EUROBAT

Association of European Automotive and Industrial Battery Manufacturers

WHITE PAPER

Battery Energy Storage Solutions for Electro-mobility

An Analysis of Battery Systems and their Applications in Micro, Mild, Full, Plug-in HEVs and EVs

Annex 1

- **Vehicle Architectures: Definitions & Outlook**
- **Battery Technology Sheets and Battery Case Studies**

February 2012

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1. Vehicle Architectures – Definitions and Outlook

Today, a wide range of different vehicle concepts exist to cover automotive needs; from start-stop micro HEV, Mild and Full HEVs to Plug-in HEV and full Electric Vehicles.

1.1. MICRO HYBRID ELECTRIC VEHICLES (MICRO HEVS) – START-STOP SYSTEM

The term micro-hybrid has become popular for a class of vehicles which is using an automatic system for vehicle start-stop. Under braking and rest the IC engine is automatically shut down. Some vehicles are even providing a certain degree of regenerative braking. The recovered energy is stored in the battery, and battery power is then used to re-start the engine again. However, there is no electrically operated power assistance to the mechanical drive train. Under typical urban driving conditions, we can expect an 8% reduction of fuel consumption.

1.2. MILD HYBRID ELECTRIC VEHICLES (MILD HEVS)

Mild Hybrid Vehicles are a technical alternative to the Full HEV. In comparison with the Full HEV, the MHEV vehicle requires a lower degree of electrical power performance. Regenerative charging under deceleration and braking contributes to a reduction of fuel consumption. Pure electrical driving is not provided. The electrical drive system of MHEVs typically operates at voltages between 100 V and 200 V. Typical fuel savings of vehicles using mild hybrid drive systems are in the range of 15% to 20%.

1.3. FULL HYBRID ELECTRIC VEHICLES (HEVS)

Full Hybrid Electric Vehicles (also called Strong Hybrids) use the electrical storage system for relatively short periods in which the combustion engine runs with lower energy efficiency. Regenerative braking with storing of the reclaimed energy in batteries is an important feature. Pure electric driving is possible for short distances but plays only a minor role. It is regarded as an interesting feature for some special situations e.g. silent cruising in remote areas. For energy efficiency reasons the electrical drive system operates at voltage levels above 200V. The efficient combination of both the combustion engine and the electrical drive system enables a reduction of fuel consumption of up to 40% in comparison to normal combustion engine propelled vehicles.

Because of their continuous typical stop-and-go operation, city-buses and delivery trucks are considered as an ideal application for a hybrid drive system. Especially in European and Asian urban areas with relatively short distances between stops, energy recovery under braking and electrical acceleration can significantly improve fuel efficiency. Figures of more than 30% fuel savings have been reported.

1.4. PLUG-IN HYBRID ELECTRIC VEHICLES (PHEVS)

Plug-in HEVs combine the advantages of an electrical vehicle with those of a vehicle using a combustion engine. Concerns about range limitation are solved with the additional use of an internal combustion engine (ICE) which in case of exhausting power from the battery system can take over the supply of the power train. Preferred applications of PHEVs will be delivery vans which can be recharged periodically during their daily driving route. However, private cars, especially those used for daily commuting, will also be an interesting option for PHEV technology. Similar to a Pure EV, a PHEV may use power from the grid. The amount of CO_2 savings will depend upon the power mix with its shares of fossil energy, nuclear energy and energy from renewable sources.

1.5. ELECTRIC VEHICLES (EVS)

Electric vehicles are operated with electrical power only. Most of the electric vehicles in use at present employ battery systems. The design and layout of these electrochemical storage devices have to meet the demands of power performance and energy content. The energy storage capability is a crucial factor for the electric driving range of the vehicle. Most of the battery operated electric vehicles (BEV) provide an electric autonomy of up to 150 km, which can be achieved with a battery system with more than 20 kWh storage capability. Some of these vehicles have an additional fuel-operated generator on board which in case of a depleting of the batteries is capable of providing electric power and recharging the batteries (Range-Extender).

In the long-term, electrical vehicles could operate with fuel cells converting hydrogen into electrical energy. This will be a realistic option if the remaining technical and economic hurdles can be overcome and a hydrogen infrastructure established. But these electric vehicles too will use a power assist battery system for optimizing their energy efficiency. They are commonly categorised as Fuel Cell Electrical Vehicles (FCHEV)

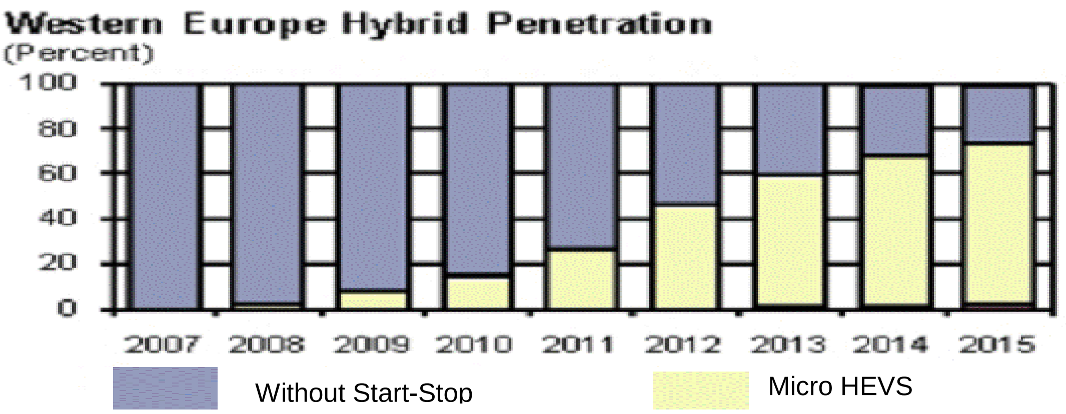
The evolution of the different vehicle architectures and their markets will depend both on incentives and technological evolutions. According to well-informed consulting companies (IHS, Roland Berger) and some major stakeholders (ERTRAC, ACEA), different vehicle architectures will eventually co-exist and the ICE will remain important in coming decades; even up to 2050.

Also, the evolution of the market is now very much driven by political decisions, and not only consumer demand. The battery industry can deliver solutions that meet both political objectives aimed at reducing dependency on fossil fuels and GHG emissions, and consumer expectations.

We are now at a turning point where car manufacturers and the entire supply chain are moving in a new direction to scale up and improve different electric concepts from start-stop micro, mild, full and plug-in HEVs to full EVs, which are all in permanent evolution. Eventually, a range of diverse solutions will be made available to meet the different driving-profiles (urban transport, use of motorways… commuter, fleet operation).

