THESIS

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Unified Electric Vehicle (EV) main battery architecture, utilizing standardized hot-swappable modules of specialized capabilities

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1. INTRODUCTION

1.1. The importance of the topic

Electric powered vehicles gained a rapid widespread adoption in the past 3 decade, driven by the need for sustainable, more efficient, and less polluting means of transport. This is nothing but a revolution - sky rocketing sales figures fueled by many countries change in transport policies, in a bid to meet the strict deadlines for carbon neutrality as dictated by the 2019 Paris accords. The market demand for EVs, being a rich substrate for many new manufacturers and design houses to join the big giants such as GM, Toyota and VAG, building a wide variety of vehicles to suit different segments and demands.

Current EVs boast very impressive performance and range figures, featuring ever growing battery packs that aim to satisfy not only increased power demand, but first and foremost extended range, which is the biggest bottleneck of EV propulsion. In practical terms this means a very expensive, sophisticated and heavy battery pack to be installed in increasing amount of newly delivered vehicles. This trend is foreseen to continue and even increase in years to come, as more ICE vehicles are planned to be phased out.

Widespread acceptance of Li-Ion technology for EV propulsion as well as use in Digital devices and Stationary energy storage leads to severe over-mining and concerns of scarcity of nickel, cobalt and other battery consisting materials in the long-term. Better utilization of these and other resources, by properly designing and allocating battery packs to their intended use is needed. Increase in Li-Ion battery size packs more lithium and lithium organic electrolyte into EVs. These already proved to be a major fire safety hazard, in the complete vehicle life cycle. Major EV fires reported involving leading edge vehicle manufacturers, such as Tesla. Occurring both in casual vehicle use, as well as collision initiated. Fires and thermal runaways during servicing are also reported albeit less common.

Even the best modern packs have a duty life of 5-10 years at most (depending on charge-discharge cycle rate and environmental conditions). Battery capacity decrease over time and tendency for battery pack individual modules to fail are just some of the common signs of a battery pack close to the end of its useful life. In many cases a depleted battery life has a heavy repair bill attached to it, leading to many perfectly useable vehicles to reach their end of useful life prematurely, as repair is not an economically viable option. What happens when the battery pack or vehicle reaches its end useable life? Commonly the battery pack is broken down to its constituting elements, with some components actually being recycled. But generally speaking – most of the constituting material by weight is not easily repurpose-able.

To allow modern EVs to be more competitive and feature higher energy capacity, manufacturers are utilizing every bit of space available in the vehicle frame and body. This leads to bespoke designs that cannot be interchanged between different models of different manufacturers, and even between varying generations of the same model. This is a major setback and a limiting factor when it comes to repurposing/repair of battery packs in the aftermarket services. Proprietary designs and higher sophistication of the battery packs drive the ability to service both vehicles and packs away from the realms of the DIY mechanics and traditional automotive workshops alike, necessitating retraining and retooling to be able to work and repair these vehicles. The bulkiness of the pack, in many cases weighing half a ton, logically calls for the repair to be carried out locally, but scarcity in certified professionals leads to costly transportation, with many battery packs considered "OEM serviceable only".

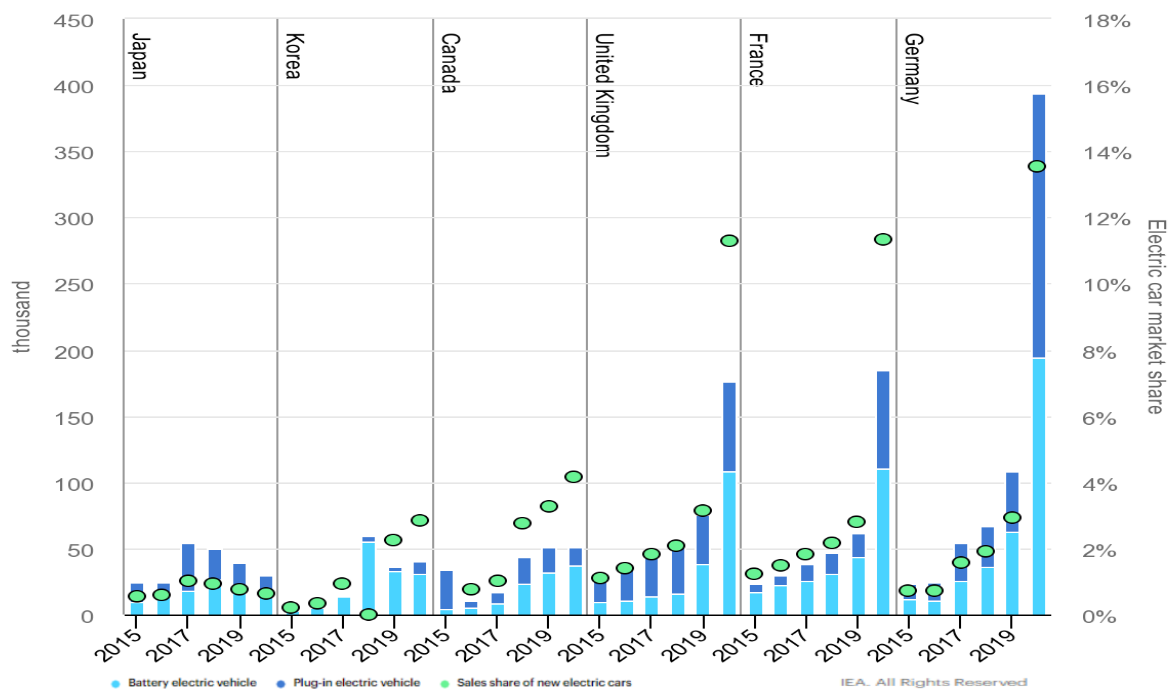


Fig. 1 - Global EV vehicle sales in main markets. (IEA)

