Current and future development of battery technology and its suitability within smart grids

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The following project partners have been involved in the elaboration of this document:

<table>
<thead>
<tr>
<th>Partner No.</th>
<th>Company short name</th>
<th>Marcel Meeus (Sustesco), Giuseppe Pace (UGENT)</th>
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Executive summary

Beginning with the principle of battery functioning, this report describes the ongoing development of batteries and its potentialities in terms of exchanging energy with a smart grid.

First, it outlines relevant parameters to use in order to identify a "good" battery for any particular application (e.g. voltage match, polarization/rate capability, capacity/volume and weight, cycle life/shelf life, operating temperature range, safety, toxicity, cost, maintenance). Then, it introduces an overview of major rechargeable batteries (NiCd, NiMH, Li-ion).

For the scope of the research, the report defines the key parameters (e.g. energy density, power density, cycle life, charging/discharging rate).

In the second chapter, the report explores the advancements of Li-Ion advanced batteries, by exploring current limits of the Li Ion chemistry (energy density +/- 350 Wh/kg). Once these limits will be reached, further improvements will have to come from new systems. For the cathode, the first material in 1990 for Li-ion batteries was lithium cobalt oxide (LCO), but since 2010, there have been real breakthroughs in its technology, leading to an increase in either energy density, safety, or even both (e.g. high voltage cathode materials, such as LiM02.Li2M'O3).

The commonly chosen materials for the anode in Li-Ion batteries are carbon based and represent over 95% of the market. The reports describes the various research directions, mainly based on lithium intercalation (e.g., LTO or Li4Ti5O12), alloying (e.g., Sn, Si, and compounds), or conversion reactions. The ultimate breakthrough is expected to come from a combination of a high voltage (± 5V) cathode material and a new type of anode material with higher gravimetric energy density. Such a system will also require a new kind of electrolyte that is stable at the targeted higher voltage levels.

The report describes also a number of post Li-Ion batteries (e.g. Na-Ion batteries, Metal-air based rechargeable batteries, Zinc-Air and Zinc-Nickel rechargeable batteries, Sulphur based rechargeable batteries).

Another sensitive development is related to the battery cost for EVs, which at today depends for Li-Ion batteries on many variables including materials choice, energy contents and degree of manufacturing scale. Current studies suggest that a cost reduction will be achieved by lowering the material cost with a simultaneous increase of energy content and industrial manufacturing.

There is a possible timeline towards 2020 of the implementations, which introduces the need for recycling or/and a second use of the end of life battery in stationary energy storage. The need for that implementation has also been supported by EU, which set the standards for CO2 reduction towards 2030 and 2050, as well as many other world countries. Limiting CO2 as well as fuel consumption, are urgent topics to solve in the near future, especially in the domain of transportation, which is a major source of CO2 and a big consumer of oil. In particular, EV are a viable way to address these problems. Their “heart” is the battery, and automotive applications demand “high power” batteries, i.e. the energy needs to be delivered quickly when it is needed (e.g. during acceleration). The battery has to withstand quick recharging as well: this is imperative for the implementation of regenerative braking and for reducing recharging time of EVs.

Relevant success factors are increasing energy density, minimising battery weight, guaranteeing safety in a wide range of behaviours and temperatures, and finally reducing their cost.

The most plausible and realistic electrification scenario corresponds roughly with a penetration of 5% by 2020, consisting of 3% HEV, 1% of PHEV and 1% of pure EV, and by 2020 a yearly new EV sales of 100 M.

The report explores also the believe that energy storage for stationary power will become an important component of the future “Smart Grid”, by helping utilities to optimize power transmission and distribution. To that scope, a suite of stationary energy technologies is needed; no single storage technology option meets all the needs. The range of stationary storage requirements, spanning orders of magnitude in power and in discharge time, necessitates batteries,
capacitors, hydrogen, flywheels, compressed air, pumped hydro, superconductor magnetic systems.

Energy storage will provide essential services in the transition towards a secure, competitive and decarbonized energy system. However, storage is still a new and rather expensive solution and has still to prove its sustainability versus usual non-storage solutions, which are the instalment of new gas peaker plants or Transmission & Distribution Upgrade.

The report describes some storage solutions, varying by power capability and discharge times.

Today the position of Li-Ion is still modest (20 to 50 MW installed worldwide) and the major part of energy storage capacity is still provided by pumped hydro commodity storage.

Expectations are that Li-Ion energy storage (ESS) will represent an additional market of roughly 10% by 2020 next to the traditional market of portable electronics and emerging automotive market. Finally, the report introduce the role of the smart grid in the energy transition, as well as their potential for increasing storage capacity.