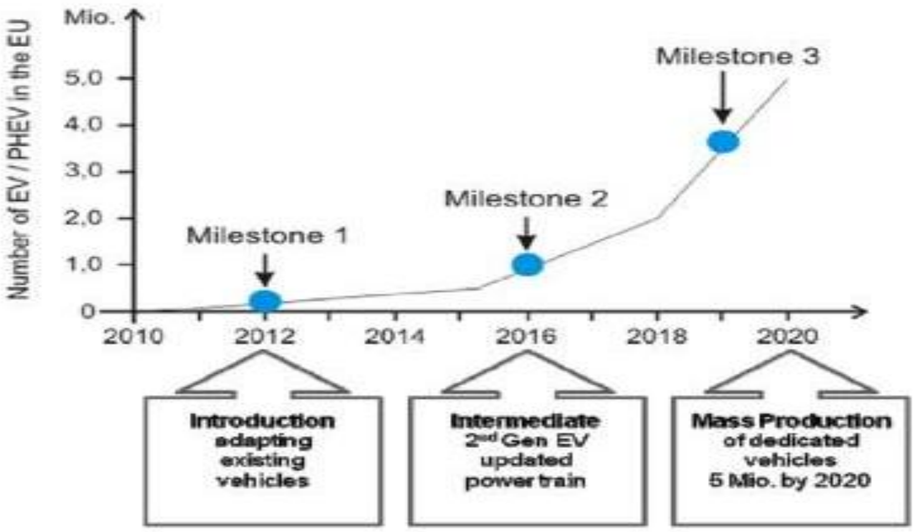
As it has become clear that Europe will take leadership in CO_2 reduction, is should also be the place to launch PHEVs and EVs large scale demonstration projects to test how they work and fit. Start-Stop Micro application is increasing rapidly. The mild, full and plug-in HEVs and EVs/ will initially have a small market share but will increase after a certain period. With regard to standardization and manufacturing, Europe should act in a coordinated way in order to move fast.

Fig. 1: Penetration of Start-Stop systems in Western Europe, up to 2015
Car Park: passengers and LCV
Source: IHS Global Insight – January 2011



The European Road Transport Research Advisory Council (ERTRAC) identified three milestones in the electrification roadmap, which will lead to mass production of dedicated vehicles:

Fig 2: ERTRAC Electro-mobility milestones
Source: ERTRAC Electrification Roadmap 2010



Milestone 1:

Introduction (2012): Implementation of electrified mobility, demonstration and field operational tests; first fleets developed for niche applications, e.g. taxis, car sharing systems, delivery services and other captive fleets available for public acceptance and field testing

Milestone 2:

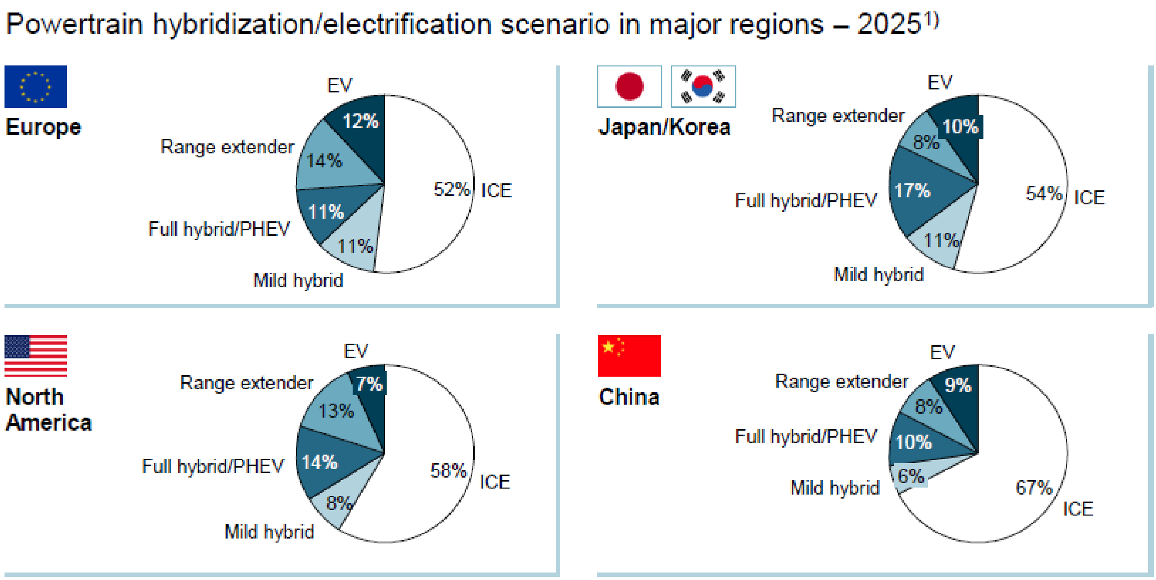
Intermediate (2016): More efficient electric vehicles available for all consumers, increased performance of energy storage systems, and enlarged charging infrastructure available

Milestone 3:

Mass Production (2018-20): One can credibly expect to see 5 million grid-enabled vehicles (PHEV & EVs) on European Roads by 2020; batteries with improved life-time and improved energy density; infrastructure for grid integration including contactless induction and quick charging at high efficiencies

As for the longer run and after 2025, different vehicle architectures will continue to co-exist with the ICE being more electrified but still pre-dominant in the next decades.

Fig 3: Powertrain Electrification - Automotive landscape 2025:
Penetration of EVs and hybrids could exceed 40% in triad markets by 2025
Source: Roland Berger report March 2011 - Opportunities and challenges ahead



1) Assumption: ICE includes micro hybrid functionality

2. Electro-mobility Battery Technology Sheets

2.1. Lead Technology

The electrodes of lead acid batteries used in cars (SLI, start-stop and BEVs), consist mainly of flat plates which contain lead dioxide (PbO_2) as the positive electrode and spongy lead for the negative electrode as active materials. The electrolyte is diluted aqueous sulfuric acid which contributes in the charge discharge reaction according to:

$$PbO_2 + Pb + 2H_2SO_4 \longleftrightarrow 2PbSO_4 + 2H_2O$$

The carrier and conductor of the active material is a grid consisting of lead which is alloyed with elements like Antimony or Calcium to improve the hardness. Both polarities are separated by polymer separators which work as electrical isolators but have a high porosity and can be wetted completely with the sulfuric acid.

The conventional SLI lead battery has steadily improved, but the results from consecutive improvements over the last 30 years were off-set because of the increased electricity demand in cars.