1.2. The aim of research

The aim of this paper is to research and collect information from the mentioned methods, and to produce a workable unified architecture design for EV main battery, that will address current and emerging trends in E-mobility, allow for interchangeability, scalability and upgradability. Furthermore, it must be at least comparable if not superior in terms of safety and serviceability. The results of this examination will enable willing manufactures to adopt the suggested architecture for their vehicles and compatible applications, while in parallel – lead to the creation of a competitive aftermarket sector that will both manufacture, recycle and service the units. For the experiments, a CAD model of the complete system will be made and analysed in conjunction to other common designs and applications, by market leading suppliers, including TESLA and BMW. The new design will be compared and thoroughly analysed to determine its suitability for the automotive sector and applications. To achieve the mentioned goals, the following steps must be taken:

- Research the current state of the art EV vehicle and battery designs on major automotive brands.
- Research the current and foreseen trends in automotive propulsion, battery technology.
- Research typical EV use profiles.
- Concepts and main ideas will be considered towards the proposed design.
- Specification will be set for an automotive compatible unitary module and system architecture.
- A unified system will be designed.
- The proposed system will be analysed and compared to the current state of the art system architecture, in a qualitative and quantitative way.

The fruits of this research can be used as a set of guidelines for mass production and adoption of such technology in the general automotive market and in the personal mobility segment, particularly.

2. LITERATURE REVIEW AND BACKGROUND INFORMATION: EV VEHICLE AND BATTERY ARCHITECTURE

EV technology is more than 100 years old, as it predated Internal combustion powered vehicles. In the early 1900s, these were popular for their main benefits of reliability and low maintenance. Modern EVs keep these main characteristics but evolved greatly in terms of power, range and sophistication. The main enabling technology is battery chemistry, design, size and management – most modern vehicles are based around thousands of closely packed Li-Ion cells, currently these provide the best power-to-weight ratio and are very reliable. In order to pack as many of these cells, manufacturers resorted to innovative approaches, including battery-in-frame approach. These driving factors led to modern EVs battery packs being increasingly model specific and hard to service and repair, additionally there is no accommodation for upgrade if superior technology is becoming available.

Fig. 2 – 1909 Baker Electric, one of the first successful EVs. (NY Times)

In order to have a prefund market and technological knowledge base when it comes to redesign the battery packs on EVs, according to current and future trends, first we will review the current and future state of the art approaches in the vehicles themselves as well as the battery pack technology.

2.1. Electric Vehicles

Electric Vehicles is a broad definition for any vehicle which include an electric propulsion mechanism, these include both personal and commercial vehicles, as well as all sort of hybrid manifestations. Electrical energy can be supplied from external sources (such as a trolleybus) or internally – Battery, Solar, Fuel cells or ICE driven generators. All these vehicles share the same basic components and rely on some sort of Electric motor to convert the electric energy to rotational motion, propelling the vehicle, that otherwise share similar characteristics as a fossil fuel burning counterpart.

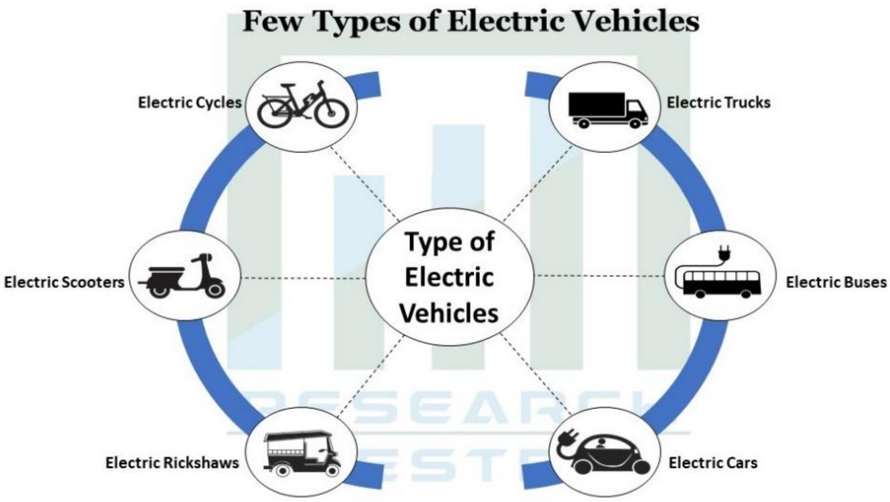


Fig. 3 – Broad range of EVs. (Research Nester)

Electric propulsion has been around since the mid-19th century, existing from the dawn of electricity, and provides a very simple, reliable and efficient propulsion method. As ICE powered vehicles became more widespread, driven by cheap fuel prices, better performance and much longer ranges, EV sales plummeted. It was only in the last three decades, as the consensus about the impacts of fossil fuels pollution, its adverse global effects, as well as climate changing potential, became clear - there was a renaissance in the application of e-motion in transport.

The majority of EV propulsion structure and design is standardized, with many common components shared between platforms – motors, motor drivers and controllers, battery cells. Industrial (Stationary), commercial transport (trains, busses), and small scale applications(E-Bikes) usually use these off the shelf components. In the Personal vehicles this trend is not followed, with many manufacturers use their own proprietary architectures.

2.1.1. EV characteristics

Electric vehicle propulsion has expended greatly and is a leading option for almost all vehicle types, sizes and applications, these vehicles differ between each other in many parameters, but mainly can be divided into these groups:

