ELECTRIC VEHICLES IN A DISTRIBUTED AND INTEGRATED MARKET USING SUSTAINABLE ENERGY AND OPEN NETWORKS

REPORT: WP1.1 ELECTRIC VEHICLE TECHNOLOGY

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CONTENT

1 DISCLAIMER

This is the report from work package 1.1 of the EDISON project. The work has been carried out as a combination of literature studies, surveys involving key industry personnel and contributions from own participation in international working groups.

The short description of the EDISON project is “Electric vehicle meets grid”.

The EDISON project develops the technical solutions that facilitates larger shares of renewable energy in the power system, and at the same time makes sure that distribution grids are not over loaded. Open standards and information- & communication technology are key topics in the project.

The focus of this report has been to gather information on EV technology which is relevant for the other work packages in the EDISON consortium. Hence, the report deals with EV topics which are relevant for the power system.

2 ELECTRICAL VEHICLES

A wide range of car manufacturers have started EV development programs. The products range from electric scooters and quadra cycles to high performance sports cars and medium sized lorries.

2.1 OVERVIEW OF EXPECTED CARS

In appendix 1 several links to overviews of EVs that are on the Danish and international market today and future EVs can be found.

2.2 ENERGY CONSUMPTION

In March 2009 Energinet.dk and the regional transmission companies made a report on the future transmission grid in Denmark[1].

The assumptions for the work can be found in the appendix to the report. In appendix, it can be seen that the analysis uses 135 Wh/km for EVs. This figure is a compromise between the energy consumption of an old Citroën Saxo EV (175 Wh/km) and the figure (100 Wh/km) that was used in the Danish contribution to the European RES-directive.

When measuring energy consumption or fuel consumption of conventional combustion engines, it is not normal to include the energy consumption of the gasoline station. However when addressing the impact on the electricity grid from EVs it is necessary to include the energy loss in the charger to see the total load on the system. The figure below show typical values of the energy efficiency of different components in the EV.

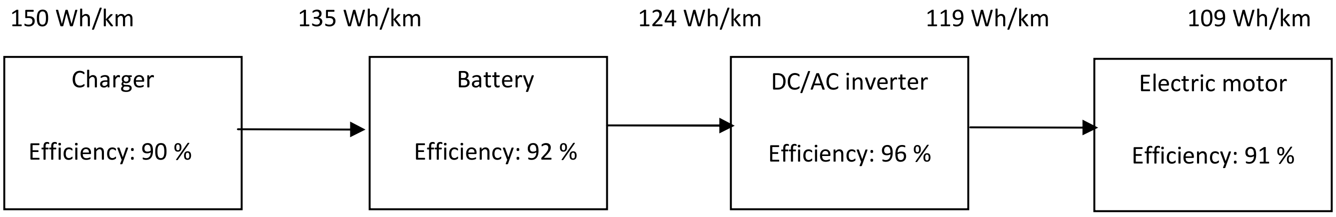

Figure 1. Efficiency of EV components, [2]

WP1.1 recommends that an average EV energy consumption of 150 Wh/km is used for network analyses.[*]

Today the average Danish car drives approximately 50 km on an average day. When estimating the amount of energy consumed of electric vehicles different assumptions can be made:

Option 1: We are looking into a future where e-mobility has the ability to cover all travel needs for the average car owner. EV driving patterns can then be assumed to be equal to today's driving patterns of conventional cars.

Option 2: EV owners will only be a big city phenomena. Hence the EV average daily driving distance will be shorter than today's conventional cars'.

Option 3: EV owners will mainly be suburb commuters. This would most likely mean that the EV average daily driving distance will be longer than today's conventional cars'.

EDISON work package 1.3 will contribute with more detailed data on driving patterns based on option 1.

[*] Siemens expects the energy consumption to be in the range from 130 to 180 Wh/km

2.3 COMMENT TO ENERGY CONSUMPTION

The energy consumption of a car depends a lot on how the car is driven. Furthermore it is a question of efficiency of energy transfer from the energy storage to the propulsion of the car. Weight and shape of the car and rolling resistance also influence the energy consumption. An electric car has one extra ordinary feature more, which will affect the overall energy efficiency; namely the regenerative breaking.

Rolling resistance:

$$F_r = m \cdot 9{,}81 \cdot (C_r + C_s)[N = kg \cdot \frac{m}{s^2}]$$

Where:	F_r is the rolling resistance in N *m* is the mass of the of the car in kg 9,81 is the gravity in m/s^2 C_r is the coefficient of the wheels rolling resistance C_s is the coefficient of the drive train and breaks

Drag force:

$$F_d = C_w \cdot \frac{1}{2} \cdot p \cdot A \cdot v^2 \left[\mathrm{N} = \frac{\mathrm{kg}}{m^3} \cdot m^2 \cdot \left(\frac{m}{s}\right)^2 \right]$$ 3 †

Where	F_d is drag force in N C_D is drag force coefficient determined by the shape of the car p is the density of the medium (e.g. dry air at sea level at 15 degrees Celsius = 1,225 kg/m^3) A is the cross sectional area perpendicular to the flow in m^2 v is the velocity of the car in m/s

Kinetic energy of the car:

$$E_k = \frac{1}{2} \cdot m \cdot v^2$$

Where	Ek is the kinetic energy of the car m is the mass of the car v is the velocity of the car

† Typical values of drag coefficients: sports cars 0.2 – 0.3; typical cars 0.5; station wagon 0.6; truck 0,8 – 1,0.

So to move a car, power is needed to give the car kinetic energy and power to overcome rolling resistance, drag force and internal energy losses in the car. When the car manufacturers state the fuel consumption of regular internal combustion cars, they use different pre-defined driving patterns. There are differences between urban and mixed driving but there are also differences between different markets. In the USA Federal Urban Driving Schedule (FUDS) and the Dynamic Stress Test (DST) specified by the United States Advanced Battery Consortium (USABC) are used. In Europe the drive cycle defined in the ECE 101 regulation is used. The cycle is repeated until the EV is not able to maintain 50 km/h or until the combustion engine starts for PHEVs.

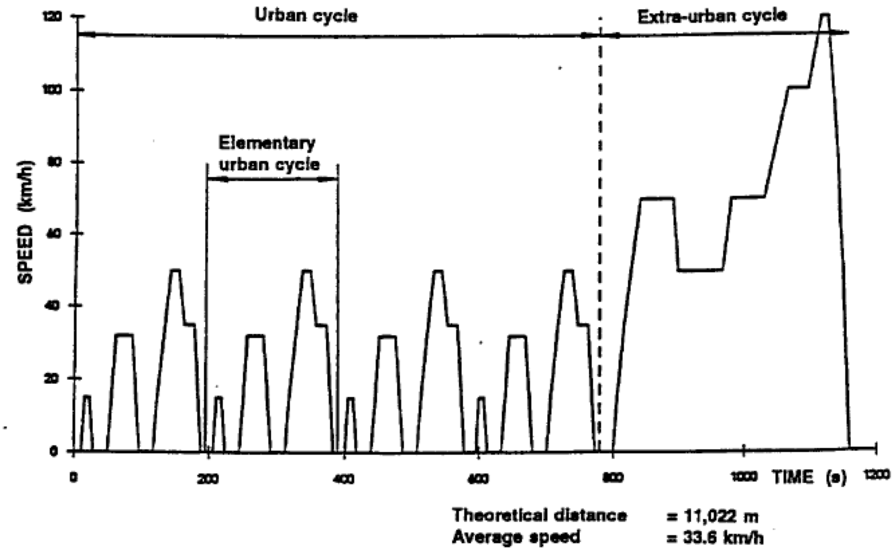

Figure 2. Example of simulated driving cycle from ECE101[4]

Tesla Motors is one of the companies which already have several hundred EVs on the road. The figure below show energy consumption for the Tesla Roadster broken down into different loss components:

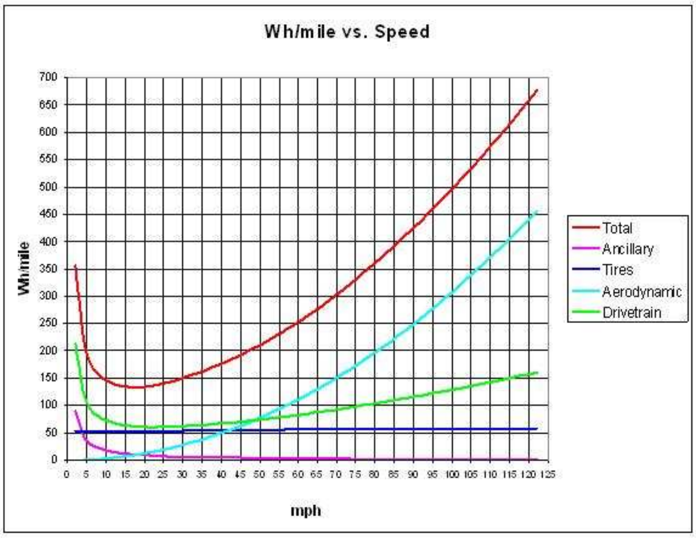

Figure 3. Energy consumption for Tesla Roadster [5]

2.4 EXPECTED BATTERY STORAGE CAPACITIES

The EVs on the market in 2010 typically have batteries with energy storage capacities from 10 to 25 kWh.

Siemens expects that EVs in the future will have batteries with up to 40 kWh of storage capacity. The choice of battery storage capacity will be affected by:

- Battery prices
- Mobility needs (request for range)
- Deployment of charging infrastructure

WP1.1 recommends that 25 kWh/EV is used for network analyses with a short horizon (10 years). In scenarios with longer horizons 40 kWh/EV should be used.

2.5 THE GLOBAL MARKET

One of the factors that might favour the market potential for EVs is the global trend of urbanisation. According to the Population Reference Bureau[6] the majority of the world's population now lives in urban areas, and the urbanisation is predicted to continue.

