall battery performance, hardware improvements should be implemented. As an example, an issue that should be targeted is the **re-engineering of the electrode stack**.

At the chemistry level, a **more optimal complexing agent** should be utilised, which would improve the performance of the electrode while complying with cost requirements.

Policy

With the objective of using policy to accelerate battery storage deployment and development, the electricity market should be designed to include tariff structure and regulation of system operators. This should provide a **clear definition of energy storage** in the grid, and its ownership across Europe. In parallel, the regulatory environment in Europe should be harmonised cross borders, this is important for: i) creating a level playing field for all technologies (technology neutral), ii) increasing adoption (independent providers can operate in more than one country)[10, 11].

Another issue that needs to be addressed is **how self-consumption customers** (households that generate energy from RES for their own consumption and sell the excess to the energy provider) **will contribute to the maintenance of the network**, as for the moment this is not defined. A potential solution would be through smart-metering.

In order to accelerate deployment, the policy framework should provide **incentives for installing capacity** (e.g. via the Connecting Europe Facility or the European Investment Bank), especially for technologies that have high up-front investment requirements. If subsidising deployment is not the preferred option, then authorities should consider **auctioning grid locations**, taking into consideration the physical constraints of the location for finding the most efficient overall grid solution (following the examples of the UK and German regulators).

One aspect to keep in mind when deciding on policies is that they should ensure that there are **no unnecessary regulations** for some technologies that can delay their commercialisation (e.g. fire safety requirements which are not necessary for all technologies).

Moreover, **better coordination** and facilitation between stakeholders on a European level is required, so that input given to the European Commission is not biased towards a specific technology, sector or material.

To **increase the impact of European (funded) initiatives**, European project results should make use of existing European associations to reach a broader and more targeted audience.

As mobility is closely interconnected with energy storage, policy regulations should accelerate the de-fossilisation of the mobility sector, using financial and non-financial incentives (e.g. more car charging stations to incentivise the use of EVs). Furthermore, the development of the European battery value chain should be facilitated and encouraged to serve a common strategic interest by incentivising **car manufacturing countries to join forces with the EV battery value chain**; and incentivising the demonstration of mass battery cell production, particularly for next generation Li-ion technologies.

Focusing on the raw materials challenges, a **'responsible sourcing culture'** of raw materials should be promoted through voluntary schemes with companies (instead of stricter regulatory frameworks which would not be optimal due to the volatile geopolitical situations in several areas).

Finally, it is key to facilitate the deployment of the **circular economy principles** in the early stages of development.

10: European Commission (2017). *Energy storage – the role of electricity.*

11: EASE/EERA (2017). *European energy storage technology development roadmap towards 2030.*

Financial and market

Up to now, the electricity grid has been mainly about **transferring energy over space**, using power plants and transmission lines. With energy storage being added to the grid, we now have the possibility of **transferring energy over 'time'**. This change calls for the development of new business models which take into account such changes, in order to be in line with the 'new energy economy'.

Aiming to address specific needs of different applications, long duration hybrid storage should be examined, e.g. Li-ion to start and stabilise grid for 30 minutes, then switch to flow batteries.

Furthermore, **applications should be designed in a way that they can serve more than one role in the system** (e.g. voltage support and congestion management). The more roles an application serves, the more value it provides.

Targeting the materials issue, raw material suppliers should source critical raw materials such as Cobalt and Nickel from stable European countries (e.g. Finland).

Finally, **European players should focus on developing cell production capacity in Europe** in order to complete the value chain and allow a full integration, from material to batteries.

Other

Aiming at customising the technology, efforts should be targeted on the development of technologies and systems towards specific applications (e.g. power back-up, arbitrage, etc.).

Finally, it is important to create a **comprehensive material life-cycle understanding** to be used throughout the industry, so harmful materials can be defined. It is important to avoid over-regulating and creating defensive research initiatives.

About SusChem

SusChem is the European Technology Platform for Sustainable Chemistry. It is a forum that brings together industry, academia, policy makers and the wider society.

SusChem's **vision** is for a competitive and innovative Europe where sustainable chemistry and biotechnology together provide solutions for future generations.

SusChem's **mission** is to initiate and inspire European chemical and biochemical innovation to respond effectively to societal's challenges by providing sustainable solutions.

SusChem was officially launched in 2004 as a European Commission supported initiative to revitalise and inspire European chemistry and industrial biotechnology research, development and innovation in a sustainable way.

At SusChem we believe that sustainable chemistry can inspire a change of pace and the new mind-set that society needs in order to become (more) sustainable, smart and inclusive.

In partnership with European and national public authorities, SusChem contributes to initiatives that aim to provide sustainable solutions to society's big challenges. Together we develop and lead large-scale, integrated research and innovation programmes with chemical sciences at their core. These public private initiatives link research and partners along the value chain to real world markets through accelerated innovations.

SusChem across Europe

SusChem has established a network of National Technology Platforms (NTPs) in 15 countries across Europe: Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Greece, Italy, Netherlands, Poland, Romania, Slovenia, Spain, Switzerland and United Kingdom.

NTPs help to connect SusChem thinking with national and regional programmes. It also facilitates transnational collaboration and advice SusChem at the European level on collective national priorities that need to be considered in European initiatives.

Credits

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