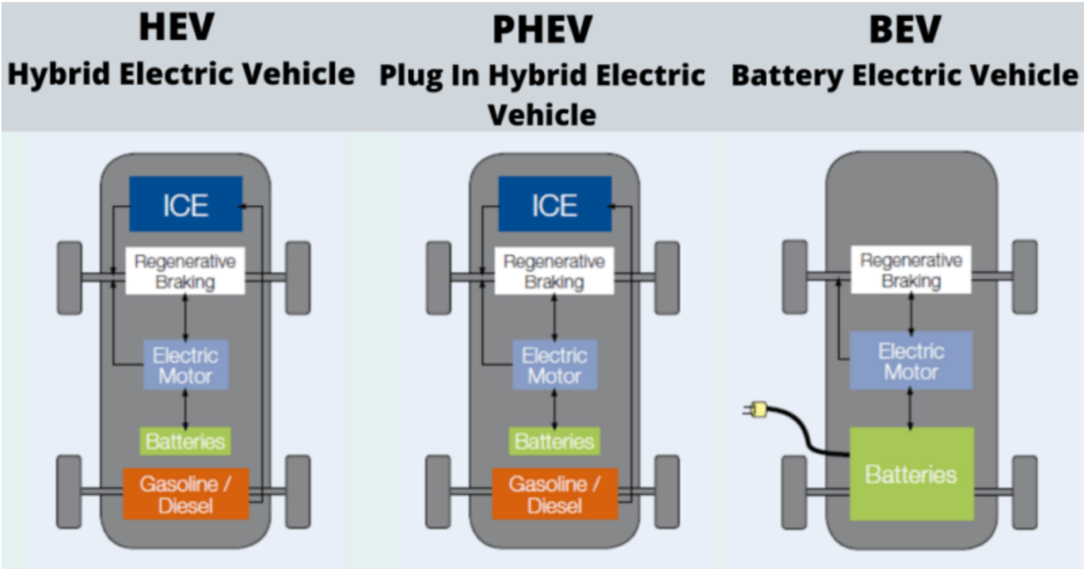


Fig. 4 – topology of common EV types. (AAR GO)

- Vehicle Size and types – various common sizes Sub compact, compact, family car, trucks, executive saloons, as well as more innovative streamlined and 3-wheel shapes.
- Topography –
    - Battery (BEV) – Utilizing on-board battery pack only, to provide the E-energy to power the E-motor. Braking energy is regenerated via the E-Motor to recharge the battery. Can be charged from the power grip.
    - Hybrid (HEV) – Vehicle that utilize an on-board battery pack, that is either used solely as source of energy (E-Mode), or in conjunction with a conventional ICE engine, that either recharges the battery pack, powers the E-motor directly or driving through a conventional mechanical drivetrain separately from the E-drive system. Regenerative breaking is also enabled. Some earlier vehicles did not allow for charging of the battery from the grid.
    - Plug in hybrid (PHEV) – combining both HEV and BEV into one, by enabling recharging from the grid, reducing the need for the ICE to function, proving the ability to drive on E-power only.
- Motor type – Single or multiple axle motors, In-Wheel motors.

- Range – From 40-50km for HEVs\PHEVs to 500+ kms for latest BEVs.
- Type of battery pack and battery technology – Ni-MH, Li-Ion, and others.
- Charging technology/Battery swap – with Fast charging, high current DC/AC charging circuits, battery swap technologies became rare.
- Performance – light to heavy duty and sport vehicles. 6kW (Citroen Ami) -1500kW (Lotus Evija). Fig. 5.
- Other future-proof features as Autopilot and AI assist technologies.

Fig 5 – One of the smallest EVs – Citroen Ami, to the most powerful – Lotus Evija.

The main variable between these vehicles is the amount of battery storage required to meet its design specifications, leading to the inclusion of larger and more involved battery packs designs. The size of the battery in many cases drives the size of the vehicle and vice-versa, as a heavier vehicle need more energy storage to maintain the same range goal. By maintaining a very aerodynamic and light vehicle, the battery pack can be kept to a minimal size and thus easier to integrate into the vehicle structure.

Another emerging trend is ditching the common layout of ICEs, and adopting a more standardized modular frames, that used near-wheel or in-wheel motors, saving a lot of space in the vehicle cabin for passengers and luggage, while simplifying the battery integration.

2.1.2. EV battery integration

The traction battery pack is one of the biggest variables driving the resulting characteristics of the vehicle. Therefore, EV manufacturers aim to increase energy volumetric efficiency while keeping vehicle overall weight as low as possible, leading to innovative approaches in the way the battery pack is formed.

Traditionally, albeit now defunct, the "battery packs" consisted of a set of lead-acid deep cycle batteries, (Fig. 6) each weighing around 30kg, mounted in the vehicle frame. Each battery could have been serviced and replaced individually, with common tools and training.

Fig. 6 - 1970 Legrand EV – Battery pack, Deep-cycle lead batteries. (Carscoops)

As lead-acid technology was phased out in the late 90's as means of traction battery, replaced by Ni-MH and eventually Li-Ion battery cells, stacked together and interconnected in series and parallel, forming modules. These modules comprised of dozens if not hundreds of cells, interconnected to provide the final module voltage and output current. For example, Tesla Model 3 – 74kWh long range battery consists of 4416 batteries, assembled into 96 groups of 46 batteries each. All packed into a common casing in 4 large internal modules.

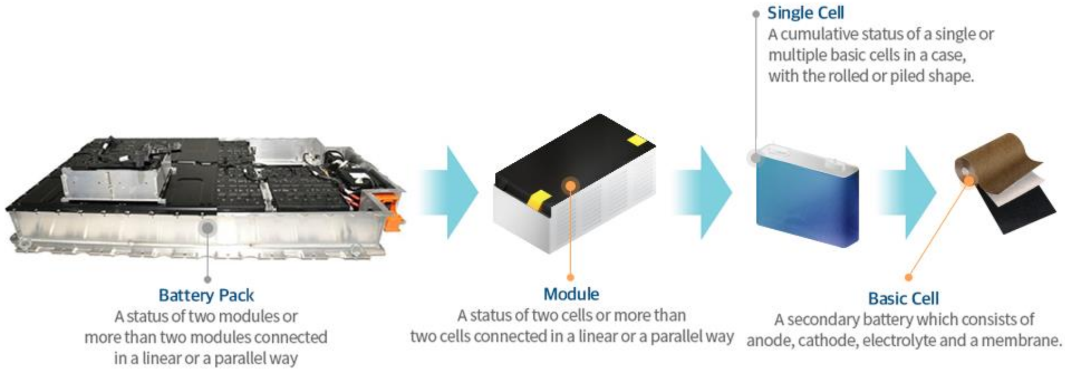


Fig 7. – Modern battery pack architecture – cells-modules-pack (SamsungSDI,2016)

Most modern battery packs are based around a sturdy frame, mounting provisions for the individual modules, means of environmental control – heating-cooling (Air or Liquid), electrical interconnections between the modules, Motion and current sensitive Fuses and most important – Battery Management System (BMS).