The report, in addition, describes the dedicated process for recycling rechargeable batteries initiated by the Umicore Company, which established the first battery recycling plant in the world at Hoboken Belgium, with a capacity of 7,000 tons of batteries (equivalent to 150,000 cars or 250,000,000 mobile devices) per year.

Finally, it reflects on the possibility to re-use batteries after the first life. A business case needs to be developed for such a case and the basic question becomes what the total cost of second life batteries will become compared with the decreasing cost evolution of first life batteries.
1. Principles: Electrochemical cell–basic components

Structure

The anode is the electrode at which oxidation takes place and where electrons are fed into the external circuit. The cathode is the electrode at which reduction takes place and into which electrons are fed from the external circuit.

In a primary cell, the anode is also the “negative” electrode and the cathode, the “positive” electrode. In a secondary cell on charge, the negative electrode becomes the cathode and the positive electrode, the anode.

The electrolyte serves as a medium for completing the electrical circuit via the transport of ions.

The reactants comprising the electrodes may be gaseous, liquid or solid, massive or porous. The electrolyte may be liquid or solid.

What makes a “good” battery for a particular application?

Voltage match: the electrochemical system determines the cell voltage, which may vary from 1.2 V for a Nickel based rechargeable cell to 4.2 V for a Li Ion system.

Polarization/Rate capability: the change in the potential of a cell or electrode from its equilibrium value caused by the passage of an electric current through it. Battery life is influenced by the charging rate and discharging rate. The capacity reduction at high charge/discharge rates occurs because the transformation of the active chemicals cannot keep pace with the current.

Capacity/Volume and Weight: important battery characteristic expressed respectively as Wh/kg and Wh/l.

Cycle life/Shelf life: cycle life is expressed as the number of cycles before the capacity drops to 80% of the initial capacity. Shelf life expresses the capacity loss of a cell sitting on the shelf (not active) due to unwanted chemical reactions.

Operating temperature range: the temperature window within a battery performs satisfactory, has to be as broad as possible e.g. -20°C to + 60°C.

Safety: very important parameter in any battery application and perhaps in particular for automotive. Safety depends on chemistry and can be regulated by internal (choice of materials, additives...) and external measures (Battery Management System...).

Toxicity: no environmental harmful materials tolerated (one of the reasons of the decline of the Ni-Cd batteries).

Cost: perhaps the most critical parameter for EV market penetration as further outlined in this report.
Maintenance: less of a parameter today because all systems became maintenance free.

Table 1: Overview of major rechargeable batteries

<table>
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<tr>
<th></th>
<th>NiCd</th>
<th>NiMH</th>
<th>Li-ion</th>
</tr>
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<tbody>
<tr>
<td>Introduction</td>
<td>1956</td>
<td>1989</td>
<td>1992</td>
</tr>
<tr>
<td>Voltage</td>
<td>1.2V</td>
<td>1.2V</td>
<td>3.6-3.7V</td>
</tr>
<tr>
<td>Energy density</td>
<td>40Wh/kg</td>
<td>80Wh/kg</td>
<td>160Wh/kg</td>
</tr>
<tr>
<td></td>
<td>150Wh/L</td>
<td>300Wh/L</td>
<td>450Wh/L</td>
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<tr>
<td>Applications</td>
<td>Power tools</td>
<td>Cordless phones</td>
<td>Portable electronics</td>
</tr>
<tr>
<td></td>
<td>Emergency lighting</td>
<td>Household</td>
<td>Power tools</td>
</tr>
<tr>
<td></td>
<td>R/C toys</td>
<td>Replace alkaline</td>
<td>Gen #2 (P) HEV/EV</td>
</tr>
<tr>
<td>Umicore presence*</td>
<td>Reducing</td>
<td>Moderate</td>
<td>Strong</td>
</tr>
</tbody>
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*Umicore is a Belgian based but internationally active company specialized in the development, manufacturing, marketing and recycling of advanced materials in numerous applications ([www.umicore.com](http://www.umicore.com)). Amongst others, Umicore is the world leader in cathode materials for Li Ion batteries and the first company in the world to recycle Li Ion batteries on industrial level.

Key Parameters

**Energy Density:** Long Term Wh/kg target for Li Ion is ca 300-350 Wh/kg together with +/- 800 Wh/L in other words makes the batteries smaller and lighter.

**Power density:** expressed as W/kg e.g. for Li Ion 1500 W/kg. Ratio Power/Energy depends on the application with for (P) HEV ratio P/E=-10 and for EV ratio P/E=3.