2.1.1. Enhanced or Improved Flooded Batteries (EFB, IFB)

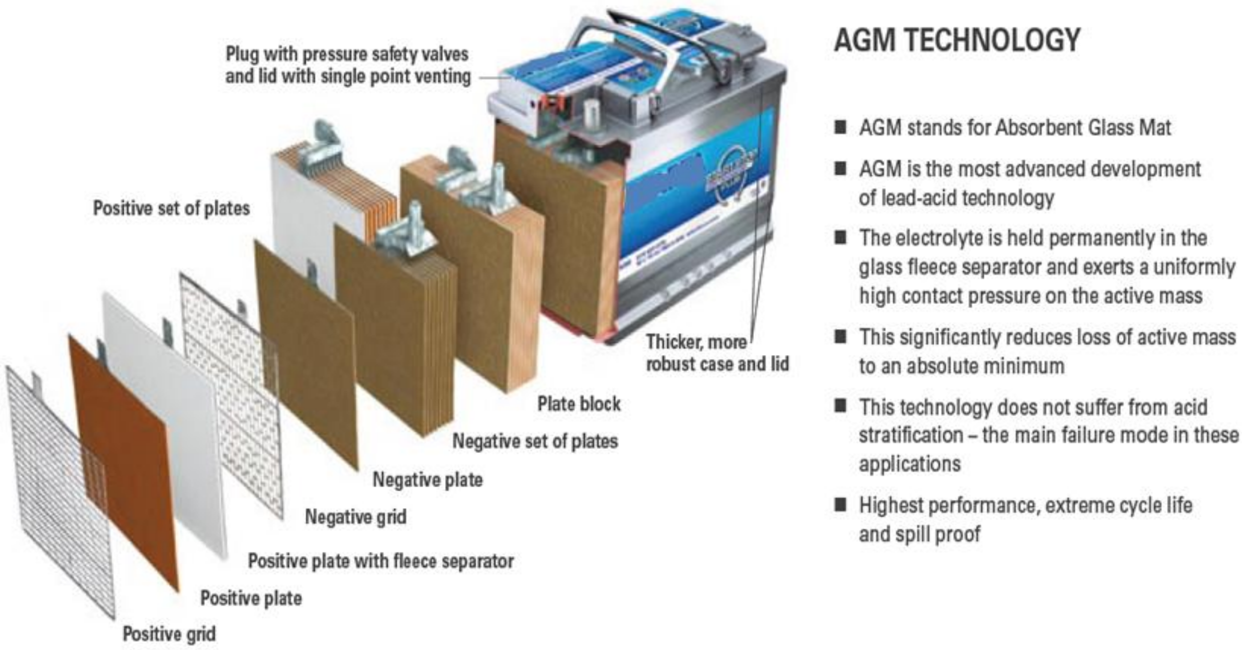
For some years, grids for lead acid batteries have been produced with alloys that contain Calcium as a hardening element; sometimes combined with tin, aluminium and silver. Batteries using these alloys are categorised as “maintenance free“, and in many cases can be permanently sealed. In recent start-stop applications the energy throughput of batteries used in cars with this specific application had to be improved by a factor of 4. This was possible by additional improvements to lead acid batteries, which are known as enhanced flooded batteries (EFB) or improved flooded batteries (IFB).

2.1.2 Valve Regulated Lead Acid Batteries (VRLA)

The latest technology is a new generation of lead acid batteries, known as VRLA (Valve Regulated Lead Acid). They are divided into two categories: AGM (Absorbent Glass Mats) batteries and Gel batteries. In both technologies the sulphuric acid electrolyte is not free in liquid form. In AGM accumulators it is totally absorbed in glass mats, while in gel batteries the sulphuric acid is jellified by use of silica. The batteries are hermetically closed and vented by each cell with a valve.

During charge, the oxygen can build up internal pressure and diffuse without hindrance to the negative electrode. Before hydrogen is created as a gas on the negative electrode the oxygen is reduced on the negative electrode to form water; meaning all the gasses flow internally and do not escape. This internal gas recombination cycle facilitates the chargeability of the battery. In case of mechanical damage of the battery, the acid remains in an absorbed state and is not released into the ambient.

Fig 4: AGM Technology – Battery lay-out
Source: Johnson Controls International



Key Features

- Low-cost solution; low cost/kWh to install as well as low cost/kWh electricity throughput;
- Cell nominal voltage: 2.0 V;
- Charge-discharge efficiency: 75% - 85 %;
- Lifetime: 1800 cycles @ 80% DOD, or 20+ years in stationary (float) applications.
- Operating temperature range between -30°C and +50 °C;
- Significant lead ore reserves and resources, combined with a high level of material recycling (virtually 100% of lead is recycled from collected batteries) with 50% of annual lead consumption from recycled material;
- Mass produced, and many readily available commercial product lines;
- Industry has extensive experience in many applications including small, medium and large Battery Energy Storage Systems(BESS) for Renewable Energy Systems (RES), but also typically for SLI, start-stop or mild hybrid automotive applications

Deployment Status

The SLI lead acid chemistry, having been commercialized more than 100 years ago, has different designs currently in use for various applications, including: the aforementioned flooded and VRLA designs; positive electrodes with tubular or flat grid plate design; negative electrodes with lead or copper grid; and spiral (round) or prismatic cells and mono-blocs. The large variety of applications includes long calendar life with continuous overcharge (up to 20 years), high-rate cycling in motive power (e.g. forklifts) and high power at low temperatures in automotive applications (SLI).

AGM technology with increased performance (cyclic loads, CCA) will further develop applications such as auto-stop with regenerative charging. The inclusion of battery management with sensors and software will also positively improve lifetime.

The board-net and electronic component supply for all vehicles -micro, mild, full, plug-in HEV and EVs- are still made for 12V. The on-board energy demand in cars will further increase because of car makers - wanting to avoid C02 emissions- adding additional functions to electrify; such as the power train, water-pumps, a/c compressors, power steering and maybe other components.

2.2. NICKEL TECHNOLOGY

There are two Nickel based rechargeable battery systems: the Nickel-Cadmium system (NiCd) and the Nickel-Metal Hydride system (NiMH). Both are based on a strong alkaline electrolyte. NCd has been an important battery system over the last hundred years. It was improved continuously over this period and became the technology for a variety of products ranging from small portable batteries to large industrial battery systems. Technical achievements with metal hydride materials enabled the replacement of Cadmium at the anode polarity. The resultantly generated NiMH system replaced NiCd batteries in many applications as portable batteries, and won a big new market with the rise of Hybrid Electric Vehicles.