BMS – is a functional element, consisting of a microprocessor and high-power control circuit, that provides monitoring, management and protection to the battery and its cells. By maintaining the battery cells in their optimal conditions during operation, throttling - shutting down in case of excessive current draw, under-voltage or excessive temperature. In most batteries it controls the charging and battery cells balancing.

The newest approach is the so-called structural battery or battery in chassis approach, led by the likes of Tesla and CATL. In this design the individual battery cells are installed in cavities specially dedicated in the frame of the vehicle. Thus, reducing the necessity for the secondary layer of the battery pack and the corresponding brackets and mounting hardware.

Structural batteries have some major drawbacks, such as being model specific, along with major concerns regarding serviceability and safety. Proponents of this approach state that improvements in Li-Ion cell manufacturing and BMS controllers lead to improved reliability of the whole battery pack, reducing the need for battery maintenance. Safety concern circle around chassis deformation from collision damage, being transmitted to the battery cells, potentially bursting them and igniting the lithium or electrolyte.

Fig. 8 – Structural battery pack. (CATL,2021)

2.1.3. Future trends in EV tech

The EV market is very dynamic, with both governmental and private sector pushing for cutting edge technologies, refinement and reduction in costs. There are several dominant vectors:

1. Reduction in electricity consumption kW/km:
    a. reducing the drag coefficient, with more streamlined designs. Such as the Lightyear One/Zero, Mercedes Vision EQS
    b. reducing rolling resistance, 3 wheeled vehicles (Aptera)
    c. More efficient drivetrains – utilizing in-Wheel motors, less rotating mass, etc. (Lightyear One)

Fig. 9 - left - Aptera, Right – Vision EQS - high efficiency EV cars. (Aptera, Daimler)

2. Reduction in grid dependency - Integration of more efficient solar cells, to supplement or replace charging from the grid. Aptera-Lightyear vehicles.

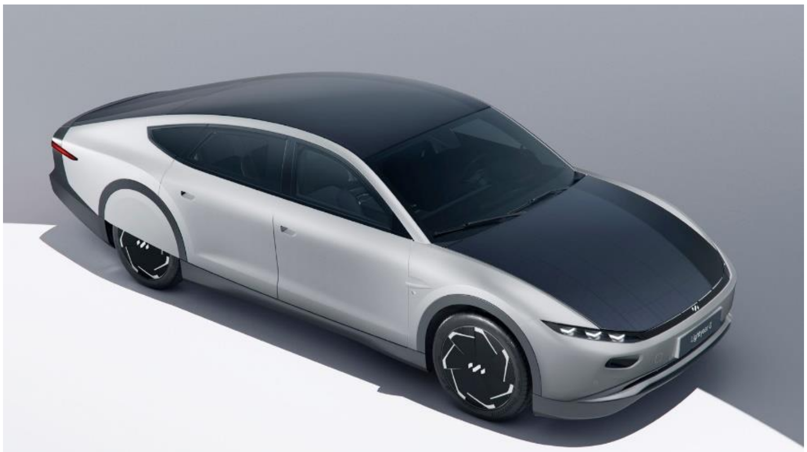


Fig. 10 – Lightyear One – Solar assisted charging. (Lightyear)

3. Electric common chassis approach – Using a common chassis with suspension unit-motors on the 4 corners, with variable bodies mounted on the chassis according to model and application. REE EV platform

Fig. 11 - REE EV platform. (REE, 2020)

4. V2G readiness – Many future EVs will allow for reversed charging, pushing power from the traction battery back to the grid, as a distributed energy buffers (Virtual power plant) or as an emergency power source.

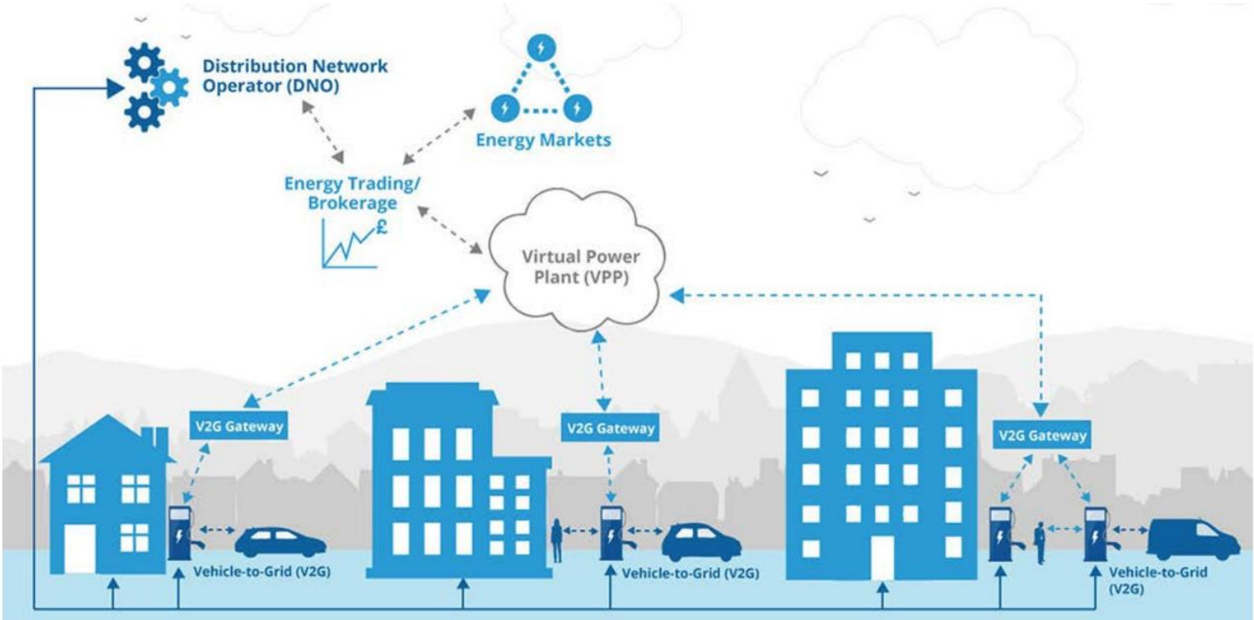


Fig. 12 – Vehicle to Grid (V2G) system architecture(GreenBiz, 2022)