There are several examples of ambitious national targets for EV or PHEVs, e.g. goals of 1 million EVs in Germany by 2020[7], 2 million EVs in France by 2020[8] and 1 million PHEVs in the US by 2015[9]

A (not publically available) market report projects annual production figures of 500.000 EVs in Europe 2015. Whilst Bosch which is an important component manufacturer for the auto industry has publically announced that they project 500.000 EVs in 2015 for the world wide market and 3 million in 2020.[10]

During the 2010 Paris Motor show, representatives from 15 governments, experts and high level representatives discussed a range of issues related to achieving rapid market development of EV/PHEVs around the world, to reach a combined target estimated by the IEA to be about 20 million EVs and PHEVs on the road by 2020. According to the IEA, this target would put global EV/PHEV stock on a trajectory, if maintained, to exceed 200 million by 2030 and one billion by 2050.[11]

For comparison, data from OICA[‡] show the total number of cars produced every year, the last 5 years.

Year	Cars produced in the world
2009 (projection)	51.971.328
2008	52.940.559
2007	54.920.317
2006	49.886.549
2005	46.862.978

Table 1. Data from OICA

2.6 SCENARIOS FOR NUMBER OF EVS IN THE DANISH MARKET

The narrow range of EV models on the Danish market today combined with high prices relative to comparable gasoline models yield small chances for massive market penetration before mass production is started.

Although there are several large car manufacturers that have stated that they will launch pure EV models within a few years, it is quite difficult to predict how many cars that will be consumed by the Danish market. The amount will depend on:

[‡] Organisation Internationale des Constructeurs d'Automobiles

- the total number of EVs produced
- governmental supported test fleets
- the economic incentives of the Danish consumer
- EV market in other countries
- General exchange rate of cars

The governmental test fleet program initiated by the Danish Energy Authority has 35 million DKK to support EV projects. This will help kick starting the market for EVs, since the extra cost of the EVs will be covered by the government. Experiences from the first call for projects is however that the extra cost for EVs are relatively high and that it is difficult to find EVs to buy. Denmark`s Road Safety and Transport Agency have established Centre for Green Transportation which has 200 million DKK to set up test and demonstration programs for energy efficient transport solutions. The first call for projects is expected to be in the spring of 2010.

Danish EV costumers also have a powerful economic incentive, since the EV registration tax exemption was prolonged to the end of 2015.

Other countries have also set ambitious goals for EV market penetration. This may create a situation where the demand for cars is much bigger than the supply. In such a situation, the markets with the best economic incentives will probably take the majority of the market supply. But other factors such as infrastructure, user incentives (free parking, use of bus lanes etc.) and dealership networks are also parameters that manufacturers are considering when which markets to prioritize.

3 BATTERIES[§]

For many years batteries have been the main reason to why EVs have not been able to compete with conventional cars with internal combustion engines. During the last 10-20 years there has been a massive development in battery technology, mainly due to the development of portable electronic devices like mobile phones and laptops. In section 3.1 some basic properties of different chemistries are described[**]. In the following sections only different variations of lithium batteries are considered.

[§] Description of properties of battery chemistries is never a 100 % accurate. There will always be differences in battery cells even though they are made of the same elements. Producers of batteries also have different ratios between the different elements in the cells, hence giving the cells different properties.

[**] This report only deals with secondary battery types. (Secondary batteries = rechargeable batteries)

3.1 BASIC PROPERTIES OF DIFFERENT CHEMISTRIES

The information in this section is mainly from BatteryUniversity.com.

The lead acid battery was invented in 1859 and was the only battery used in EVs until the 1990'ies.

<table>
<tr>
<td>Advantages with lead acid batteries:

- Cheap and easy to manufacture
- Mature and reliable technology – if utilised properly
- Low self-discharge (5 % losses per month)
- Low maintenance
- No memory effect ††
- Capable of fast discharge</td>
<td rowspan="2">

Table 2. Lead acid battery [12]</td>
</tr>
<tr>
<td>Limitations with lead-acid batteries:

- Low energy density ca. 30 Wh/kg
- Cannot be stored with 0 % state of charge
- Allows only a limited number of discharge cycles (200-500)
- Lead and electrolyte content is an environmental hazard</td>
</tr>
</table>

†† Memory effect means that the battery capacity is reduced if the battery is not deeply discharged before charging.

Nickel cadmium batteries were used in the EVs which were introduced in Denmark in the early 1990'ies.

Advantages with nickel cadmium batteries:

- Fast and simple charging, even after long term storage
- Allows many charge cycles, > 1.000 if treated correctly
- Has good performance a low temperatures
- Can handle rough operation conditions, heavy load and high C-rates

Limitations with nickel cadmium batteries:

- Cadmium is an environmental hazard (EU commission has banned NiCd-batteries in new EVs)
- Relatively low energy density (40-60 Wh/kg)
- Memory effect
- Relatively high self discharge rate, 20 % losses pr month

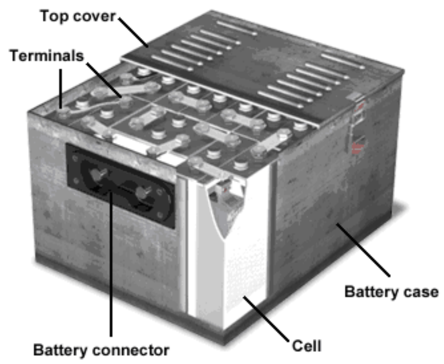

Table 3. Nickel cadmium battery [12]

The development of Nickel metal hydride (NiMH) batteries started during the 1970'ies. The first NiMH batteries were unstable at the cell level, and it was not before around 1990 that the NiMH became a commercial product. In the automotive industry, the NiMH battery is best known as the battery in the Toyota Prius.

Advantages with NiMH batteries:

- 30-40% higher capacity than standard nickel-cadmium. NiMH has potential for yet higher energy densities.
- Less prone to memory than nickel-cadmium - fewer exercise cycles are required.
- Simple storage and transportation - transport is not subject to regulatory control.
- Environmentally friendly - contains only mild toxins; profitable for recycling.

Table 4. Toyota Prius [12]

Limitations with NiMH batteries:

- Limited service life - the performance starts to deteriorate after 200-300 cycles if repeatedly deeply cycled.

- Relatively short storage of three years. Cool temperature and a partial charge slows aging.
- Limited discharge current - although NiMH is capable of delivering high discharge currents, heavy load reduces the battery's cycle life.
- More complex charge algorithm needed - NiMH generates more heat during charge and requires slightly longer charge times than nickel-cadmium. Trickle charge[‡‡] settings are critical because the battery cannot absorb overcharge.
- High self-discharge - typically 50% higher than nickel-cadmium.
- Performance degrades if stored at elevated temperatures - NiMH should be stored in a cool place at 40% state-of-charge.
- High maintenance - nickel-metal hydride requires regular full discharge to prevent crystalline formation. nickel-cadmium should be exercised once a month, NiMH once in every 3 months.

Lithium metal primary cells were available as commercial products in 1970. Any attempts to make secondary cells of lithium metal as commercial products failed due to the unstable nature of lithium metal. The solution was to use lithium ions instead of lithium metal. The first commercialized rechargeable lithium ion battery was made by Sony in 1991. Since then lithium has gained popularity in consumer electronics and power tools, and in the recent years the lithium ion batteries have been predicted to play a major role in future EV designs.

Advantages with Li-ion batteries

- High energy density (still improving through new chemistry combinations)
- Does not need priming when new. One regular charge is all that is needed.
- Relatively low self-discharge
- Low maintenance (no memory effect)
- High power density compared to other chemistries

Figure 4. Tesla Roadster [13]

[‡‡] Trickle charge: An electric charge supplied to a storage battery at a continuous low rate to keep it fully charged.

Limitations with li-ion

- Requires protection circuit to maintain voltage and current within safe limits.
- Subject to aging also when not used. Aging of new li-ion chemistries are not well understood yet.
- Historically li-ion has been expensive, but prices are decreasing.
- Transport restrictions
- Not a fully mature technology yet (can also be seen as an advantage, since a significant development potential is present).

Another source, Electropaedia, shows the following shelf life and self discharge rate for different chemistries:

The following shows the typical shelf life for some primary cells:

- Zinc Carbon (Leclanché) 2 to 3 years
- Alkaline 5 years
- Lithium 10 years or more

Typical self discharge rates for common rechargeable cells are as follows:

- Lead Acid 4 % to 6 % per month
- Nickel Cadmium 15 % to 20% per month
- Nickel Metal Hydride 30 % per month
- Lithium 2 % to 3 % per month

These numbers are not exactly the same as those from BatteryUniversity.com. This might be due to misinformation, advances in the technology, or differences in products that has been investigated.

3.2 COMPONENTS IN A CELL (SECTION FROM ELECTROPAEDIA)

A battery cell basically consists of 4 components:

- Anode material
- Cathode material
- Electrolyte
- Separator

Changing any of these 4 elements will change the characteristics of the cell's performance.