2.2.1. NiCd

Nickel-Cadmium (NiCd) accumulator systems apply different electrode technologies: pocket plate, sintered plate, foam type, fibre structure plate technology, and plastic-bonded plate. The electrodes are filled or coated with the active material, the positive electrode with nickel hydroxide as basic component, and the negative electrode with cadmium hydroxide. The following equation describes the basic reaction during charge / discharge of a NiCd accumulator:

$$2\ Ni(OH)_2 + Cd(OH)_2 \underset{Dch}{\overset{Ch}{\leftrightarrow}} 2NiOOH + Cd + 2H_20$$

NiCd cells have a very good power performance even at low temperatures and a high electrochemical stability at elevated temperatures, resulting in a long lifetime and a high reliability at both extremes. The nominal voltage of Ni-Cd cells is 1.2 Volts. The cells normally have a prismatic casing or container design made of high impact resistance poly-propylene (PP) material. Other plastic materials with flame retardant additives and stainless steel are also in use for cell cases.

Fig 5: Ni-Cd cell construction - Saft

Key Features

- Extremely high electrochemical robustness
- High mechanical robustness
- Excellent power performance
- Usable at extremely low and high temperatures ranging from -50°C up to +60°C
- High number of operating cycles (from 2000 up to 3000 full cycles @ 80% DOD, depending on cell design)
- Chargeable with high currents
- Different electrode designs available for high power to high capacity performance
- No damages caused by overcharging, deep discharge and partial state-of-charge operation

Deployment Status

The Ni-Cd technology battery is an advanced, easy to charge, and robust battery technology; suitable for all industrial applications under extreme environmental conditions. Ni-Cd based batteries provide moderate acquisition costs and also low life cycle costs for the operator.

Superior service life of Ni-Cd batteries is one of their important features. The cells can be stored without capacity loss over a very long time. Based on present experiences with Ni-Cd technology, a service life of more than 20 years can be achieved in standby power systems even under difficult environmental and operational conditions. Ni-Cd batteries are recycled in established recycling facilities with a close-to-100% recovery of Cadmium. The reclaimed Cadmium can be re-used for battery manufacturing purposes (closed-loop recycling).

Outlook

Further research and development of the Ni-Cd technology will improve the energy density, the weight, and the dimensions of this battery technology. Also, the consequent reduction of manufacturing costs and life cycle costs are targets for Ni-Cd battery manufacturers.

2.2.2 NiMH

Nickel-Metal hydride (NiMH) is a commercially important rechargeable battery technology for both consumer and industrial applications due to design flexibility, excellent energy density, high power performance, and environmental compatibility. Its main difference to the NiCd system is the use of hydrogen-absorbing at the negative electrode.

The basic charge / discharge reaction is as follows:

$$\mathbf{Ni(OH)2 + M \underset{Discharge}{\overset{Charge}{\leftrightarrow}} Ni\,OOH + MH}$$

Fig 6: NiMH cell construction - Saft

Under charging, the hydrogen storing alloy (M) in the negative electrode absorbs hydrogen from the electrolyte; thus forming a metal hydride (MH). The most common hydrogen absorbing materials are based on AB5 type alloys, where A is a rare earth mixture and B represents a metal composition consisting of nickel (main constituent), cobalt, manganese, and aluminum. Like NiCd cells, NiMH cells use a strong alkaline electrolyte, usually with potassium hydroxide as the main constituent.

Key Features

- Highly compact design (300 Wh/l, 70 Wh/kg)
- High power performance (up to 1500 W/kg)
- Extremely high capacity turnover under low depth of discharge (DoD)
- Lower weight and less volume than NiCd
- Environmentally compatible components
- Reliable and safe operation, sealed cells
- Temperature limits of operation (-20°C (pulses) ... +40°C)
- Completely recyclable

Deployment Status

NiMH batteries are highly advanced and mature products. Although there is a displacement in many applications by Li-Ion batteries, NiMH batteries still play a significant role in the consumer business. However, the main application of the NiMH system is batteries for hybrid electric vehicles (HEVs).

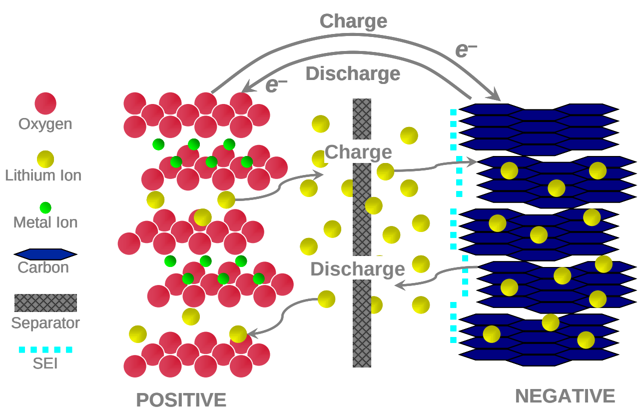
Outlook

NiMH batteries will not be used for future battery electric vehicles. The weight advantage of Li-Ion batteries is too pronounced. However, there are several industrial applications where NiMH batteries will be used as a replacement for NiCd and Lead-Acid batteries. Chances for further technical improvements are limited, as the technology has already achieved a high maturity level.

2.3. LITHIUM TECHNOLOGY

The cathode in these batteries is a lithiated metal oxide ($LiMn_2O_4$, $LiFePO_4$, $LiCoO_2$, etc.) and the anode is made of a carbon material. The electrolyte is made up of lithium salts (such as $LiPF_6$) dissolved in organic carbonates. Depending on the choice of the cathode material, the nominal voltage of an individual Li-ion cell varies between 3.2 V and 3.8 V.

Fig 7: Reaction mechanism of Li-ion cells (Saft)



When the battery is being charged, the Lithium atoms in the cathode become ions and migrate through the electrolyte toward the carbon anode; where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge.

Key features

The main advantages of Li-ion batteries, compared to other advanced batteries, are:

- High energy density (150-250 Wh/l, 100 Wh/kg at the battery level)
- High efficiency (near 100%)
- Long cycle life (1000 cycles @ 85% depth of discharge) combined with a long calendar life 5-8 year
- Maintenance-free
- Versatility: electrodes can be optimized for different power / energy patterns
- Sophisticated BMS allows SOC & SOH indication (state of charge, state of health)

Deployment Status

Commercialized since the beginning of the 90's, Li-ion batteries took over 50% of the small portable market in a few years. Despite the early adoption of Li-ion batteries in theautomotive industry (in 1995 Nissan released the world’s first electrically propelled car with Li-ion batteries), many challenges still remain today and manufacturers are working to engineer new materials capable of bringing better battery performance and to reduce cost. Furthermore, Li-ion battery prices are expected to drop with the take-off of automotive and energy storage markets.