2.1.4. Ecological impact and future concerns

It is widely accepted that EVs have major benefits over ICEs, enabling better control on polluting emissions distribution and in many user profiles major reduction in pollution. EVs are mechanically simpler, reducing maintenance frequency and complexity, amounts of replacement parts, drivetrain lubricants and brake linings - EVs are typically heavier and could produce more tire, brake, and road dust air pollution, but their use of regenerative braking greatly reduces particulate pollution and energy consumption.

Electric motors are significantly more efficient than internal combustion engines, even when accounting for E energy production and transmission losses – less energy is involved in the operation of these vehicles. For comparison, on average 38 megajoules per 100 km for EVs versus 142 megajoules per 100 km for ICE cars.

That said, the premise of Zero Emissions is telling a false narrative that ignores the emissions related to the manufacturing of the vehicle and battery, their end-of-life treatment procedure and obviously charging using electricity produced with a fossil fuel driven method. While the consensus that EVs provide a reduction in CO_2 emissions compared to ICE vehicles, these adverse effects must be considered.

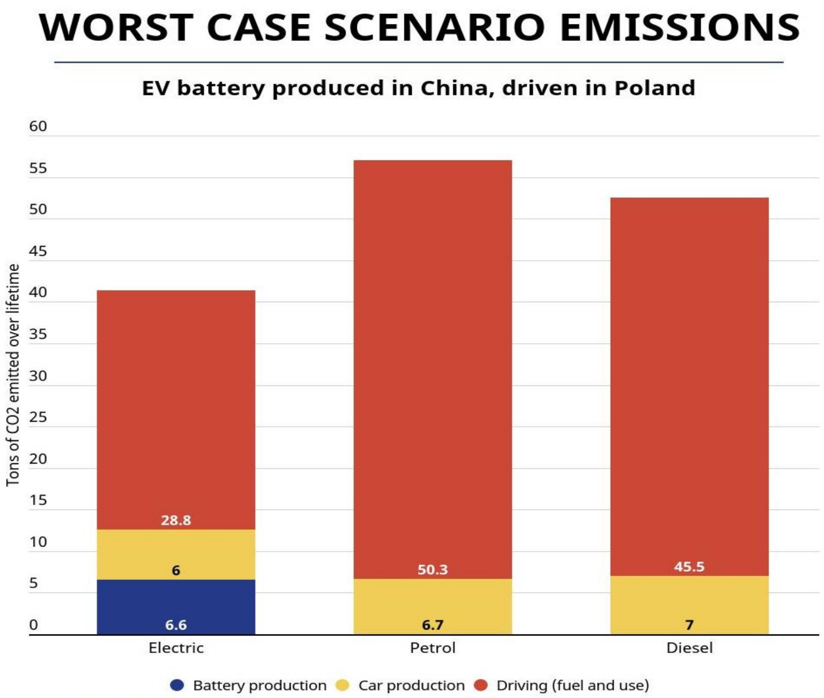


Fig 13 – worst case scenario comparison between electric and ICE. (CGTN)

Analyzing the past decades adoption of EVs reveals several concerns regarding their negative impacts, these include adverse effects from Battery manufacturing, vehicle manufacturing, and End-Of-Life related procedures.

EVs designs are much simpler, and in many cases easier to manufacture, with less components and at its heart based around a simple electric motor (or motors). In some cases where the motor is of a permanent magnet type, it requires the use of rare earth magnets that in turn necessitating extensive mining.

The biggest concern comes from EV battery manufacturing, a resources intense process involving large amounts of raw materials and energy. Therefore, in order to improve on the environmental footprint, one must deal with this production phase. Mining processes for the raw materials-metals, such as lithium, are a latent polluting factor that only increases in the past decades following the increase in production of these vehicles.