The operating principle of a Li-ion cell [14]:

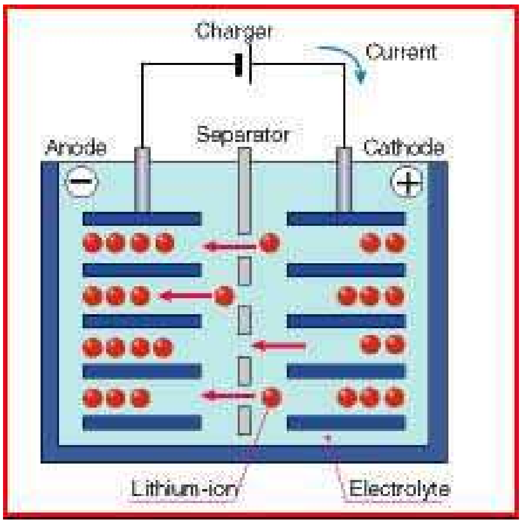

Figure 5. Charging of Li-ion cell

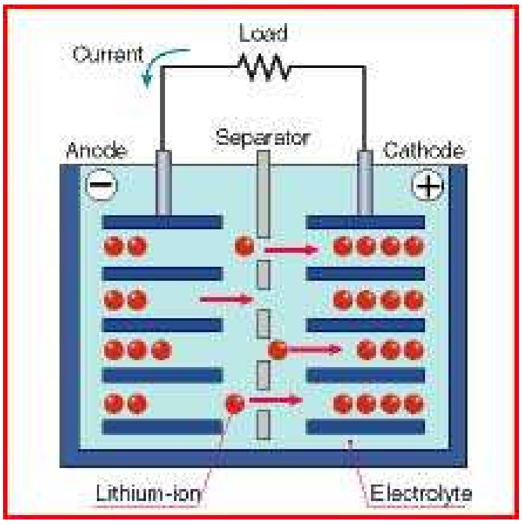

Figure 6. Discharging of Li-ion cell

When the battery is charged, the (positive) lithium ions in the cathode material (lithium compound) migrate via a separator between the layers of carbon material that form the anode, and a charging current flow.

When the battery is discharged, the (positive) lithium ions in the carbon material that form the anode migrate via a separator to the cathode material (lithium compound), and a discharging current flow.

The difference in electrical potential between the anode and the cathode decides the voltage of the cell (also called electromotive force, EMF). The atoms in the periodic table have different electron affinity values. This means that some atoms tend to absorb electrons while others tend to emit electrons.

Anodes are chosen for their ability to emit electrons during oxidation (discharge), while cathodes are chosen for their ability to absorb electrons. Good material for cathodes can be found on the left side of the periodic table of elements, while good material for anodes can be found on the right side of the table.

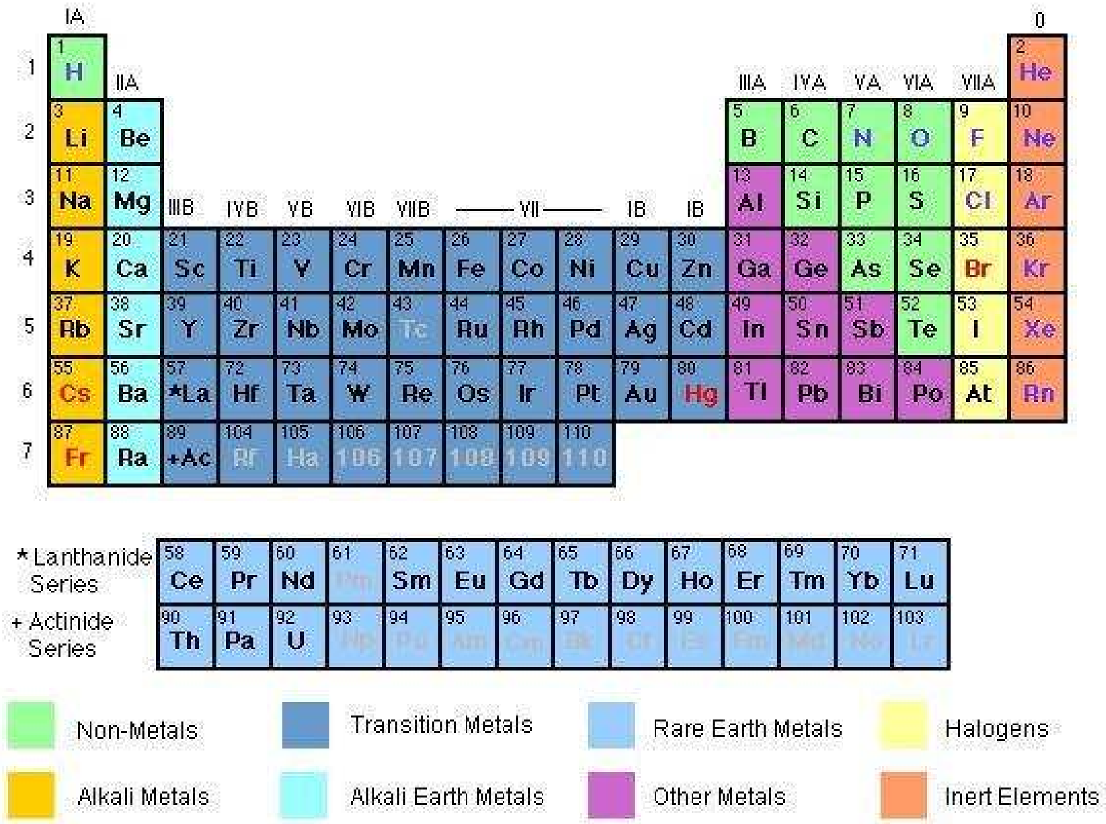

Table 5. Periodic table of elements

The table below shows some examples of electrode potentials for different metals and ions.

Cathode (Reduction) Half-Reaction	Standard Potential E °(volts)
Li^+ (aq) + e^- --> Li(s)	-3.04
K^+ (aq) + e^- --> K(s)	-2.92
Ca^{2+} (aq) + $2e^-$ --> Ca(s)	-2.76
Na^+ (aq) + e^- --> Na(s)	-2.71
Zn^{2+} (aq) + $2e^-$ --> Zn(s)	-0.76
$2H^+$ + $2e^-$ --> H_2	0
Cu^{2+} (aq) + $2e^-$ --> Cu(s)	0.34
O_3^+ (g) + $2H^+$ (aq) + $2e^-$ --> O_2 (g) + H_2O(l)	2.07
F_2 (g) + $2e^-$ --> $2F^-$ (aq)	2.87

Table 6. Strength of oxidizing and reducing agents

A large negative potential yields a good anode, while a large positive number yields a good cathode. Hence material for anodes and cathodes can be ranked as shown in the table below:

Anode Materials (Negative Terminals)	**Cathode Materials** (Positive Terminals)
BEST - Most Negative	BEST Most Positive
Lithium	Ferrate
Magnesium	Iron Oxide
Aluminium	Cuprous Oxide
…	…
…	…
Mercury	Silver Peroxide
Platinum	Permanganate
Gold	Bromate
WORST Least Negative	WORST Least Positive

Table 7. Ranking of anode and cathode material

3.3 VOLUMETRIC AND GRAVIMETRIC ENERGY STORAGE CAPACITY

When discussing the volumetric and gravimetric energy storage capacity of batteries there is mainly focus on the cathode part as in the figure below.

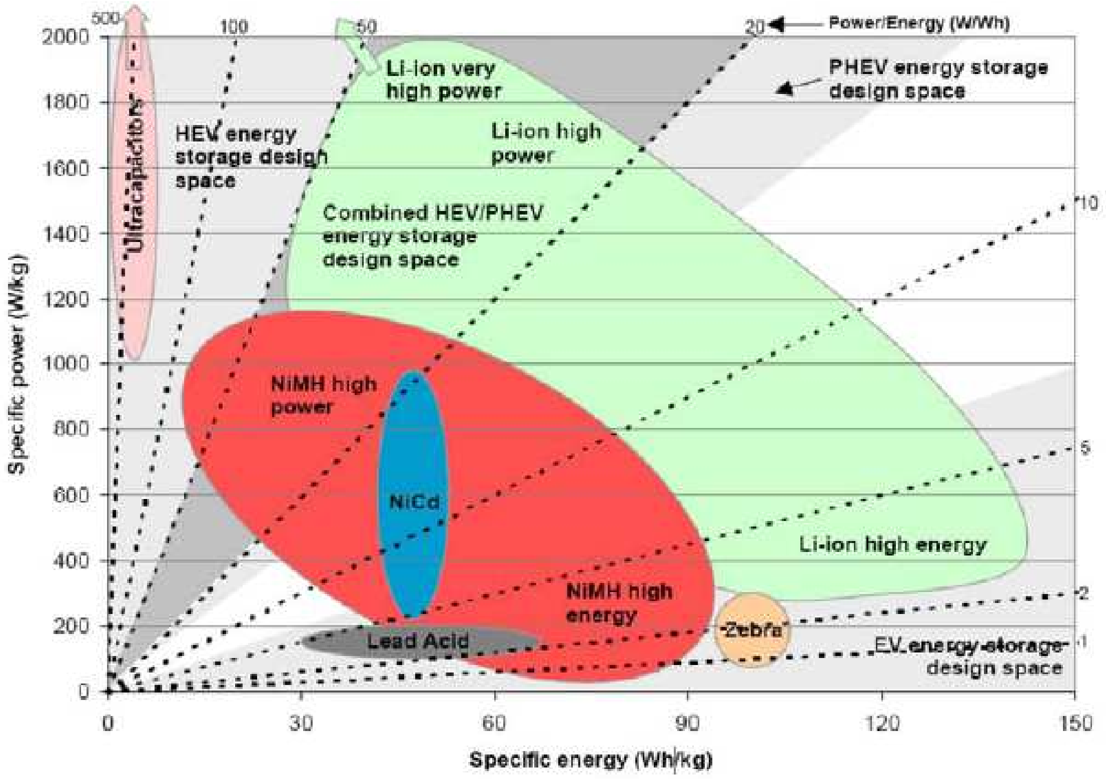

Figure 7.Specific energy and power for a range of battery types. [15]

The cathode is generally one of three materials; a layered oxide, such as lithium cobalt oxide, one based on polyanion, such as lithium iron phosphate, or a spinel, such as lithium manganese oxide. The table below shows alternative cathode materials and some of their properties.