Fig 8: Examples of an automotive paunch type Li-ion cell, battery module and a battery pack. (source: NISSAN).

Li-ion batteries have practically become a default technology in the automotive applications for full battery electric vehicles. Today, all leading car OEMs either offer or have a full battery electric vehicle in their development pipe-line. Today’s battery electric vehicles allow > 160 km driving autonomy and quick recharging capabilities. Recycling processes and installations are in place, achieving a recycling efficiency of well above 50%.

Outlook

Batteries capable of delivering greater vehicle autonomy, increased safety, and shorter charging times are expected in the coming years. The industrial capacity for mass production of the Li-ion cells and batteries is poised to reduce the overall battery system cost in the future. Current engineering efforts target the improvement of cell materials for the further increase of power and energy density, cycle, and calendar life; as well as looking towards cheaper and more abundantly available substitutes of some cell materials.

The negative electrode material may see the evolution by shifting from carbon-based materials (incl. graphite) to new materials. New directions in engineering for the positive electrode materials include materials such as $LiNiO_2$, $LiMn_2O_4$, $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$. On the other hand, apart from the latter active components, innovative and unique materials based on new ideas are expected.

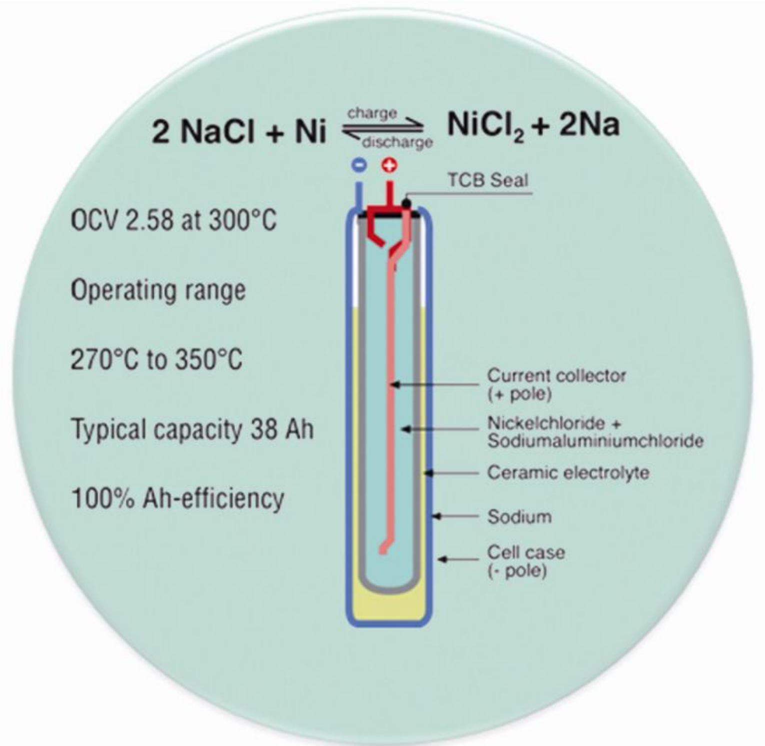
2.4. SODIUM TECHNOLOGY

The core of a sodium based battery is the cell, which has an OCV of 2.58V and operates at temperatures between 270 °C and 350°C. Each cell has a stable steel case and a metal-ceramic seal closes the cell hermetically providing a long life and maintenance free operation.

The electrodes are separated by a ceramic wall that is conductive to sodium ions but an isolator for electrons. The sodium ions generated in the cathode during the charge process move through the ceramic and fill up the anodic compartment. In discharge mode, the ions move in the opposite direction; therefore the reaction can occur only in the presence of a flow of electrons, ie a current external to the cell, equal to the sodium-ion current inside the cell.

The cathode is based on Nickel and common salt NaCl. The liquid electrolyte is tetrachloralluminate of sodium ($NaAlCL_4$). During charge, salt (NaCl) and nickel (Ni) are converted into nickel-chloride ($NiCl_2$) and sodium (Na), and the reaction is reversed in discharge. There are no chemical side reactions.

Fig 9: Reaction mechanism of the Sodium technology



Key Features

- High specific energy (120 Wh/kg)
- Three times lighter and 30% smaller than conventional batteries
- Immunity to ambient temperature conditions constant performance and cycle life in harsh operating environments (-40°to +60°C)
- Long calendar and cycle life
- Maintenance free
- Proprietary battery management system
- Low environmental impact
- Fully recyclable materials
- Free from toxic materials
- Raw materials readily available
- Minimal commodity risk

Deployment Status

Commercialized since the middle of the 90's, Sodium Nickel Chloride batteries have applications for EV cars and vans, and EV or plug-in HEV buses and trucks. Today the use of such technology has been broadened to include telecom and back-up markets and on/off grid energy storage systems. We are currently working to increase the production capacity and to reduce the cost of the batteries. The present target is to triple production by 2013.

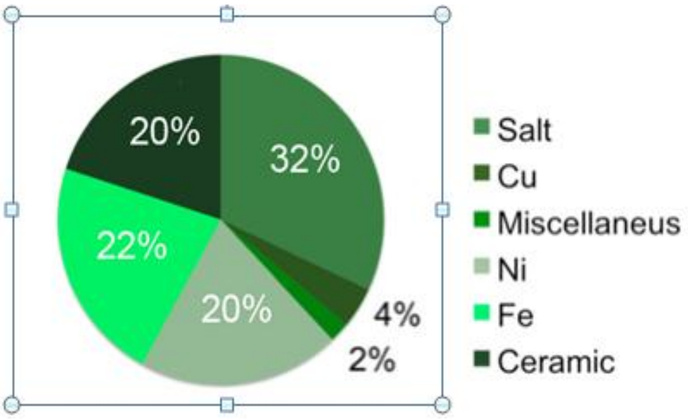
Fig 10: Examples of Sodium battery and modules (Source: Fiamm-Sonick)

Environment

Based on common raw materials - nickel, iron, common salt and ceramic - sodium based technology is not affected by possible shortage of raw materials. Sodium based batteries are easily recyclable as they are free from materials that require difficult treatment.

The battery material is used for stainless steel production, the nickel and iron content become part of the product and the salt and ceramic form the slag in a process consistent way, so the batteries are 100% recycled after use.