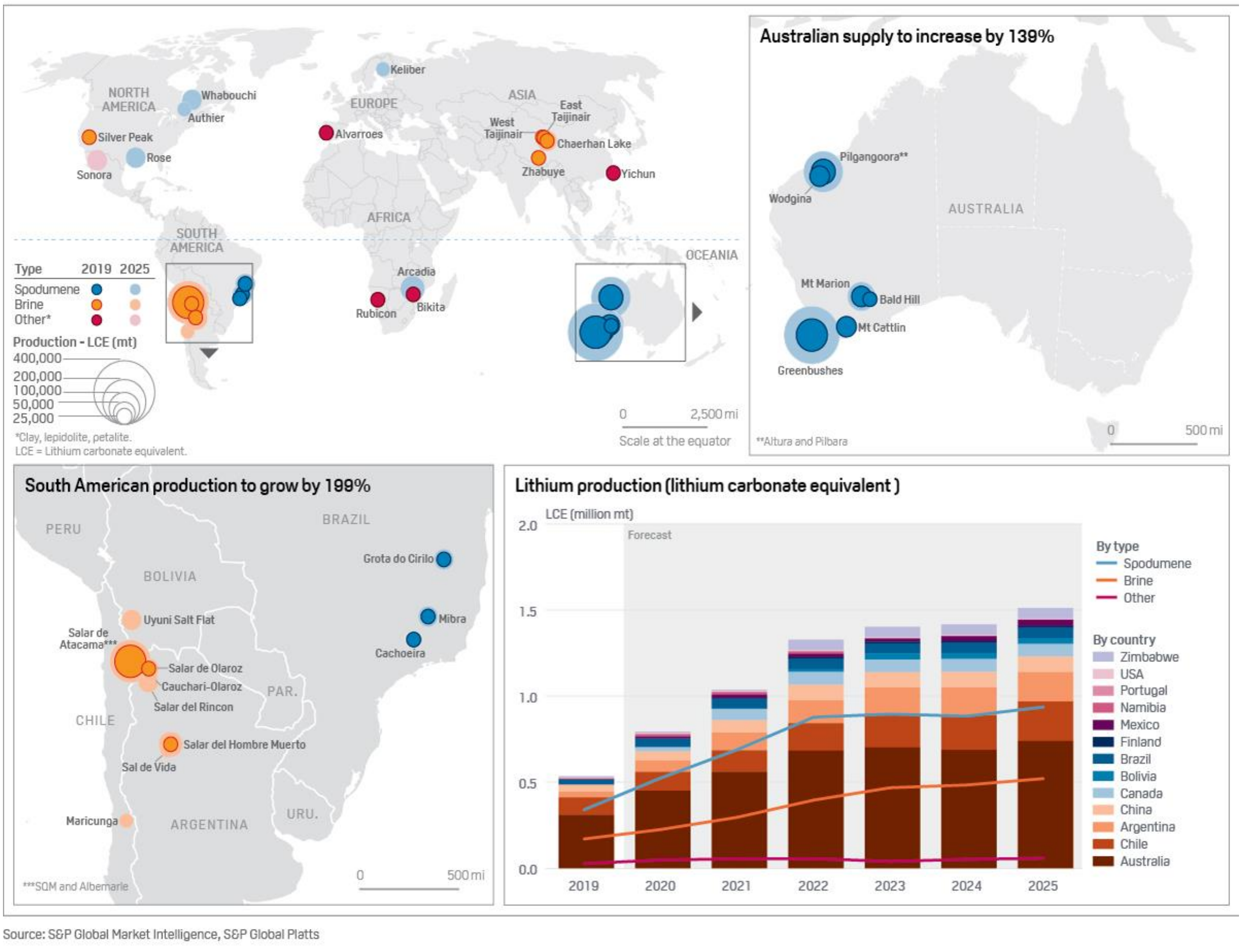


Fig. 14 – Lithium mining global report and forecast for 2025 (S&P global, 2022)

On the Global scale, deposits of lithium are concentrated in China and throughout the Andes Mountain chain in South America, Bolivia being especially rich with 5.4M tons, half of the worlds known reserves. In 2008 Chile lead lithium metal production with 30% of the global market, followed by China, Argentina, and Australia. Lithium is recovered from either spodumene hard-rock deposits by excavation or from brine, such as in evaporation pools in Nevada and Cornwall, and is much more environmentally friendly. Other concerns relate to ethical conduct impacting the local ecosystems and communities involved in lithium mining.

Producing lithium-ion batteries for electric vehicles is more material-intensive than producing traditional combustion engines, with Li-Ion hard rock mining, for every 1 ton of lithium, 15 ton CO2 is emitted. For example, Tesla Model 3 has 75kWh lithium-ion battery. Costing between 2.4 to 16 tons of CO2 emissions through mining and manufacturing. a 6.62% reduction in total GHG emissions can be achieved with the use of remanufacturing.

Since Lithium supply is a finite resource, in order to balance the lithium supply and demand for the rest of the century, a widespread adoption of good recycling systems, vehicle-to-grid integration, and lower lithium intake ratio per vehicle are needed. Currently, Recycling of Li-Ion batteries remains in its infancy and much remains to be done to improve the efficiency and comprehensiveness of the process to reinstate more of the raw materials.

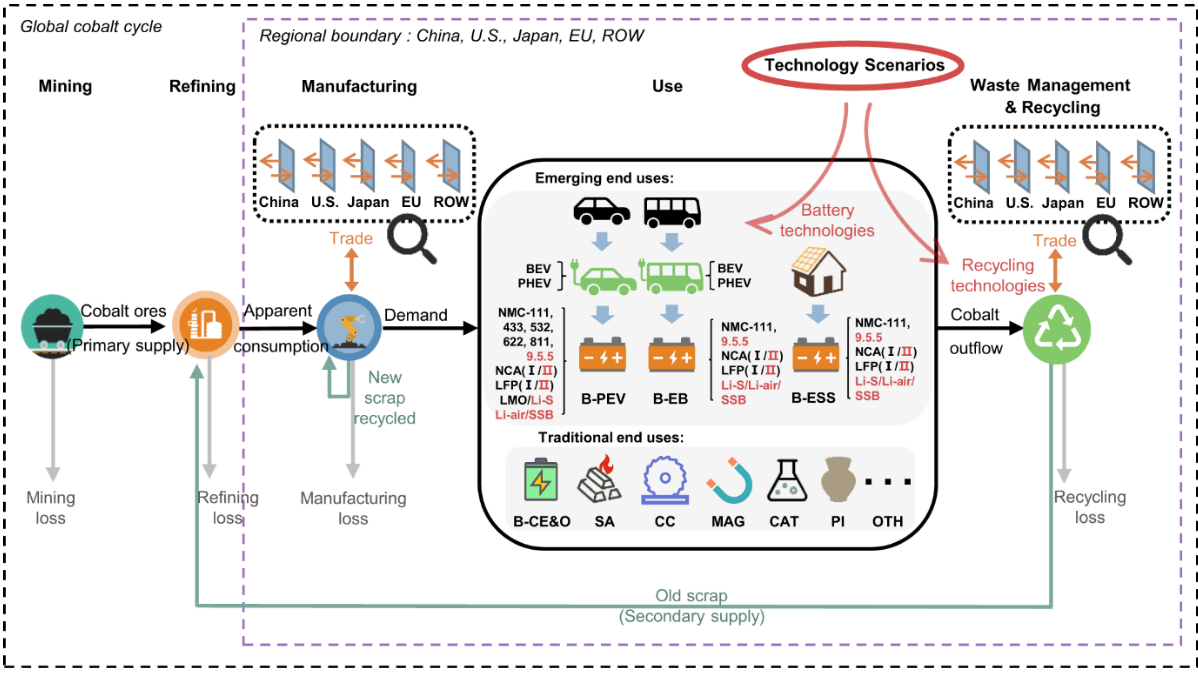


Fig. 15 – Comprehensive Life-cycle overview of battery cells. (Nature Communications)