Cathode material	Cost	Life	Safety	Wh/kg	Wh/l
Cobalt Oxide	----	+++	+	195	560
Nickel Cobalt Aluminum Oxide (NCA)	+	++++	-	220	600
Nickel Cobalt Manganese Oxide (NCM)	++	?	++	205	580
Lithium Manganese Oxide (LMO)	++++	-	+++	150	420
Iron Phosphate (LFP) (carbon coated)	+++	?	++++	90-130	333

Table 8. Properties of different cathode materials containing lithium [16]

According to the proceeding of Dr. Robert Spotnitz at AABC09 [16], more than 90 % of Li-ion consumer cells use cobolt oxide as cathode material (2009). However LFP is foreseen to be a candidate for hybrid and plug-in hybrids with its high power capabilities and LMO is considered to be a good candidate for pure EVs due to higher energy density.

The most popular choice for anodes is graphite. $Li_4Ti_5O_{12}$, Si ($Li_{4.4}Si$) and Ge ($Li_{4.4}Ge$) are alternative anode materials.

Within the class of graphite/carbon there are different options[17]:

- Synthetic graphite
- Natural graphite
- Surface modified graphite.
- Hard carbon
- Partially graphitized soft carbon

Given the relatively low price of anode materials compare to that of the cathode materials, the incentive for research to reduce the anode material cost is relatively less compelling.[18]

3.4 FROM CHEMICALS TO CELL TO BATTERY PACK

The figure below shows the different steps in the assembly of a battery cell. The next figure shows how several battery cells are combined in a battery module. To make the complete battery pack, several battery modules are connected and controlled by a BMS. A more detailed description can be found at Electropaedia [19].

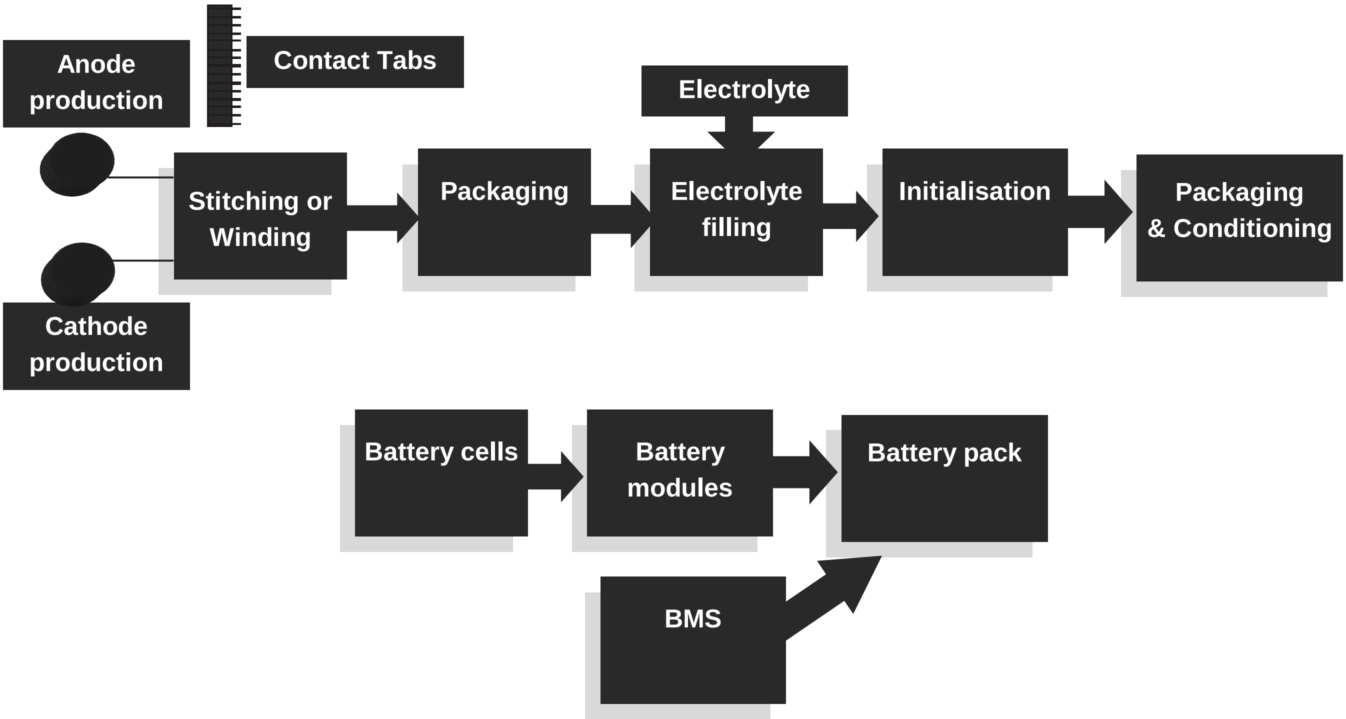

Figure 8. From chemical components to cell, from cells to battery modules and from modules to the complete battery pack

There are three main designs for packing the basic battery elements into cells. [20]

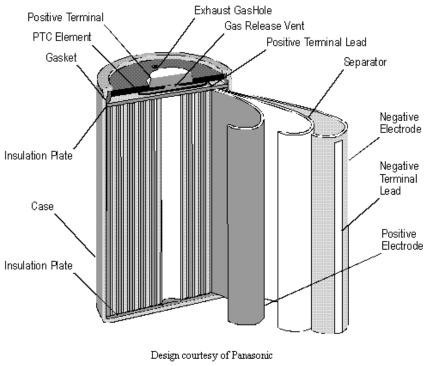

Figure 9. Cylindrical cell [12]

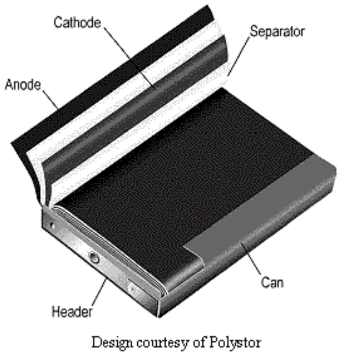

Figure 10. Prismatic cell [12]

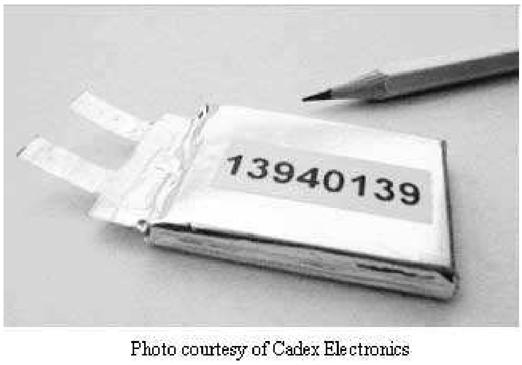

Figure 11. Pouch cell [12]

The different Li-Ion battery manufacturers all have their own product, where materials and properties are different. In the table below a brief overview of different manufacturers' cell designs is given.

Company	Source	Cathode	Anode	Electrolyte	Packaging	Structure	Shape
Toyota	2003 Vitz	NCA	Graphite	Liquid	Metal	Spiral	Elliptic
Panasonic	AABC-06	NMC	Amorphous Carbon	Liquid	Metal	Spiral	Elliptic
JSC	USABC	NCA	Graphite	Liquid	Metal	Spiral	Cylindrical
Hitachi	Unconfirmed	LMO/NMC	Hard carbon	Liquid	Metal	Spiral	Cylindrical / Elliptic
AESC	AABC-08	LMO/NCA	Hard carbon	Liquid	Pouch	Stacked	Prismatic
Sanyo	Unconfirmed	NMC/LMO	Surface modified Graphite	Liquid	Metal	Spiral	Cylindrical
GS Yuasa	Unconfirmed	LMO/NMC	Hard Carbon	Liquid	Metal	Spiral	Elliptic
A123 Systems	AABC-08	LFP	Graphite	Liquid	Metal / pouch	Spiral	Cylindrical
LG Chem	AABC-09	LMO	Amorphous Carbon	Gel	Pouch	Stacked	Prismatic
Samsung	Unconfirmed	NMC/LMO	Graphite	Liquid	Metal	Spiral	Cylindrical
SK Corp	AABC-08	LMO	Graphite	Liquid	Pouch	Spiral	Prismatic
Toshiba & EnerDel	LLIBTA-08	LMO	LTO	Liquid	Pouch / Metal	Spiral	Prismatic
AltairNano	AABC-07	LMO	LTO	Liquid	Pouch	Stacked	Prismatic

Table 9. Examples of design differences between different battery manufacturers [17]

The picture below show how battery cell design relates to power and energy density.