**Cycle life:** Targets in automotive are set at +/- 5,000 for EV and 300000 for HEV.

**Charging/discharging rate:** High C-rates important for Power applications, recovery braking energy and fast charging.

![Figure 2 and 3]
2. Li Ion advanced batteries

The working principle of the Li ion battery is illustrated in Figure 4 and relies on the shuttling of Li ions between cathode and anode.

![Figure 4: Working principle of the Li-ion battery](image)

Figure 5 introduces the on-going work for a substantial improvement of the present Li-ion generation towards an advanced next system, by exploring current limits of the Li ion chemistry (energy density +/- 350 Wh/kg). Once these limits will be reached, further improvements will have to come from new systems.

| NiMH (1.2V) | Li-Ion (~3.6V) | Advanced Li-Ion (3.6V and more) | New Systems |

Figure 5: Li ion battery development

**NMC Platform for EV/(P)HEV materials**

The first cathode material for Li-ion batteries in 1990 was lithium cobalt oxide (LCO). However, going into 2010, there have been some real breakthroughs in cathode technology leading to an increase in either energy density, safety, or even both.

![Figure 6: Structure of the different cathode materials](image)
LiCoO$_2$ (LCO):
Lithium cobalt oxide has a layered structure and its usable capacity typically amounts to 145 mAh/g at 3.7V versus Li/Li+. Doping and surface coating with inert oxides to stabilize the material up to cell voltages as high as 4.3 – 4.4V are generally applied. Decomposition of the material occurs above 180°C. Depending on the price of cobalt, which has been quite variable historically, LCO may turn out to be an expensive material due to its high cobalt content.

LiNiO$_2$ (LNO):
Lithium nickel oxide shows as well a layered crystallographic structure and its typical capacity is 180 mAh/g at 3.7V versus Li/Li+. High power densities are possible. It is not used as pure 100% active material due to safety and stability issues. However, it is often used in a stabilized structure containing cobalt and aluminium. The common name of this product is NCA (nickel-cobalt-aluminum) and a typical composition is LiNi0.8Co0.15Al0.05O2.

LiMn$_2$O$_4$ (LMO):
Lithium manganese oxide typically displays the spinel structure of an AB2O$_4$ compound. The practical capacity is only about 100 mAh/g at 3.9 V versus Li/Li+. The material exhibits improved safety: Stabilized spinels have been developed and are now commercially available. However, their cycle life raises issues especially at elevated temperatures. On the positive side, manganese is a cheap and widely available material and is environmentally friendly. LMO is often used in mixtures with other cathode materials.

LiCo$_x$Ni$_y$Mn$_z$O$_2$ (generally known as the NMC family) $(x + y + z) = 1$:
Generic NMC covers a range of different layered compounds and was developed with the aim to compromise between capacity (Ni), reversibility (Co), and safety (Mn). Capacity and voltage depend on the values of x, y and z, which are generally chosen between 1/4 and 2/3. The ‘1-1-1’ type material, which is short for LiCo1/3Ni1/3Mn1/3O2, is a typical composition. Such a material shows a capacity of 165 mAh/g at 3.9 V versus Li/Li+. The discharge curve is similar to those of LiCoO$_2$ or LiMn$_2$O$_4$ or mixtures thereof. Compounds with higher Ni content have also been developed. The current NMC platform, developed and commercialized by Umicore, is shown in Figure 7. The trends is to use Cobalt as low as possible.

LiFePO$_4$ (LFP):
Lithium iron phosphate was developed by Professor John B. Goodenough in 1996 and exhibits an olivine type crystallographic structure. Typical capacities are around 130 mAh/g at 3.2V versus Li/Li+ in practice. The charge/discharge curves show a very flat shape.

Figure 7: NMC Platform for EV/(P)HEV materials
The intrinsically poor electrical conductivity of the material needs to be improved by adequate coating with carbon on or by new processes such as those developed by MIT. Decomposition of LFP does not occur below 260°C, making it a stable material with good safety performance. Material availability (Fe) is not an issue.
What is new now at the cathode level for the next generation advanced batteries, going hand in hand with new anode materials?

**High voltage cathode materials (4.5 to 5V)**

Fundamental improvements, such as an increase of the specific energy of new Li-ion batteries up to 300 to 350Wh/kg, are required to meet the growing needs of modern markets. In order to achieve such a breakthrough, novel concepts for the lithium-ion battery chemistry and/or design, such as multiphase electrodes, must be developed.

Thackeray et al. have developed multicomponent cathodes such as LiMO2.Li2M’O3 (M= Co, Ni, Mn; M’= Ti, Zr, Mn). Such an electrode approach is used in an attempt to improve the cell’s specific energy values by shifting the cathode’s voltage up into the 5V region and at the same time increase the specific capacity by adding the second electrode component.