2.2. Electric energy storage and generation technologies

EV battery technology has come a long way since the days of wet plate, lead-acid, based batteries, with modern state of the art designs using Li-Ion and Li-Po cells across the board. As mentioned before, thousands of cells, of the same type and rating are interconnected to form a Battery pack. While electrochemical cells are the obvious way to store and deliver electric power, other methods exist and considering the limiting factors for common battery chemistry, such as energy density and finite charge cycles, more research and development is pointed towards hybrid designs including other electric storage solution as super capacitors and Fuel cells.

Each one of these technologies have vastly different characteristics, when combined intelligently can produce a system with value from the strengths each.

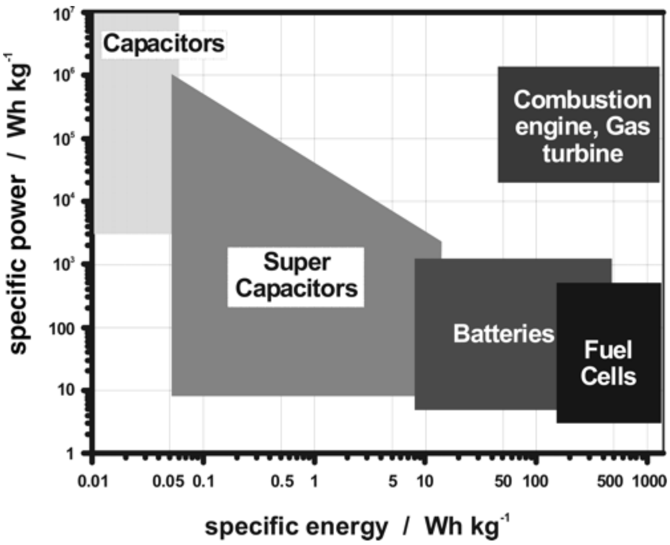


Fig. 16 – Comparison between energy storage technologies (MDPI)

Electrochemical cells provide the best all-around source of energy being energy dense, all the while being rechargeable, self-contained, featuring low self-discharge. Fuel cell technology is nothing new but with Hydrogen storage and supply solutions still not widespread, limiting its useful alternative.

The latest trend is combination of super capacitors in battery packs and as a sole energy storage solution. These have a much higher energy density compared to regular capacitors, are lighter then battery cells, and feature very high energy discharge capability, to support high power drive trains.

2.2.1. Battery cells.

Battery Cell, or electrochemical cell, is a device that can produce electrical energy from a chemical reaction of reactive materials housed inside the cell. These include a cathode and anode, negative and positive electrodes, respectively and an electrolyte. When charged the Anode is oxidized, emitting electrons and the Cathode get reduced, collecting electrons. Cells differentiate into two types, primary and secondary, with the major variance in rechargeability. When primary cell's chemical reaction reaches equilibrium, it cannot be reversed, and the cell cannot be recharged without dismantling it.

Cells can be of various chemical composition, with the most commonly used type is Li-Ion(Lithium Cobalt), but some vehicles use NiMH and Li-FePo4. For the most part, cells are of standardized sizes and form factors – cylindrical cell, prismatic cell, pouch cell. These are indicated in the cell name. ex. INR21700 is a 21x70 Li-Ion cell, found on many EV traction battery packs.

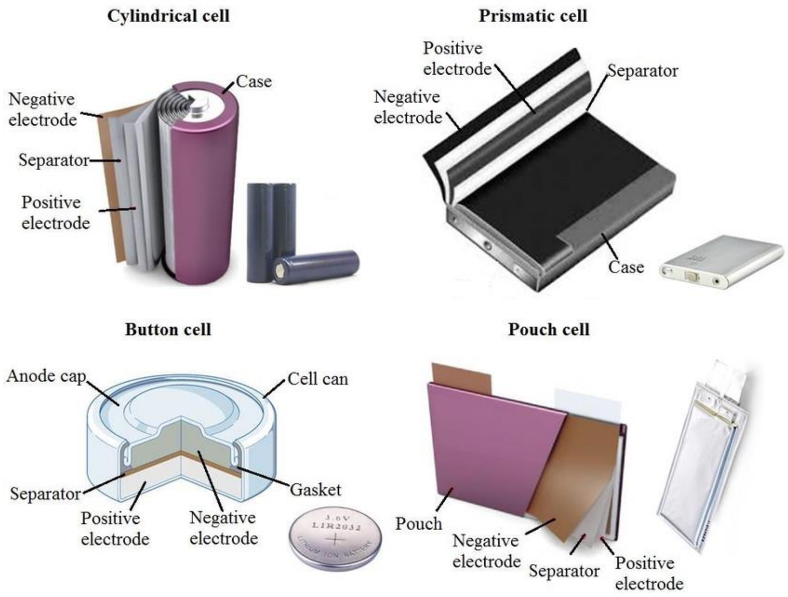


Fig. 17 – Common battery cell designs (Kirill Murashko)

Ultimately the battery cell chemistry dictated all of the operational characteristics, that's the reason for abandoning Lead-Acid based wet cells, which are heavy, bulky and prone to leaks as well as degradation from sulfurization of the lead plates, to a modern Nickel based dry cells, such as Ni-Cd and Ni-MH. Dry cells are sealed; thus leakage risks involve the rupture of the outer sheath and are unlikely under normal operating circumstances. They can be mounted in all orientations and easily interconnected into series and parallel modules. The biggest improvement in the shift to Nickel batteries is the higher volumetric and mass energy densities, albeit are more costly.