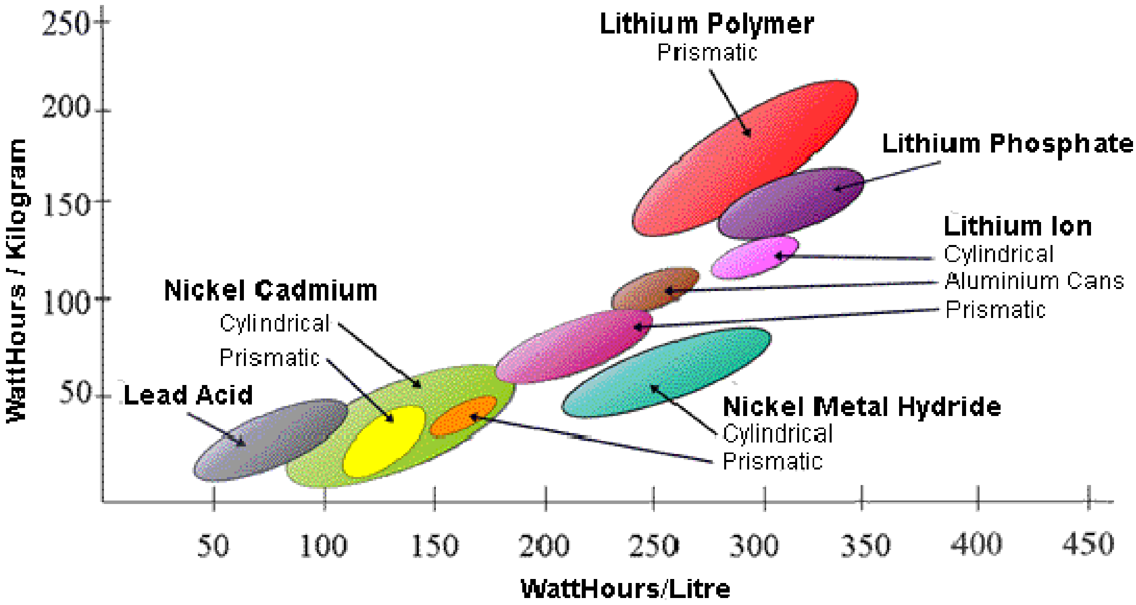

Figure 12. Energy density of different battery chemistries (from Electropaedia)[21]

3.5 CYCLE- AND CALENDAR LIFE

Cycle- and calendar life of batteries are very important parameters when assessing the possibilities of using batteries as power system tools. There is very little experience on how the automotive grade batteries can handle the strain from EV usage since the technology is still quit new. Analysing cycle life of lithium batteries often includes accelerated degradation which means that there is some uncertainty to the results.

However battery manufacturers claim cycle life ranging from 1000 to 3000 deep cycles for lithium ion batteries. Historically calendar life (degradation over time even though not used) has also been an issue for lithium ion batteries. This parameter is seldom mentioned in the EV battery discussion.

3.6 AVAILABLE POWER AS A FUNCTION OF STATE OF CHARGE

Some Li-ion batteries can be discharged at up to 40 C-rate[§§]. There is however a relation between energy storage capacity and power when designing Li-ion batteries. Typical EV batteries will most likely have a charging rate of 2-3 C.

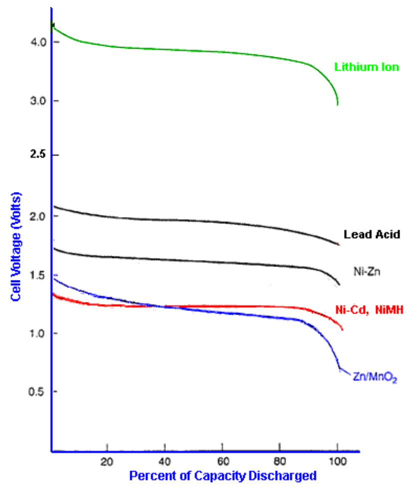

Figure 13. Discharge voltage profile (from Electropaedia). [21]

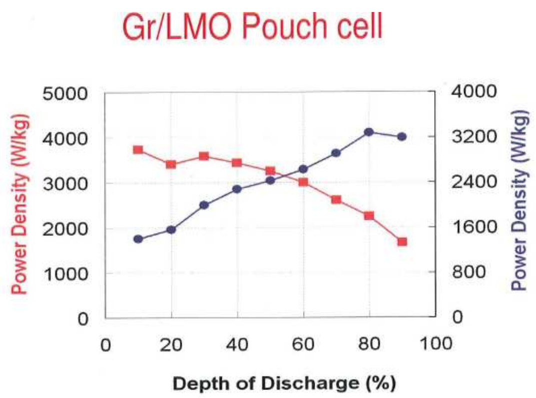

Figure 14. Power as function of depth of discharge [17]

According to [19] modern Li-ion cells maintain a relatively constant voltage for over 80% of its discharge curve. It thus delivers nearly constant power down to 80 % DOD. This does however not correspond well with the graph in Figure 14 which was presented by Dr. Anderman at AABC 2009. This is most likely due to differences in properties for different Li-ion batteries. Li-ion iron phosphate is e.g. known to have a very stable voltage profile during discharge, and is probably the chemistry which is referred to in Figure 13, while figure 14 show the LMO type.

3.7 NANO TECHNOLOGY IMPACT ON BATTERY TECHNOLOGY

Using nanotechnology in the manufacturing of batteries offers the following benefits[22]:

- Increasing the available power from a battery and decreasing the time required to recharge a battery. These benefits are achieved by coating the surface of an electrode with nano particles. This increases the surface area of the electrode thereby allowing more current to flow between the electrode and the chemicals inside the battery. This

[§§] 1C means that the battery can discharge all of its energy in 1 hour. Hence 40C means that the battery can discharge all of its energy in 1h/40= 1,5 minutes.

technique could increase the efficiency of hybrid vehicles by significantly reducing the weight of the batteries needed to provide adequate power.

- Increasing the shelf life of a battery by using nanomaterials separate liquids in the battery from the solid electrodes when there is no draw on the battery. This separation prevents the low level discharge that occurs in a conventional battery, which increases the shelf life of the battery dramatically.

- Reducing the possibility of batteries catching fire by providing less flammable electrode material.

3.8 PRICE LEVEL

The manufacturing costs for low power batteries used in mobile phones could be as low as $2.50 whereas a high capacity EV battery could cost upwards of $10,000. In both cases the major cost is the cells. In small batteries this may be 80% to 85% of the total costs. Large batteries use more electronics and higher power components. They are also more labor intensive. For large batteries the cost of the cells could be between 60% and 80% of the total costs depending on the battery specification. Since most cells are sourced from Asia, shipping costs also contribute significantly to the costs.

Manufacturer	Chemistry	Current Price	Target Price
Ener1 (HEV)	Li-polymer	$660 per kWh	N/A
Valence Technologies (VLNC)	Li-phosphate	$1,000 per kWh	$500 per kWh
Altair Nanotechnologies (ALTI)	Li-titanate	$1,000 per kWh	N/A
A123 Systems (power tool packs)	Li-phosphate	$1,228 per kWh	N/A
2008 DOE SEGIS-ES Estimates (PV Solar battery packs)	Various	$1,333 per kWh	$780 per kWh
2009 NEDO Survey Results (Average of Japanese Producers)	Various	$2,018 per kWh	$1,000 per kWh (next year)

Table 10. Examples of lithium battery pack prices [23]

The table above shows prices from manufacturers in the American market from April 2009.

A market report from Deutsche Bank from March 2010 [24] states that “Battery costs appear to be coming down faster than we expected”. Deutsche Banks initial expectations from November 2009 were a 25/50 % decline in cost over the next 5/10 years and a doubling of performance over the next 7 years. Their latest discussions with auto manufacturers indicate bids in the mid-400$/kWh range for large volume EV battery pack contracts in the 2011/2012 time period (implying a 30 % decline).

3.9 LI-ION BATTERY MARKET

Today the majority of Li-ion cells are produced in Asia and the market has for many years been dominated by small cells for consumer electronic applications, as can be seen from the chart below:

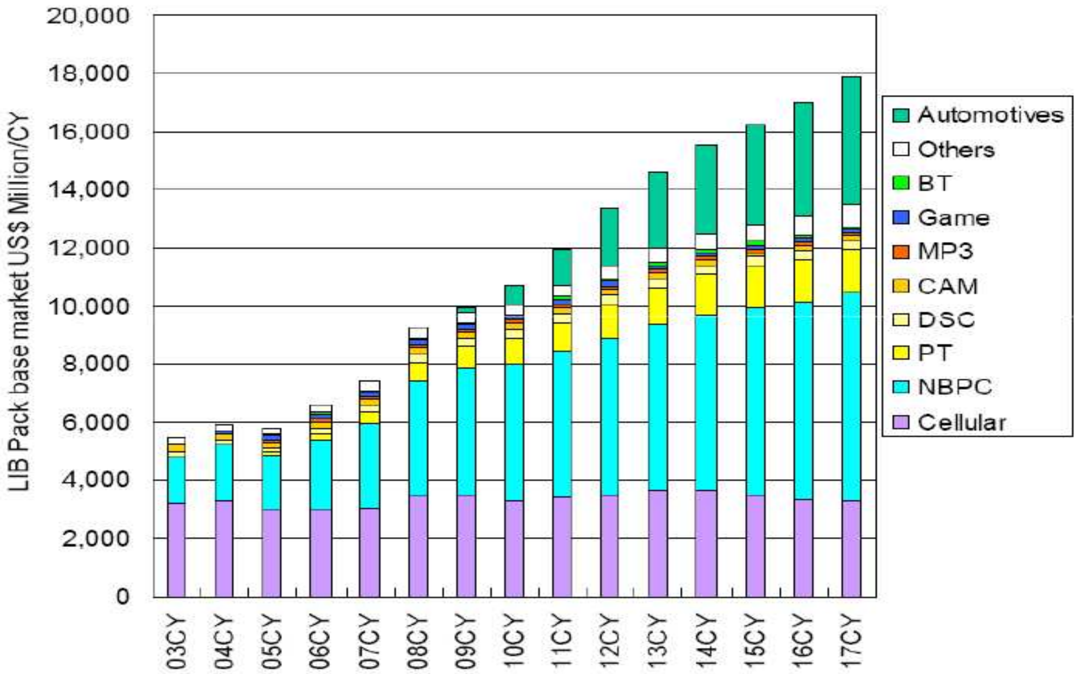

Figure 15. Market data from Hideo Takeshita

Department of Energy in the US announced in August 2009 which battery producers that will be granted a share of the American Recovery and Reinvestment Act (ARRA).[***] More than 2 billion US$ from ARRA will be used to develop the American battery industry in the coming years.

[***] A list of the awardees can be found at http://www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf

3.10 GLOBAL RESERVES OF LITHIUM CARBONATE

There is an ongoing debate on the global reserves for lithium carbonate. The debate is evolving around two questions; "How much lithium carbonate is available?" and "Will this be enough to support a massive introduction of electrical cars?".