**Anode Materials**

The materials of choice for the negative electrode in Li-ion batteries are carbon based. They represent over 95 per cent of the market. Their success is the result of a good compromise between all desired properties:

- Safe thanks to the formation of a protective layer on the electrode,
- Good cycle life,
- Acceptable irreversible capacity loss,
- Low volume change during cycling,
- Economic (for low-end products) and abundantly available

The drawbacks are:

- Limited density,
- Limited charging rates due to the risk of Li dendrites forming

Lately, a great amount of research effort has been devoted to the development of **new anode** types with much higher volumetric capacity; however, several problems need to be solved to enable their widespread introduction. Currently, the only commercial system is Nexelion by Sony, making use of a nano composite of Co-Sn alloy with carbon. Si-based systems will be launched in the near future. The motivation is to be able to offer high-energy cells (above 3000 mAh for 18650 cells), which is not possible with classical carbon based anodes.
New anode materials
The various research directions are given in Figure 9. They are based on lithium intercalation (e.g., LTO or Li4Ti5O12), alloying (e.g., Sn, Si, and compounds), or conversion reactions.

Only a few of them will be discussed in this chapter:
- Li4Ti5O12 is one of the most promising negative electrode materials: Its Li intercalation potential is 1.55V, its theoretical capacity 168 mAh/g, and the changes in the lattice volume upon lithium intercalation/de-intercalation are small. High power performance has been reported. The material’s drawback is a decrease in Li-ion cell voltage by ±1.4V compared with the use of graphite.
- Electrodes based on alloying reactions: It has been known for a long time that alloying reactions of metallic lithium with metallic or semi-metallic elements are electrochemically feasible in a lithium cell at room temperature in a no aqueous electrolyte. The huge theoretical capacities expected for the formation of LixM binaries are very appealing for high-energy storage applications. If abundance, price, and toxicity are taken into account silicon and tin seem to be the most suitable electrode choices. However, the material’s volume expands drastically during alloying (‘swelling’) and that results in electrode disintegration: The volume expansion can reach up to 300% whereas with graphite it is only in the range of 12%. This phenomenon is now a research topic of the first order (in composite and nanotechnologies) and once it is under control, Si and Sn based alloys will be candidates for appealing new anode choices.

Summary of cathode and anode developments
Figure 10 shows a summary of the current cathode and anode research aiming at developing and introducing advanced Li-ion systems. The ultimate breakthrough is expected to come from a combination of a high voltage (±5V) cathode material and a new type of anode material with higher gravimetric energy density. Such a system will also require a new kind of electrolyte that is stable at the targeted higher voltage levels. Many material problems, however, still have to be overcome.
3. Post Li Ion batteries

**Na-Ion batteries**

The working principle is the same as for Li Ion but the studies relate to the substitution of Li by Na in the active compounds and in the electrolyte.

**Metal-air based rechargeable batteries**

Lithium-air batteries are interesting because of their high energy density (600 – 800 mAh/g compared to ~300 mAh/g for Li-Ion batteries). They are based on pure lithium metal as anode and a cathode that will help the reduction of oxygen from air. Most of the research has so far been focused on lithium-air for primary batteries. However, during recent years it has been shown that it can be made rechargeable. Since then it has attracted a lot of research interest. There are many elements affecting the performance of a lithium-air battery, such as cathode structure, anode morphology, electrolyte composition and the cell assembly. The cathode is usually made of a porous carbon, a catalyst and a binder.

**Zinc Air batteries and Zinc-Nickel rechargeable batteries**

Zinc has long been considered as an ideal battery electrode not only in primary batteries but also in rechargeable configurations e.g. for large format applications. It has the second highest capacity of the known chemistries and its manufacturing is potentially cheap. Rechargeability and low cycle life due to shape change and dendrite issues have prevented commercialization.

**Sulphur based rechargeable batteries**

Two main systems Li S (ambient temperature) and Na S (300° C) are developed both based on metal type anodes.
4. Cost reduction Li Ion batteries

The present cost price of LiIon batteries depends on many variables including materials choice, energy content and degree of manufacturing scale. Typical costs in highly automated production lines for portable electronics are around 150 \$/kWh but in less automated (P) HEV/EV these are still ca 700 \$/kWh meaning that an automotive battery e.g. of 24 kWh still bears a high cost hampering commercial development. Cost targets by 2020 are set at 250 \$/kWh by the industry (USABC). They will be achieved by lowering the material cost simultaneously with an increasing energy content and industrial manufacturing (as shown in Figure 12).