Fig 11: Battery composition - Share of raw materials used (Source: Fiamm-Sonick)



2.5. FUTURE BATTERY SYSTEMS AND THEIR PROSPECTS

Besides the battery technologies presented in chapter 7, there are a couple of other electrochemical systems which currently receive a lot of attention because of their potential to enable significantly higher energy storage densities than Li-Ion batteries. With a Lithium-Sulphur system, specific energy data of up to 500 Wh/kg may be possible. This electrochemical system is still in a state of infancy. The main challenge facing introduction is its endurance in terms of capacity turnover and calendar life.

A high potential for drastically improving the energy data is seen with systems based on air cathodes. Up to now these systems have suffered from tremendous problems with recharging and bad efficiency. With alkaline Zn/air cells, specific energy data of up to 300 Wh/kg has already been demonstrated in the past. However, the biggest potential for a future high energy battery is seen with the employment a Li-Air based system. Specific energy with Li-Air may even exceed the threshold of 1000 Wh/kg.

The progress with all future battery systems will strongly depend on the progress with active storage materials; but future achievements with materials and components needed for passive components (electrolyte, separator, housing etc.) are also regarded as key for coming to technical solutions which may become an acceptable replacement of the fossil based energy storage and conversion technology in vehicles, which have dominated for more than a hundred years.



CASE STUDY 1: PILOT PROJECT: PERFORMANCE OF ELECTRIC VEHICLES ON SMALL ISLAND AND IN SMALL CITIES (SOURCE: ABERTAX)

A project in the archipelago Malta, Gozo and Comino; three small islands located in the central Mediterranean and so called "Malta". The test areas are made up of low hills, steep-sided valleys and small areas of plain.

The ongoing pilot project has been running since 2002 on the archipelago of Malta, Gozo and Comino; three small islands located in the central Mediterranean. The total length of a line trending NW to SE covering the three islands is 50 km.

Figure 1: Reva cars used for daily use and as a field test facility of battery accessories in industry

The EV fleet consists of 20 Reva cars. As the daily distances traveled are limited to a few tens of km, the islands are an ideal place for EV use as a means of reducing emissions and energy use in transport. The cars are used by a variety of owners but it became clear during the test that domestic use for commuting to work and back became dominant.

No serious accidents were reported and the max car speed of 65km/hr was adequate on the Maltese roads where speed is generally limited to 60 km/hr with some exceptions going up to 70km/hr. Acceleration at traffic lights and roundabouts which is essential is very good and better than that of a similar size of car. Speed drops to about 40 km/hr on most hills and this was found to be somewhat limiting.

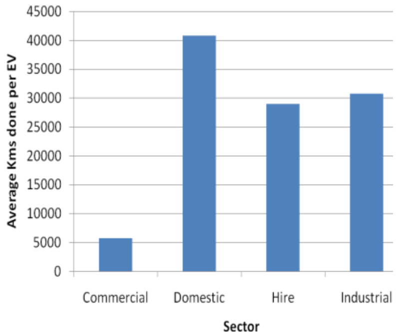


Figure 2: Sector versus average km/car

The technology of the cars is basic, still using the DC drive technology. The cars are equipped with a 48V 200Ah tubular plate flooded lead acid battery pack and a separately excited DC motor controlled by a four quadrant DC controller. The heart of the system is an energy management system, which controls the drive and charger while sending the necessary critical information to the driver's display. Some cars today have better performance due to the use of AC drive technology because;

1. cheaper and more robust
2. no maintenance
3. higher efficiency
4. higher peak power to size ratio

The range of the car varied from 55km to 65 km depending on the journey and way of driving. The economy switch which limits the current to 200A was very useful especially to ensure a good range when the batteries start to age. The batteries lasted up to 8 years and covered up to 40,000km (approx. 800cycles @ average of 50km per charge which consumes 9kWhr of electricity i.e. 180Whr/km) for careful drivers who made regular use of the switch. However there were also some surprises especially with lower quality batteries. The cost of the disturbance, disappointment of customers and guarantee claims is surely much more than the cost difference between the lowest and highest quality batteries together with a sophisticated management unit. In our pilot project an online BMU with internet data access was added to each car and this improved the battery performance enormously as we could detect what was the cause of any trouble. Most of the battery problems occurred during winter time and hardly anything during summer. One has to point out here that in this region the lowest winter temperatures is around 8deg while the highest is around 40deg. For most of the year, the temperature is between 20 and 30deg.

This pilot project has shown that EVs are economically viable and even the lead acid technology can be ideal for daily transport on small islands or cities worldwide. In order to improve the reliability and reduce maintenance, AC drives and the use of the highest quality batteries with a proper management unit are essential. Obviously the setting up of the right infrastructure including high technical servicing facilities is vital for the success of EVs.

The EV trend line in figure 3 ranges from 310Wh/km down to 160Wh/km. These can be compared to 450Wh/km for a petrol engine vehicle with a consumption of 5litres/100km. From the point of view of emissions, the absence of tailpipe emissions from vehicles moving on the narrow streets of maltese towns and villages offers a great advantage. Transferred emissions from the EV go from 300g CO_2/km to 155g CO_2/km, taking a Malta value of 970g CO_2/kWh delivered to the grid. The upper value is higher than the CO_2 emissions from current models of small cars but it does represent a situation where one covers less than 5km/day in the EV. A more realistic daily distance of 15km/day gives a CO_2 emission of 218g CO_2/km, which is similar to current ICE models but higher than the average (120gCO_2/km) Euro5 standard. These emission advantages are further enhanced in cases where a significant fraction of the car fleet carries no catalytic converters or short distances make catalytic converters inefficient.