The origin of the debate was the paper, "The Trouble with Lithium"[25], made by Mr. W. Tahil in 2007. The content of this report was afterwards challenged by a report from Mr. R. K. Evans named "An Abundance of Lithium, March 2008"[26]. Mr. Tahil defended his 2007 paper with a report named "The Trouble with Lithium 2 - Under the Microscope"[27]. Yet again this was challenged by Mr. Evans in "An abundance of Lithium, July 2008).[28]

The International Lithium Alliance claims [29] there is plenty of lithium available for advanced transport batteries and other applications. They state that lithium ranks as the 33rd most available element in the earth's crust and 16th in the ocean. Furthermore they are referring to figures from 2009 edition of Roskill study of lithium[30] which estimates that that worldwide lithium reserves total 28,400,000 tonnes of lithium or 150,000,000 tonnes of lithium carbonate equivalents.

It takes 15 kg of lithium carbonate equivalents to make a battery with 25 kWh capacity according to the International Lithium Alliance[31]. Combining this information with the information of the reserve figures from the Roskill study gives an indication of the number of EVs that could be powered by lithium ion batteries:

$$\frac{150.000.000.000\,\mathrm{kg\ LCE}}{15\,\frac{\mathrm{kg\ LCE}}{\mathrm{EV}}} = 10.000.000.000\,\mathrm{EVs}$$

This figure should be related to the current global annual production of cars being somewhere around 50.000.000 as stated in chapter 2.5.

TRU Group Inc, market analysts on the Lithium supply and demand, stated in a press release January 2009 [32] that some expansions and new projects will be delayed or cancelled until market conditions improve. They further more state that the industry through expansion and development of new resources will have no problem meeting demand. Some new market entrants are also accused of boosting market price projections in order to sell projects to investors.

An American project [33] has calculated the amount of lithium used in different battery packs:

Battery Type	NCA-G				LFP-G				LMO-G				LMO-TiO			
Auto range (mi) at 300 Wh/mile	4	20	40	100	4	20	40	100	4	20	40	100	4	20	40	100
Li in cathode (kg)	0.34	1.4	2.8	6.9	0.20	0.80	1.6	4.0	0.15	0.59	1.18	3.0	0.29	1.2	2.3	5.8
Li in electrolyte (kg)	0.04	0.10	0.20	0.55	0.045	0.14	0.26	0.66	0.03	0.09	0.17	0.43	0.05	0.17	0.34	0.85
Li in anode (kg)	0	0	0	0	0	0	0	0	0	0	0	0	0.30	1.21	2.4	6.1
Total Li in battery pack (kg)	0.37	1.5	3.0	7.4	0.24	0.93	1.9	4.7	0.17	0.67	1.4	3.4	0.64	2.5	5.1	12.7

Figure 16. Content of lithium in different battery packs [33]

According to the same project, batteries did take 25 % of the global lithium production in 2007 and that share is expected to grow fast. One other major finding of the project is that recycling of batteries will significantly lower the need for virgin material:

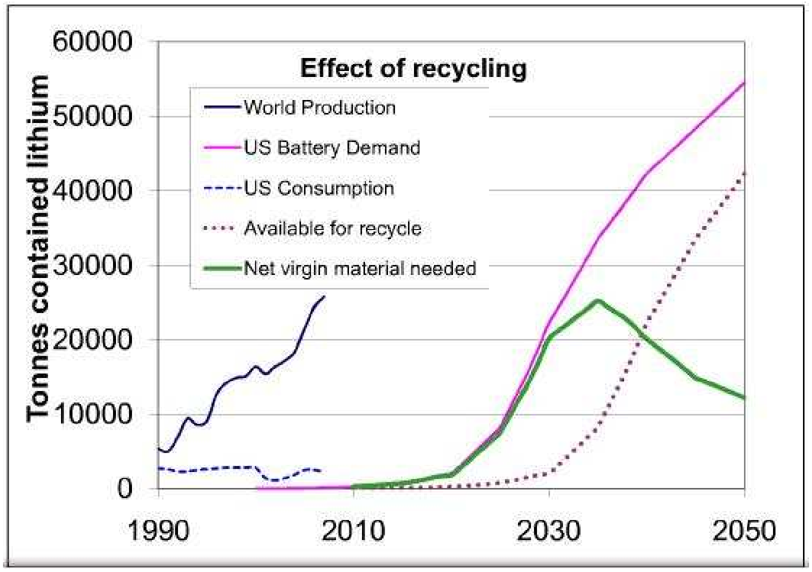

Figure 17. Effect of recycling of batteries on lithium demand [33]

3.11 SUPER CAPACITORS

A capacitor is a component that allows energy storage in terms of static charge, rather than the electrochemical energy storage in batteries. Super capacitors are special types of capacitors that have a very high capacitance in a small package. Super capacitors are generally foreseen to be used as a power boost application in hybrids, PHEVs and EVs.

A much debated company EESTOR claims to have developed a super capacitor with some incredible specifications. There is a lot of skepticism on whether their technology really exists, since there has been no public demonstration. Among their claims on their patent application the following can be found[34]:

- …the capability of components to withstand 1,000,000 full voltage cycles of 3500 V to 0 V, then back to 3500 V without degrading the leakage, capacitance, or voltage breakdown capabilities of the component.
- …EESU that can store 52.22 kWh of electrical energy
- …EESU that has a total weight of 281.56 pounds which includes the covers, connectors, and associated hardware

Similar information can also be found on ZENN's homepage which is an EV solution provider which is supposed to be the first to use the technology:

EESU Comparison (Example 52 KWh of Electrical Energy)

	Ceramic EESU	NiMH	LA(Gel)	Lithium-ion
Weight (lbs)	297	1786	3,641	748
Volume (cubic inches)	4,493	17,881	43,045	5,697
Discharge rate	0.02%/30 days	5%/30 days	1%/30 days	1%/30 days
EV Charging time (full) - 100% charge	Infrastructure limited	Battery chemistry limited	Battery chemistry limited	Battery chemistry limited
Cycle Life	1,000,000+ No Degradation	Thousands	Hundreds	Thousands
Life reduced with deep cycle use	None	High	Very High	High
Hazardous materials	None	Yes	Yes	Yes
Temperature vs. effect on energy storage	Negligible	High	Very High	High

Figure 18. EESU properties [35]

4 BATTERY MANAGEMENT SYSTEMS

Battery Management Systems (BMS) is an electronic device that manages charging and discharging of battery packs. The BMS is the component that protects the battery against misuse.

To protect the battery the BMS monitors some or all of the following parameters (some directly measured and some calculated):

- Voltage (pack, modules and/or cells)
- Temperature
- State of charge (SoC) / depth of discharge (DoD)
- State of health (State of Health)
- Current (in or out of battery)
- Air flow for air cooled batteries

One of the main tasks of a BMS is to keep the SoC of all cells at more or less the same level. Three different strategies for this are mentioned in two white papers by Elithion[36]; passive balancing, active balancing and redistribution.

BMS topology can mainly be placed in 3 categories:

- Centralised (the battery pack has one single controller which has a separate connection to every cell through wires)
- Distributed (a controller is installed on each cell)
- Modular (one controller on each battery module that communicate with each other)

5 CHARGE EQUIPMENT

5.1 CRITERIA FOR A GOOD CHARGER

When charging batteries it is crucial to have a good battery charger. Charging modern vehicle batteries is not as simple as providing constant voltage or constant current. It requires a very precise control of the current and the voltage through the charging period.

The alternate current (AC) from the electricity outlets must be rectified to direct current (DC) for charging the battery. The rectified battery charging current must have very little ripple, which means that the current and voltage must be close to a stable DC signal. Variations causing the DC voltage to go below the battery voltage will lead to zero energy transfer, while peak values of the ripple may cause high enough voltage to damage the battery.

The battery type and the application in which it is used set performance requirements which the charger must meet (information from Electropaedia):

- **Output Voltage Purity**

The charger should deliver a clean regulated voltage output with tight limits on spikes, ripple, noise and radio frequency interference (RFI) all of which could cause problems for the battery or the circuits in which it is used. It is also important that the charger does not distort the voltage of the AC mains.

For high power applications, the charging performance may be limited by the design of the charger.

- **Efficiency**

  When charging high power batteries, the energy loss in the charger can add significantly to the charging times and to the operating costs of the application. Typical charger efficiencies are around 90%, hence the need for efficient designs.

- **Inrush Current**

  When a charger is initially switched on to an empty battery the inrush current could be considerably higher than the maximum specified charging current. The charger must therefore be dimensioned either to deliver or limit this current pulse.

- **Power Factor**

  This could also be an important consideration for high power chargers. A reactive angle between voltage and current additionally loads the distribution grid. EV chargers can either compensate for this or additionally stress the grid.

5.2 TYPES OF CHARGERS

If an EV today needs to be charged at more than one location, it is easiest to place an on-board charger in the car. The on-board charger will be designed for the special battery type. One way to avoid the need for an on-board charger in the future would be to have external chargers that continuously would get information from the onboard BMS about the current need for power (voltage and current). Off board fast chargers will typically deliver DC directly to the battery. Another future solution could be to use the traction inverter (between the battery and an AC motor) in the EV as a charger. Some different technical solutions for chargers are shown below (information from Electropaedia)[37]:

- **Switch Mode Regulator (Switcher)** - Uses pulse width modulation to control the voltage. Low power dissipation over wide variations in input and battery voltage. More efficient than linear regulators but more complex.
  Needs a large passive output filter to smooth the pulsed wave form. Component size can be reduced by using higher switching frequency. Switching heavy currents gives rise to EMI and electrical noise.