**Figure 12: 250 \$/kWh: this seems possible based on the TCO drivers on a Li-ion pack**

The Avicenne forecast (2013) as presented in Figure 13 indicates that those targets are realistic (confirmed by many other publications).
5. Timeline for the implementation of the improved and new technologies

Figure 14 gives an insight in the possible timeline of the implementations and introduces the need for recycling or a second use of the end of life battery in stationary energy storage. Both items, recycling and second life, will be further discussed in Chapters 9.

Figure 14: Timeline for implementation of new technologies
6. Specific automotive requirements

Standards for CO$_2$ reduction as proposed by the EU 2050.

The development of the “auto-mobile” in the late 19th century, coupled with the discovery and exploitation of fossil fuels, revolutionized many aspects of human transportation. However, there are drawbacks. For most of its history, the automobile has been powered by combustion engines, which need (fossil) fuel to operate. These combustion engines have limitations, which are beginning to show:

- The supply of fossil fuels is not infinite.
- Combustion of fossil fuels emits greenhouse gases, the most well-known being carbon dioxide. These greenhouse gases contribute to the “global warming” phenomenon observed in recent decades. Other noxious gases and substances are emitted as well: NOx, SO$_2$, hydrocarbons, soot, etc, some of these substances are carcinogenic; others contribute to photochemical smog formation.

Figure 15 sets the standards for CO$_2$ reduction as proposed by the EU 2050.

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**Figure 15: Standards for CO$_2$ reduction as proposed by the EU 2050**

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1 Large efficiency improvements are already included in the baseline based on the International Energy Agency, World Energy Outlook 2009, especially for industry
2 Abatement estimates within sector based on Global GHG Cost Curve
3 CCS applied to 50% of large industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

SOURCE: www.roadmap2050.eu
Reduction targets exist in most regions

Figure 16 shows that is not limited to Europe but a worldwide trends.

Limiting the emission of greenhouse gases as well as the reduction of fuel consumption are urgent topics that need to be solved in the near future, especially in the domain of transportation, which is a major source of greenhouse gases and a big consumer of fuel. As well as more efficient processes and smart design, the use of electrically driven vehicles is a viable way to address these problems on and off road.

The “heart” of the (H) EV is the battery: it stores the energy and releases it in a safe and controlled manner at the desired rate. Moreover, well-to-wheel efficiency is significantly improved.

It is clear that automotive applications demand “high power” batteries, i.e. the energy needs to be delivered quickly when it is needed (e.g. during acceleration). Furthermore, the battery has to withstand quick recharging as well: this is imperative for the implementation of regenerative braking, but also to reduce recharging times for plug-in hybrids and pure electric cars. The use of batteries in automobiles is a typical power application. However, power alone is not the only criterion when choosing the battery type. There is also a certain demand for energy. The more energy the battery can store, the higher the autonomy of the (H) EV will be. Of course, car manufacturers will prefer to minimize the weight of the battery. That is why batteries with a high energy density are preferable. The next criterion is safety. The battery must be able to operate safely in a wide range of conditions and it must be able to cope with low/high working temperatures. Furthermore, it must be usable during normal operation and it must have acceptable behaviour under abuse (e.g. if it is damaged during an accident). Finally yet importantly, the cost of batteries is a major factor for their use in automotive applications.

Ragone Plot: Energy-Power

Power and energy in Li-Ion batteries can be tailored by composition and design factors: they are typically represented by Ragone type plots, as shown in Figure 17.
Conclusions

Present EV's battery of 24 kWh, 300 kg and more by weight, a range of 125-150 km and a cost of 800 $/kWh (BMS included) needs to become in future EV's max 200 kg in weight with a range of>200 km and a cost of 250 $/kWh and fully safe/reliable. Safety is addressed and optimized by many internal and external means, as shown in Figure 18.

Figure 18: Safety issue on Li-ion internal components
7. Market forecast

The Avicenne 2013 forecast is proposed as the most plausible and realistic electrification scenario and corresponds roughly with a penetration of 5% by 2020 consisting of 3% HEV, 1% of PHEV and 1% of pure EV on an expected yearly new car sales of 100 M. See Figure 19 related hereto.

Figure 19: Different Electrification scenarios
8. Smart grid integration

Main drivers of clean energy storage systems

It is believed that energy storage for stationary power will become an important component of the future “Smart Grid”; it will help utilities to optimize power transmission and distribution. An increasing use of renewables such as wind and solar will drive the use of energy storage for a smooth integration of these intermittent energy sources into the grid. The stationary utility energy storage market is still very much in its nascent stages: its market forecasts vary largely between different market researchers but all agree “billion $” markets will be possible within the next 10 – 15 years.