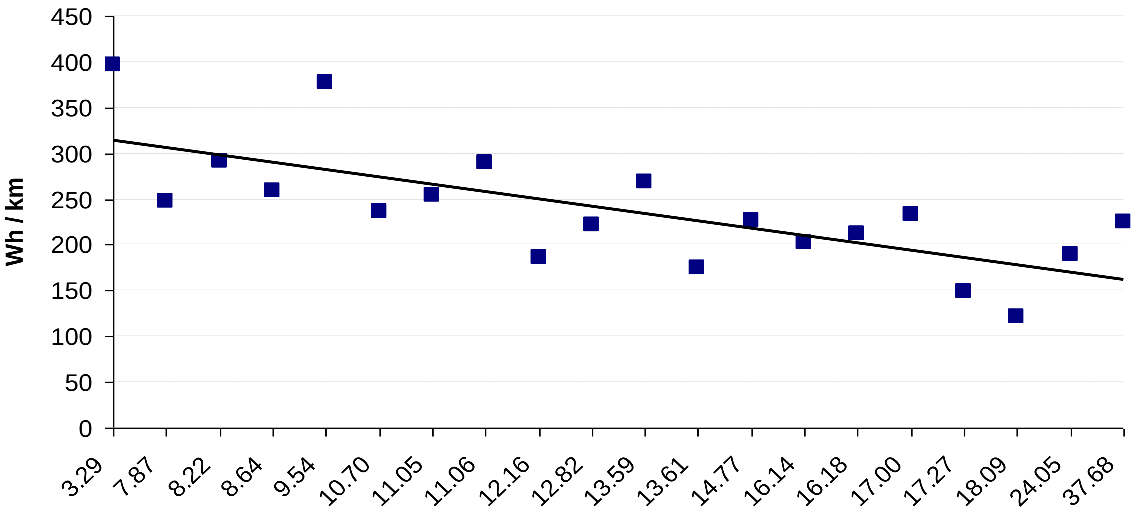


Figure 3: kWhr/km versus average km/day

The fuel cost of running an EV has been worked out using the standard residential unit cost of €0.17 per unit. The average distance covered by the fleet was 15km/day; that would cost €0.24/day or €1.68/week. The fuel to run a small ICE would cost would cost €1.05/day or €7.30/week at current fuel prices (€1.39/ltr). These are realistic values which consider normal daily usage as well as self-discharge of batteries.

The project proved that with the right team of professionals, this can be implemented and maintained over a good period of time. Without any doubt high quality and robust design of every part of the drive system has to be ensured in order for the electric car to compete with the quality and reliability of modern ICE cars. Customer feedback also has shown that they expect the design and comfort of electric cars should be of the same quality and standard of the equivalent ICE engines.

Government support is crucial at the initial stage; in fact the three main incentives that were introduced by the Maltese Government have contributed to the success of this pilot project.

CASE STUDY 2: **BATTERIES CONTRIBUTE FOR A SUSTAINABLE PUBLIC MOBILITY**
(Source: Fiamm-Sonick)

Fleets of electric and hybrid buses equipped with Sodium based batteries operate in several cities across Europe. Among them some examples are Bologna and Rome (Italy), Lyon (France), Barcellona and Madrid (Spain). Bus manufacturers include IVECO, Tecnobus, BredaMenarini, Carroccera Castrosua with vehicles operated by the local public transportation companies.

Tecnobus Gulliver in Rome

BredaMenariniBus 240 EI in Bologna, Italy

Carrocera Costrosua in Spain

IVECO Irisbus Europolis in Lyon, France

Typically mission profiles of these buses include shuttle service from parking access points to city centers, public transportation in sensitive and restricted areas such as historic sites.

Main drivers towards the use of electric and hybrid vehicles are:

- reduction of environmental pollution and noise emissions;
- lower energy consumption with improved efficiency;
- high reliability and availability with reduced downtimes for vehicle maintenance.

Pure electric buses featuring zero emission transportation have a high reliability and flexibility in driving; however their range is limited by the energy storage system.

Hybrid buses present a number of advantages: lower emissions (CO_2, NO_x), significant fuel savings, and limited noise signature. A plug in hybrid bus designed to be used both as a pure electric vehicle for downtown when the charge is depleted and as a hybrid vehicle for suburban driving can take the advantage to use cleaner energy sources.

A plug in hybrid bus is designed to be used both as a pure electric vehicle for downtown when the



charge is depleted and as a hybrid vehicle for suburban driving, with the main contribution from the on-board generator.

Traction batteries are usually optimized for high capacity in the case of pure electric vehicles or for high power in the case of hybrid vehicles. The dual requirement for the battery - energy storage for an extended pure electric range and power for an efficient management of the vehicle during acceleration and regenerative braking - will require a careful design of the energy storage. These results could be achieved by a correct matching between the design of the system and the required daily mission.

As an example, the results in Bologna city are a fuel consumption reduction of about 20% for the Alè Hybrid against the conventional ICE bus. The present reduction could be potentially improved with the increment of the km driven in pure electric mode that presently is 20% of the complete route. In a similar way, the fuel consumption reduction obtained on BredaMenariniBus HEV buses is about 30%. The operation of the pure electric and hybrid ATC fleet results in more than 250.000 kg of CO_2 not released every year and Bologna was rewarded in 2009 from Euro-mobility as the most eco-mobile city of Italy

CAM Alè Hybrid in Bologna, Italy

Iveco Downtown EV in Bologna, Italy

A real commitment and a deep cooperation among all the actors, battery manufactures, bus manufactures, and local public transportation companies is a key point for successful results on the advanced public mobility.

Designline in UAE

Tecnobus in Montreal

Around the World

CASE STUDY 3: BATTERY FUEL CELL VEHICLES USED AT THE 2008 BEIJING OLYMPIC GAMES PARKS AND STADIA (SOURCE: FAAM)

The Beijing 2008 Olympic Committee decided to purchase 35 full electric vehicles in order to reduce the pollution level in the Olympic Village and at other Olympic sites in Beijing/China. One of the vehicles is equipped with PEM Fuel Cells in combination with suitable battery propulsion.

Characteristics and Specifications

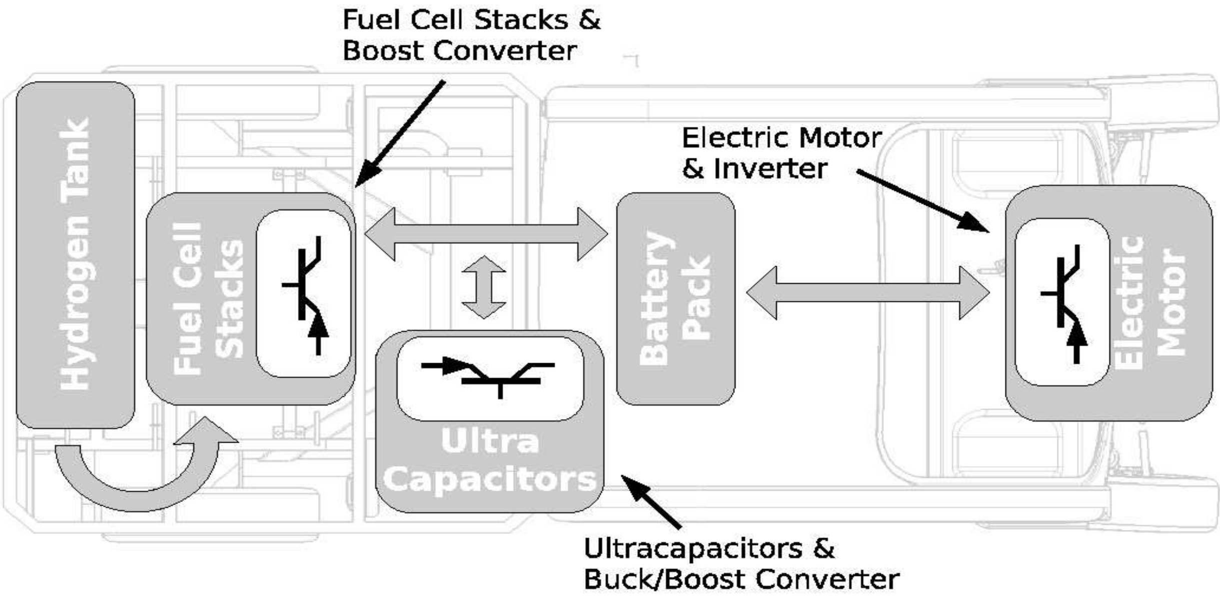
Vehicle: FAAM Smile
Net Weight: 750 kg
Maximum payload: 350 kg
Maximum weight: 1100 kg
Maximum Speed: 50 km/h