- **Series Regulator (Linear)** - Less complex but more lossy - requiring a heat sink to dissipate the heat in the series, voltage dropping transistor which takes up the difference between the supply and the output voltage. All the load current passes through the regulating transistor which consequently must be a high power device. Because there is no switching, it delivers pure DC and doesn't need an output filter. For the same reason, the design doesn't suffer from the problem of radiated and conducted emissions and electrical noise. This makes it suitable for low noise wireless and radio applications. With fewer components they are also smaller.

- **Shunt Regulator -** Shunt regulators are common in photovoltaic (PV) systems since they are relatively cheap to build and simple to design. The charging current is controlled by a switch or transistor connected in parallel with the photovoltaic panel and the storage battery. Overcharging of the battery is prevented by shorting (shunting) the PV output through the transistor when the voltage reaches a predetermined limit. If the battery voltage exceeds the PV supply voltage the shunt will also protect the PV panel from damage due to reverse voltage by discharging the battery through the shunt. Series regulators usually have better control and charge characteristics.

- **Buck Regulator** A switching regulator which incorporates a step down DC-DC converter. They have high efficiency and low heat losses. They can handle high output currents and generate less RF interference than a conventional switch mode regulator. A simple transformerless design with low switch stress and a small output filter.
- **Pulsed Charger**. Uses a series transistor which can also be switched. With low battery voltages the transistor remains on and conducts the source current directly to the battery. As the battery voltage approaches the desired regulation voltage the series transistor pulses the input current to maintain the desired voltage. Because it acts as a switch mode supply for part of the cycle it dissipates less heat and because it acts as a linear supply part of the time the output filters can be smaller. Pulsing allows the battery time to stabilise (recover) with low increments of charge at progressively high charge levels during charging. During rest periods the polarisation of the cell is lowered. This process permits faster charging than possible with one prolonged high level charge which could damage the battery since it does not permit gradual stabilisation of the active chemicals during charging. Pulse chargers usually need current limiting on the input source for safety reasons, adding to the cost.

5.3 PRICE LEVEL

The higher the DC current, the harder it is for the rectifiers to produce a smooth DC output, which means that the rectifying and smoothing circuits of battery chargers are often quite expensive, especially for high current chargers. For example, the battery charger for the General Motors EV1, cost about $2000 in 1996.[38] Power electronics have become cheaper since then, but it is still most common to see rather low rated power for chargers in EVs. But if the traction inverter will be used as a charger in the future, there will be no cost issue for chargers, since the power needed to move the car will allow rather fast charging.

Talks with car manufacturers indicate that fast charging (50 kW range) DC stations would come down to approximately 10.000 Euros per unit.

6 CHARGING INFRASTRUCTURE

6.1 NATIONAL BOUNDARY CONDITIONS

In the Eurelectric EV task force there has been discussed differences between the northern and the southern part of Europe. Low voltage radials in the northern part of Europe are typically more robust than the grids in the southern countries. This is due to geographical and historical reasons such as more electrical heating and more electrical appliances in the north. There are also differences between the number of phases that can be utilized in the costumer installation. Availability of three phases gives the opportunity to triple the charging power compared to a single phase connection with the same amp rating. Additionally single phase loads might give large differences between the loads of the different phases.

Some of the Nordic countries have existing infrastructure, currently used for engine block heaters for ICE cars, which also could be used as EV charging infrastructure. There is a concern in these countries that this infrastructure cannot be used, if there is only one standard solution for EV plugs.

6.2 WHICH STANDARDS APPLY

If we look at the EVs on the market today, most of them use the standard for industrial plugs:

IEC 60309 "Plugs, socket-outlets and couplers for industrial purposes"

IEC 60309-2 connectors are produced in many variants, designed so that a plug of one type can only be inserted into a socket of the same type. Different current ratings (such as 16 A, 32 A, 63 A and 125 A) are distinguished by different diameters of the circular housing.

The color of the plug and socket refers to the voltage and frequency range. A large part of the power grid works with 50 Hz or 60 Hz where the color refers to the voltage (in the case of three phase plugs the color code refers to the phase-phase voltage.

In Denmark the two relevant plugs would be:

	
200-250 Volt (one phase)	380-480 Volt (three phases)

Relevant international standards are either under revision or being developed from scratch. See appendix 2 for status on the different standards:

IEC 61851"Electric vehicle conductive charging system" is under revision. The work is done under IEC TC 69.

- Part 1: General requirements
  - Applies to equipment for charging electric road vehicles at standard AC-supply voltages (as per IEC 60038) up to 690 V and at DC voltages up to 1 000 V, and for providing electrical power for any additional services on the vehicle if required when connected to the supply network.
- Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply
  - This part of IEC 61851 together with part 1 gives the electric vehicle requirements for conductive connection to an AC or DC supply, for AC voltages according to IEC 60038 up to

690 V and for DC voltages up to 1 000 V, when the electric vehicle is connected to the supply network.

- Part 22: AC electric vehicle charging station
  - This part of IEC 61851, together with part 1, gives the requirements for AC electric vehicle charging stations for conductive connection to an electric vehicle, with AC supply voltages according to IEC 60038 up to 690 V.
- Part 23: DC electric vehicle charging station[†††]
  - This standard, together with part 1, gives the requirements for DC electric vehicle charging stations for conductive connection to the vehicle, with an AC supply input voltages, up to 1000 V and DC output voltages up to 1500 V.

IEC61851-1 defines 4 different modes of charging which according to the standard should be able to co-exist on the market.
Mode 1: Charging with no communication for protection
Mode 2: Communication unit in the cable for protection
Mode 3: Communication unit in car for protection
Mode 4: DC charging

The standard for plug design is also under revision. The work is done under IEC SC23H:

IEC 62196 "Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles

- Part 1: Charging of electric vehicles up to 250 A AC and 400 A DC" Ed. 2.0
  - This part of IEC 62196 is applicable to plugs, socket-outlets, connectors, inlets and cable assemblies for electric vehicles, intended for use in conductive charging systems which incorporate control means, with a rated operating voltage not exceeding: 690 V AC, 50 - 60 Hz, at a rated current not exceeding 250 A; 600 V DC, at a rated current not exceeding 400 A.
- Part 2: Dimensional interchangeability requirements for AC pin and contact-tube accessories Ed. 1.0
  - This standard applies to plugs, socket-outlets, vehicle connectors and inlets with pins and contact-tubes of standardized configurations. They have a Sockets and plugs in this standard should only be used with mode 3 charging (ref. IEC 61851-1)

Although part 2 is already under development, we know there are currently three different plug designs suggested in the standard:

[†††] A new working item proposal has been put forward in IEC by the Japanese. They will most likely pursue the TEPCO standard that will be used for fast charging of all the first Japanese EVs. Several companies and organisations have gathered in the CHAdeMO Association to promote the standard for DC fast charging.

1. Japanese proposal
2. German proposal
3. Italian proposal

IEC 62196-2-1 'Yazaki'

IEC 62196-2-2 'Mennekes'

IEC 62196-2-3 'Scame'

Most likely there will not be made a choice of a single plug in the IEC standard. But the European Commission has given a mandate to the European standardization bodies CEN and CENELEC to find a single solution for Europe.

WP1.1 recommends that the EDISON project, if possible, utilizes the German proposal from IEC 62196-2 for the demonstration phase. This is based on a set of requirements that the German proposal apparently is the only one that can fulfill:

- Suitable for 6A, 16A and 32A at least
- Suitable for 1 and 3 phase
- 1 phase cable and 3 phase cable should be allowed
- Different cable-cross sections should be allowed
- Interlock facility must be available
- Pilot facility must be available
- Coding facility must be available

The Danish Safety Technology Authority has indicated that sockets for EVSE[‡‡‡] will be required to have shutters. This is not implemented in the IEC62196-2-2 proposal (Mennekes). This is currently an unresolved issue that needs to be handled.

[‡‡‡] Electric vehicle supply equipment

6.3 SAFETY

According to IEC 61851-1 a double electric safety (RCD + earth safety control) has to be provided for both TT and TN systems during EV charging time since the vehicle is totally insulated by the rubber tires. Since not all national codes in Europe have requirements for RCD on all sockets, a single standardised EVSE solution would have to include a RCD if a fully standardised EVSE is desirable.

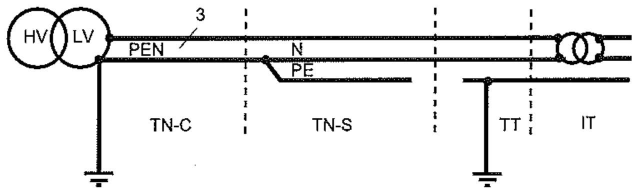

Figure 19. Grounding systems

TT	TN
Earthing provided locally at installation	Earthing provided by the grid TN-S *(But TN-C forbidden across flexible cable)* *(Europe: TN-C banned for caravans)*
Residual current device (RCD or FI)	Fuse and RCD[§§§] Denmark: HPFI[****] on all installations ≤ 20A *Germany: RCD on all sockets* *USA: RCD for garages*

It is currently an ongoing discussion whether the different boundary conditions will cause problems with choosing one common plug for Europe.

[§§§] RCD (residual current device): a mechanical switching device designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions
[****] HFI/HPFI is the Danish name for RCD. H = highly sensitive (højfølsom), P = pulse (pulserende), F = fault (fejl), I = current (strøm)

7 ELECTRICAL MOTORS

Combustion engines have been used in cars for a long time and produced in very large series. Despite of this there are many motor designs – there still is no single optimal solution for all purposes. The same applies when talking about electrical motors for EVs.

The simplest form of electric motors is the brushed DC motor. Historically DC motors have been used as traction motors, but as power electronics and controller technology have improved other types of electrical motors are often preferred in EV designs – DC brushless and AC induction motors being the two most obvious options.