Which are these stationary functions?

- Improvement of transmission efficiency
- Management of peak demand by shaving peak load and shifting to off-peak hours
- Improvement of overall power quality (PQ), smoothing out fluctuations in electricity transmission
- Temporary off-grid power solution (back-up)
- Storage for wind and solar (sources typically variable & intermittent)

Key drivers for the adoption of energy storage solutions are the growing need for energy independency, the expectation of them becoming an integral component of the future smart grid, the need to balance supply/demand, energy arbitrage and the increasing adoption of renewables that are intermittent in nature.

A suite of stationary energy technologies is needed; no single storage technology option meets all the needs. The range of stationary storage requirements, spanning orders of magnitude in power and in discharge time, necessitates batteries, capacitors, hydrogen, flywheels, compressed air, pumped hydro, superconductor magnetic systems. Battery energy storage in these applications is provided by lead-acid, nickel metalhydride, lithium-ion, sodium-sulphur (Na-S) and flow batteries:

- Historically lead-acid was the stationary system of choice
- Now this role has been taken over by Na-S in large-scale applications

- But Li-Ion are now fully in research and development with a focus on stationary usage.

It is rather unlikely that Li-Ion will be used in multi-MWh range applications but it is believed that they will find a place in future storage applications for residential, commercial and utility-owned systems as more and more utilities work on automated meter reading (AMR) and advanced metering infrastructure (AMI) developments.

Energy storage will provide essential services in the transition towards a secure, competitive and decarbonized energy system.

Stationary applications – A diluted value chain

Figure 20 shows that the value chain contains a number of beneficiaries in each of the segments corresponding with the specific advantage that energy storage presents.

Figure 20: Buyers and beneficiaries

But storage is still a new and rather expensive solution in this diluted value chain and has still to prove its sustainability versus usual non-storage solutions which
are the installment of e.g. new gas peaker plants or Transmission & Distribution Upgrade (Figure 21)

Multiple applications

Storage solutions vary by power capability and discharge times as shown in Figure 22.

Fast reacting systems are typically electro-chemical capacitors and fly wheels; large rated power systems with longer discharge times are typically pumped hydro (PSH) or compressed air (CAES). Li ion batteries (and other battery systems) bridge between both. Li ion batteries offer solutions from residential applications (few kW) to grid integration (few MW). They will definitely gain their position in the application range as schematically indicated in Figure 23.

However completely in line with the cost reduction requirements as discussed in chapter 4 for automotive applications, even more strict cost reduction targets have to be met for stationary energy storage. Cost is expressed here as € ($) / kWh / cycle and cost targets are set at < 0.1 € / kWh / cycle.

From LIB characteristics to active materials

In order to succeed with the potential applications appropriate cathode materials need to be used which in a first marketing phase can be found in the range of automotive materials but later in a second step specific energy storage materials have to be developed whose characteristics either will be power oriented or energy oriented depending on the application. Some typical material trends are introduced in Figure 24 (Source Umicore).
Li-Ion position in ESS

Today the position of Li-Ion is still modest (20 to 50 MW installed worldwide) and the by far major part of energy storage capacity is still provided by pumped hydro commodity storage as shown in Figure 25.

![Figure 25: Installed storage capacity for electrical energy](image)

But Li-Ion is nicely growing and the expectations are that Li-Ion energy storage (ESS) will represent an additional market of roughly 10% by 2020 next to the traditional market of portable electronics and emerging automotive market. This is expressed by the forecasted cathode volumes as shown in Figure 26 (Source Umicore).

![Figure 26: Forecasted cathode volumes](image)

Smart grids

Smart grids are supposed to integrate as much as possible storage capabilities in the future. In the current power grid energy generation responds on demand to user needs while in the future smart grid usage will vary on demand with production availability from renewables such as wind and solar and end users will be actively shed by the utility during peaks or the cost/kW will dynamically vary between peak and non-peak to encourage turning off non-essential high power loads.

The storage capabilities in electrified vehicles will be potentially made available to the smart grid integration in a vehicle to grid design (V2G) as outlined in Figure 28.

Distributed storage technologies will play a key role in the transition process of distribution sections of the electricity system towards more efficient and sustainable energy usage. This will include the development within the transportation sector to a growing deployment of electric mobility (HEV, PHEV, EV), their Vehicle to Grid capability, the emergence of intelligent buildings and to the smart grid in general.

Energy storage optimizes local electricity including generation and (self) consumption, and their integration with other forms of energy use like heating and cooling.