Motor
Nominal Power: 5 kW
Peak Power: 12 kW

H_2 parts
Hydrogen Tanks: 80 Liter
Fuel Cell Stack: 12 kW

Lithium-ion Battery Pack
Battery Pack: 6x12 V 105 Ah
Battery Energy: 9 kWh

Ultracap
UltraCapacitors: 165 F
Voltage range: 24.3V - 48.6V



The vehicle is equipped with an air quality monitoring device to control the CO_2 and pollution levels in the air during the Olympic Games. The vehicle is still running in the city of Beijing and it is part of the R&D projects of the Chinese universities and research centers.

CASE STUDY 4: HELIOS – HIGH ENERGY LITHIUM-ION STORAGE SOLUTIONS (SOURCE: JCI & SAFT)

Motivation and Objectives

A large consortium including six car manufacturers, laboratories and test institutes, one recycler and two battery manufacturers will combine their efforts to understand the causes behind the battery cells aging and safety behavior. The study is performed on large High Energy cells for EVs, PHEVs and Hybrid Heavy Duty trucks.

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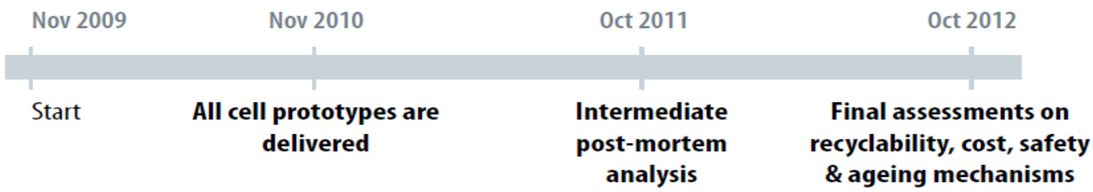
The objectives of the project are to:

• Evaluate the performances on representative large cell formats, using 4 different positive electrodes
• Propose updated safety and life test procedures for high energy battery cells used in EU context
• Have the cells samples analyzed before and after ageing tests to identify aging and safety issues
• Estimate the recyclability & perform the cost evaluation on the whole battery pack

Project Plan, Milestones and Deliverables



Technical Approach

- Select, develop and test 4 different electrochemical technologies:
- LiFP4/C – NMC/C – NCA/C – LMO+NCA/C
- The project being divided into 8 work packages:
- Manufacturing and evaluation of 40 large cells (performance, life, safety, and post-mortem analysis)
- The key issue is the evaluation of: performance, safety, life, recyclability and global cost.
- Proposition by OEM of an European standard for safety and life tests.

Achievements

- Bibliography review on ageing and safety finalized
- Specification of system targets: the recommendation is to use the PHEV cell specification for cell manufacturing.
- WP4 Selection of the most promising cathode materials to be used in cell prototypes.
- WP3 Definition of cycling requirements, safety tests and characterisation
- Schedule of the life tests
- Review on thermal reactions mechanisms for safety issues
- Start of the Economical Assessment
- Decision of the priorities for recyclability and main objectives

Organizational Information

Funded under the Green Cars Initiative EC FP7
Duration 36 months – Final Assessments in October 2012
Coordinator : RENAULT
Partners: OPEL, PSA PEUGEOT CITROËN, CR FIAT, FORD, VOLVO, UMICORE, EDF, CEA, SAFT and JOHNSON-CONTROLS, among others.

Glossary of Abbreviations

AC - Alternate Current
ACEA - European Automotive Manufacturers' Association
ACMARE- Advisory Council on Maritime R&D
AGM- Absorbent Glass Mats
ASD - Aerospace and Defence Industries Association
BES - Battery Energy Storage
BEV – Battery-operated Electric Vehicles
CEN-CENELEC – European Committee for Electro-technical Standardization
CLEPA - European Association of Automotive Suppliers
DOD – Depth of Discharge
DC - Direct Current
EARPA - European Automotive Research Partners Association
ELV - End-of-life Vehicle
ERTRAC – European Road Transport Research Advisory Council
ERRAC- European Rail Research Advisory Council
ELVA - Advanced Electric Vehicle Architecture
EV - Electrical Vehicle
EU - European Union
EUCAR – European Council for Automotive R&D
FC HEV - Fuel Cell Hybrid Electrical Vehicle
FP7 - Seventh Research Framework Programme
GHG - Greenhouse Gas
HEV - Hybrid Electric Vehicle
ICE - Internal Combustion Engine
ISO - International Organization for Standardization
LEV - Light Electric Vehicle
NREAP - National Renewable Energy Action Plan
PEM - Proton Exchange Membrane
PHEV - Plug-in HEV: Plug-In Hybrid Electric Vehicles
RES - Renewable Energy Systems
R&D - Research and Development
SLI - Starting, Lighting and Ignition
UPS – Uninterrupted Power Supply
VRLA - Valve Regulated Lead Acid
V2G - Vehicle-to-Grid
kg- kilogram
km - kilometer
mAh – milli Ampere Hour: Unit of battery capacity
NO_x - Generic term for a group of highly reactive gases
W - Watt: unit for Power output
Wh - Watt Hour: unit for energy capacity
Wh/kg or Wh/L - Energy Density
CO_2 – Carbon Dioxide
Pb -Lead
Ni - Nickel
Li -Lithium
NiCd - Nickel-Cadmium
NiMH - Nickel-Metal Hydride

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