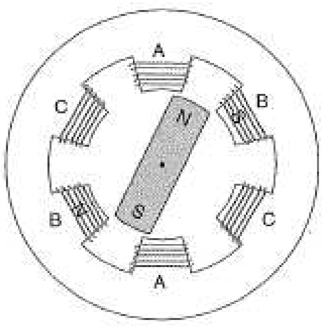

Figure 20. Illustration of DC brushless motor

The DC brushless motor[††††] is in fact an AC motor, as the current through it alternates. It is called brushless DC motor because the AC current must be variable frequency and hence must come from a DC source. The speed and torque characteristics are also very similar to the brushed DC motor.

[††††] Brushless DC motors are often given other names by manufacturers; e.g. self-synchronous AC motor, variable frequency synchronous motor, permanent magnet synchronous motor and electronically commuted motor.

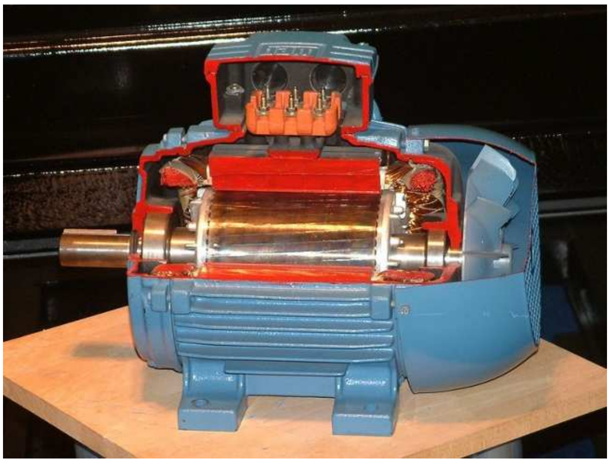

Figure 21. Illustration of AC induction motor[39]

AC induction motors can be coupled directly to the AC mains, which is not the case of DC brushless motors which produces no torque when connected to fixed frequency power. This has been one of the advantages of AC induction motors for use in industry applications (constant speed machines), thus this motor type exists in big numbers on the market. But as a motor in electric vehicles the AC induction motor will also need a controllable inverter because the battery supplies DC and the vehicle needs to be able to adjust the speed (motor rpm is directly connected AC frequency).

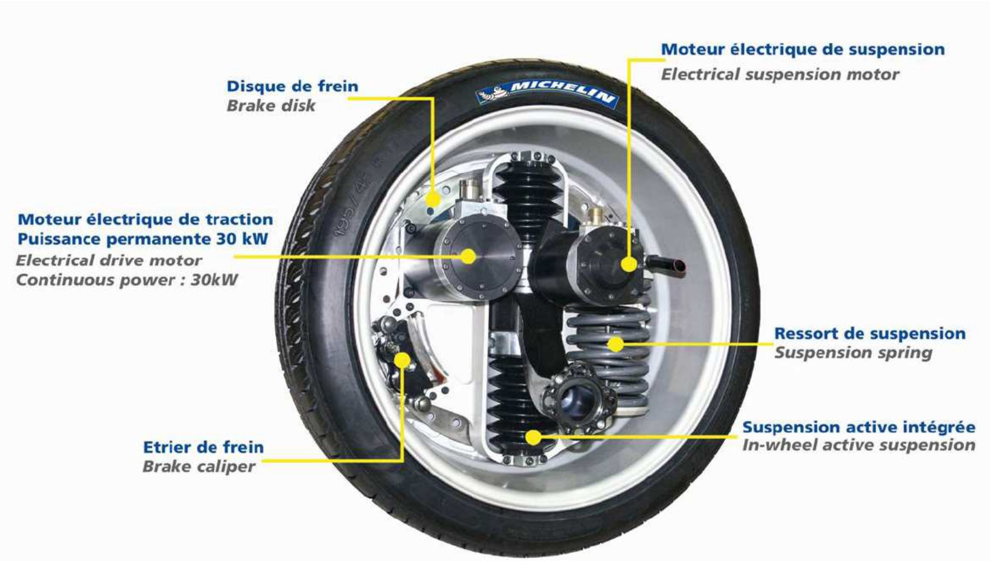

Figure 22. In-wheel electrical motor from Michelin [40]

Several manufacturers have shown interest in integrating the electrical motor in the wheels which would give several advantages in terms of design flexibility. In-wheel motors are typically of the brushless DC type with multiple poles, since their location requires a short length but allows a wide diameter. There is however one big difference between in-wheel brushless DC motors and those illustrated in Figure 20; they are usually turned inside out.

8 COMMUNICATION INTERFACE

8.1 WHICH STANDARDS ARE UNDER DEVELOPMENT

IEC 61850 is an existing standard for "Communication networks and systems in substations". Any additional standards should be well aligned with this standard.

ISO and IEC have set up a joint working group to work on the V2G communication standard. The standard will be named ISO WD 15118 V2G CI Vehicle to Grid Communication Interface.

8.2 WHAT NEEDS TO BE COMMUNICATED

There are several possible layers of the communication. The final protocols will be very dependent on the EV market design[‡‡‡‡]. The essential question is whether;

A. the charging optimisation will be done by a computer system in the EV or if

B. it will be done by an external fleet operator (also referred to as a virtual power plant operator).

These two different scenarios can lead to a need for different communication protocols. Below are some examples of what needs to be communicated for the different scenarios:

[‡‡‡‡] This topic will be elaborated in other EDISON reports.

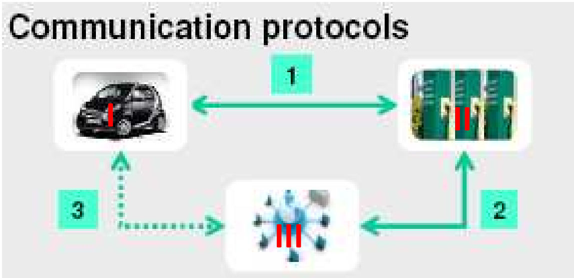

Figure 23. Communication concept from Eurelectric presentation

1. Communication between EV and charging post (TCP/IP eg. dedicate pins or power line communication)
    a. Safety – ensure ground connection and plug present
    b. Charge post maximal power capability – avoid over loading of the installation fuse and avoid over loading of components further up in the system (from charging post to EV)
    c. EV identification – for payment purpose (information forwarded to clearing house)
    d. (Only scenario A) Current price per kWh

2. Communication between charging post and clearing house
    a. EV identification together with X kWh for X DKK (from charging post to clearing house – may be sent in bulk with time delay)
    b. (Only scenario A) Continuously send current price per kWh (from clearing house to charging post)

3. Communication between EV and fleet operator
    a. (Only scenario B) EV battery status and requirements for charging (from EV to fleet operator, 1+2 or 3)
    b. (Only scenario B) Start, stop and power signals (from fleet operator to EV, 2+1 or 3)

The Danish TSO Energinet.dk is currently working on a business to business data hub. The main purpose of the data hub is to manage all transactions and communication between power market actors. As an additional feature, the hub is envisaged to assist identification of EV users at publicly available charge spots. This is intended to allow joint billing of EV consumption and household consumption.

APPENDIX 1 – STATUS ON EV PRODUCTION

International car shows are good indicators on what the development departments of the car manufacturers are working on. There has been a clear tendency that the numbers of EVs and PHEV at these shows have increased a lot during the last few years.

Several EV advocate organizations follow the development of new models. Below are some examples of such web sites with an overview of expected EV models:
http://www.danskelbilkomite.dk/Elbil_salg.htm (Danish)
http://www.danskelbilalliance.dk/Facts/Status.aspx (Danish)
http://www.greenhighway.nu/index.php/el-a-gasbilsguider (English and Swedish)
http://www.pluginamerica.org/plug-in-vehicle-tracker.html
http://evworld.com/guides/battery.cfm
http://www.evcanada.org/evtoday.aspx

APPENDIX 2 - STATUS ON STANDARDISATION WORK RELATED TO EV INFRASTRUCTURE

Status 26. March 2010

WORKING GROUPS	STANDARD	VERSION	STAGE	EXPECTED PUBLICATION DATE
IEC 61851 Electric vehicles conductive charging system				
TC69 WG4	IEC 61851-1 Part 1: General requirements	Ed.2	Comments received in CDV, now preparing for FDIS	September 2010
TC69 WG4	IEC 61851-21 Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply	Ed.2	CD expected July 2010	March 2012
TC69 WG4	IEC 61851-22 Part 22: AC electric vehicle charging station	Ed.2	CD expected July 2010	March 2012
TC69 WG4	IEC 61851-23 Part 23: DC Electric vehicle charging station	Ed.2	New working item proposal, voting dead line, 9. April 2010	To be decided if new working item proposal is accepted
IEC 62196 Plugs, socket-outlets, vehicle couplers and vehicle inlets – Conductive charging of electric vehicles[§§§§]				
IEC SC23h	IEC 62196-1 Part 1: Charging of electric vehicles up to 250 A AC and 400 A DC	Ed.2	Currently in CD, commenting deadline was 19. March	December 2011
IEC SC23h	IEC 62196-2 Part 2: Dimensional interchangeability requirements for pin and contact-tube vehicle couplers	Ed.1	Currently in CD, commenting deadline was 19. March	December 2010
ISO WD 15118 V2G CI Vehicle to Grid Communication Interface[*****]				
ISO/IEC JWG	Part 1: Definitions and use-case	Ed.1		Not defined yet
ISO/IEC JWG	Part 2: Sequence diagrams and communication layers	Ed.1		Not defined yet

[§§§§] Society of Automotive Engineers (SAE) have made their own standard for North America: SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler

[*****] Working groups for Part 3 Protocols, Part 4 Physical layer and Part 5 Safety has also been established. There is however no official "New work item proposal" for these parts yet.

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