Where can we find ESS

Where will we find the energy storage solutions (ESS)? In fact everywhere as well in bulk situations, in distributed storage and in residential home appliances (see Figure 27).
Vehicle to Grid – Example (2)

With a good mix the energy demand could be covered out of renewable energy sources.

With the energy storage systems of the vehicles the grid could be actively stabilized.

- Family house (4 Persons)
  Energy consumption/year: 4,500 kWh/a
- Battery of electric vehicles: 10 – 60 kWh/a

An electric vehicle could supply a family house for one day up to a week.

Figure 28: Vehicle-to-Grid (V2G)

ESS road mapping work in Europe

Regulatory work in Europe regarding energy storage has been quite intensive over the past recent years with following major steps:

1. December 2008, EU “20-20-20” targets, composed of two binding targets and a non-binding one on energy efficiency:
   - a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels by 2020;
   - increasing the share of renewable energy to 20% in EU’s energy consumption by 2020;
   - improving the EU’s energy efficiency by 20% by 2020 compared to business as usual.

2. EC Energy Roadmap 2050

3. SET Plan: Roadmap Energy with a specific chapter on storage

9. Closing the loop battery recycling at Umicore

Recycling of Li-ion and NiMH batteries.

In accordance with the basic Umicore philosophy, the company decided to develop a dedicated process for recycling rechargeable batteries.

Motivation

For modern rechargeable batteries (NiMH, Li-ion), no dedicated recycling process was in place. In existing processes, the recovery yields are very poor and a large part of valuable Co or Ni is lost. The EU target of > 50% recycling efficiency is not easy to reach with other processes. The Umicore process is not only suited for batteries: certain types of spent catalysts or ultra capacitors can also be recycled using this technology.

There are several good reasons to recycle Ni and Co from batteries:

- Supply chain: primary metal resources (ores) in Europe are scarce. On the other hand, a lot of metals are available in all kind of appliances. Mobile phones, laptops, videogames, cameras … they all contain small volumes of valuable and rare precious and special metals. Umicore considers this as an “above ground mine”, that has the potential to cater for a bigger proportion of the world’s metals needs. At the same time, this new source reduces Europe’s dependence on primary metal sources and avoids the depletion of natural resources. This is particularly compelling given the infinitely recyclable quantities of metals.

- The environmental footprint of metals recycling is much lower than for primary production. The CO2-release for recycled Co or Ni is only 1/3 that of virgin Co and Ni. For precious metals, the ratio is even lower.

- The legal framework (EU Battery directive) obliges OEMs to set up collection schemes and to promote recycling. They also have stringent targets (by 2016, 45% of batteries put on the market have to be collected and the recycling efficiency should be > 50%). The existing processes and installed capacity are not sufficient to reach these targets.

- Batteries in ‘old’ mobile phones or laptops can sometimes be reused (in as far as they’re not designed especially for one type of device). Although reuse is sometimes better than recycling, it is an established fact that many of the reused batteries end up in developing countries where no collecting schemes exist and the recycling initiatives are very basic: open air incineration producing hazardous gasses, low recycling efficiency leading to the diffusion of heavy metals in the environment, dangerous operations… Professional, high tech recycling is much more environmentally friendly!

Process description

The Umicore process (Fig. 29 and 30) is specifically designed to reach a high recycling efficiency for Co and Ni. It is a patented process. The process can also be used for recycling other Co/Ni containing materials, such as spent catalysts.

The smelter has three outlets:

- Metal fraction: containing all Ni and Co. These metals are further refined in the existing refinery plant of Umicore in Olen (Belgium), and transformed into Ni (OH)2 and LiCoO2. These products are materials for batteries. That way, a really closed loop “from battery to battery” is developed. The metal fraction also contains Cu and Fe, which are also valorized.

- The smelting process also produces a slag fraction. The slag is completely inert and non-hazardous and can be used as an additive for concrete. Now other applications are under development, in order to valorize lithium (Li) in the slag. A possible application is vitro-ceramic glass where Li has the property of avoiding damage due to thermal shock (e.g. in cooking plates).
- Gas emissions: the gases released during the process go through a post combustion chamber. This technology creates a very high temperature, which completely decomposes all possible dangerous gases (volatile organic carbons, dioxins), which could be generated during the pyrochemical process. Traces of dust (coming from the fluxing agents) in the off-gas are collected on filters.

- Umicore: First battery recycling plant in the world at Hoboken Belgium
- Capacity: 7,000 tons of batteries (equivalent to 150,000 cars or 250,000,000 mobile devices)
- Investment: € 25m€
- Operational since mid 2011

Although recycling of Co and Ni still represents a small fraction of the total need of these metals, in future it will reduce our economic dependence on non-European sources and it will have a tempering effect on metal prices.

- Because of the fully closed loop for battery materials, the high financial risk of fluctuating metal prices can be reduced considerably: battery producers invest in a quantity of Co and Ni and after recycling, it is returned in the form of battery powder. They only have to pay for the recycling and transformation cost, not for the metals. As metal exposure is a risk against which manufacturers want to be insured (= cost), reduction of metal exposure is a saving.

- Because the Umicore process doesn’t contain (subcontracted) pre-treatment and no intermediate trading (direct contact between OEM and Umicore), complete destruction of used batteries can be guaranteed. This is an important economic benefit for customers, because the risk of fraudulent re-use of recalled/rejected batteries is significant. Even the illegal use of parts of batteries can be disastrous for the OEM’s image (e.g. the hologram on certain batteries is much sought after in order to produce illegal copy batteries).

- Batteries offered for recycling are often offered together with WEEE. Umicore is the biggest recycler of WEEE. By offering battery recycling, the company offers a one-stop service.
Specific environmental benefits

The general advantages of recycling have been set out above; below, we focus on the benefits of the Umicore process.

- High Recycling Efficiency (RE). According to the actual RE definition of the Battery Directive, the Umicore process has an RE of about 80% (the real figure depends on battery blend), which is much better than the EU target (50%).
- Low waste: the only deposit produced is off-gas dust. This contains some halogens.
- No hazardous pre-treatment: the batteries can be loaded as such in the furnace. Shredding and fraction separation (which could include the release of hazardous compounds) is not necessary. Only very large batteries, for example from hybrid electric vehicles, have to be reduced for mechanical reasons.
- The unique post combustion step guarantees that no hazardous dioxins or other volatile organic compounds are released into the environment.
- The whole process is energy efficient: the process is autogenous, meaning that once the smelting process is initiated, the heat release from the chemical reaction is sufficient to maintain the temperature. Moreover, the energy excess can be recuperated.
10. Second life batteries

Usage in ESS?

An electric vehicle (EV) battery is considered to have reached its end-of-life when it can no longer provide 80% of the energy or 80% of the peak power of a new battery. Stationary battery applications often do not have these severe requirements. Considering these end-of-life EV type Li-Ion batteries in a second life in stationary applications requires the acquisition of used (HEV) EV batteries, testing of these batteries and reconfiguration for this stationary use (e.g. in 25 kWh modules). However the long term opportunities are still to be proved.

- Automotive packs will have to be repacked module/modules.
- Cell/cell repacking could be too expensive (ca 80-100 usd/KWh)

- Utilities might buy EOL car batteries, but only at a very low price
- Utilities are considering these issues from prospective point of view.

For how many cycles?

State of Health of the batteries after the first life has to be well defined in order to make a prognosis for its second life, warranties probably have to be given and ownership of the batteries has to be made fully clear. A business case need to be developed for such a case and the basic question becomes what the total cost of second life batteries will become compared with the decreasing cost evolution of first life batteries.
11. Key messages

1. PHEV/EV is definitely arising and Li Ion is the preferred battery system minimum until 2030. Performances (range...) are expected to double in the next 5 to 10 years, cost will come down to acceptable commercial levels.

2. Reliable and affordable energy storage is a prerequisite for using renewable energy.

3. Energy storage therefore has a pivotal role in the future and Li Ion batteries are well placed in the power ratings from KW to several MW and discharge times from seconds (power/frequency regulation) to hours (energy storage).

4. A state of the art battery recycling process and plant has been established by Umicore meeting the most stringent environmentally requirements.

5. Serious doubts still exist on the economic feasibility of second life batteries.

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About E-Mobility NSR

The Interreg North Sea Region project North Sea Electric Mobility Network (E-Mobility NSR) will help to create favorable conditions to promote the common development of e-mobility in the North Sea Region. Transnational support structures in the shape of a network and virtual routes are envisaged as part of the project, striving towards improving accessibility and the wider use of e-mobility in the North Sea Region countries.

www.e-mobility-nsr.eu

Contact Author(ing team):

Ghent University
Center for Mobility and Spatial Planning
Ir. Giuseppe Pace
Vrijdagmarkt 10/301
9000 Gent
Belgium
Phone: +32-9-3313255
giuseppe.pace@ugent.be

Sustesco
Dr. Marcel Meeus
meeus.mar@gmail.com

Contact Lead Partner:

Hamburg University of Applied Sciences
Research and Transfer Centre “Applications of Life Sciences”
Prof. Walter Leal
Lohbruegger Kirchstrasse 65
21033 Hamburg
Germany
Phone: +49-40-42875-6313
Email: e-mobility@ls.haw-hamburg.de