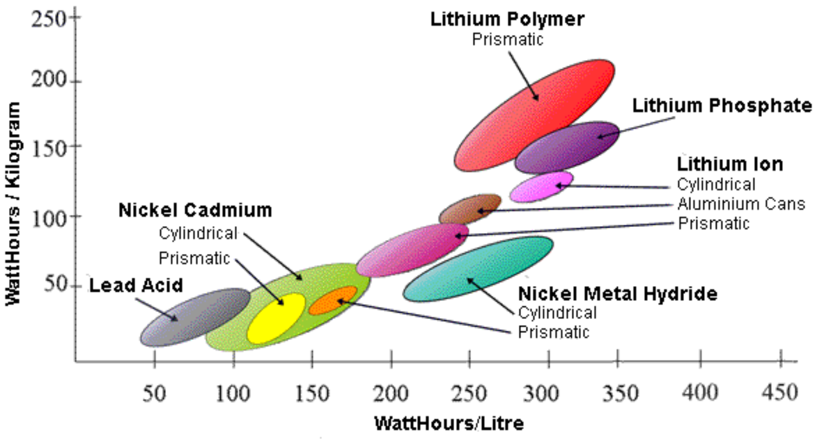


Fig. 18 – Chart comparing battery technology E-energy mass and volume densities. (MDPI)

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

Table 1. – Comparison chart between common battery cell types. (BatteryUniversity 2021)

The latest technology widely adopted is the Lithium chemistry which is much safer than acid based wet batteries, doesn't contain heavy metals as lead or cadmium and has a considerably higher volumetric and mass energy density, enabling the age of long range EVs. These cells are not without problems though, heavy dependency on lithium, as mentioned before and limited recharge cycles and well as a missing recycling infrastructure, to name a few.

Alternatively, there is new interest in Zinc, Carbon, Nickel and Sodium based technologies, which feature lower volumetric densities but feature a more stable chemistry and lower production and raw material costs. These technologies base themselves upon more common and readily available materials to support the large expansion of EVs globally, while accounting for more stable, reliable and safer cells, that will extend the useful life of battery packs and enable faster charging, as demand for longer range is at the Achilles heel of EV adoption. As many manufacturers are push their technology forwards, with various pros and cons to the end consumer, it's not certain that the future of EV energy storage will be based on Lithium technology, alas its important to have that in mind while designing battery packs to accommodate change of technology when it becomes available.

2.2.3. Super capacitors

Supercapacitor, also referred to as an ultracapacitor, is an extremely high-capacitance capacitor, storing 10-100 times more energy than electrolytic capacitors, albeit with lower voltage limits. With applications in the gap between electrolytic capacitors and rechargeable batteries. Supercapacitors are beneficial in case rapid charge/discharge cycle is needed, rather than long-term energy storage. They are also more stable and allow for 100times more charges compared to a Li-Ion battery. Typical applications include automobiles, buses, trains, cranes and elevators - used for energy regeneration, short-term energy storage, or burst power delivery.

Unlike ordinary capacitors, supercapacitors use electrostatic double-layer capacitance or electrochemical pseudo capacitance technique:

Electrostatic double-layer capacitors (EDLCs) use carbon electrodes with much higher electrostatic double-layer capacitance than electrochemical pseudo capacitance, achieving separation of charge in a Helmholtz double layer between the surface of a conductive electrode and an electrolyte.

Electrochemical pseudo capacitors use metal oxide or conducting polymer electrodes with a high amount of electrochemical pseudo capacitance additional to the double-layer capacitance. Pseudo capacitance is achieved by Faradaic electron charge-transfer with redox reactions, intercalation or electro absorption.

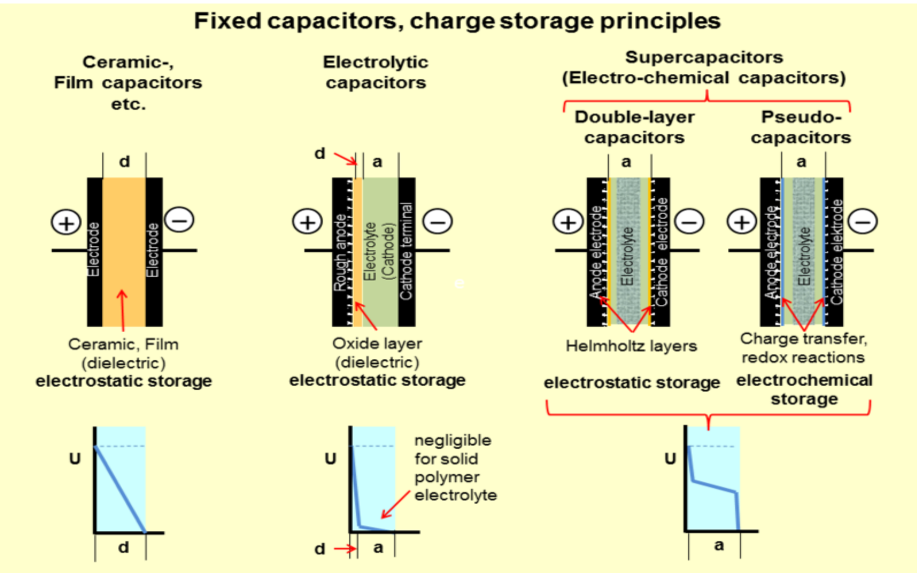


Fig. 19 – Comparison between capacitors and Super capacitors (ELCap, 2012)

Hybrid capacitors, feature electrodes with differing characteristics: one operating on basis of electrostatic capacitance and the other mostly electrochemical capacitance. Contrary to conventional electrolytic capacitors dielectric layers and electrolyte, in hybrid SCs, The electrolyte forms an ionic conductive connection between the two electrodes. Supercapacitors are polarized by design with asymmetric electrodes, or, for symmetric electrodes, by a potential applied during manufacturing.

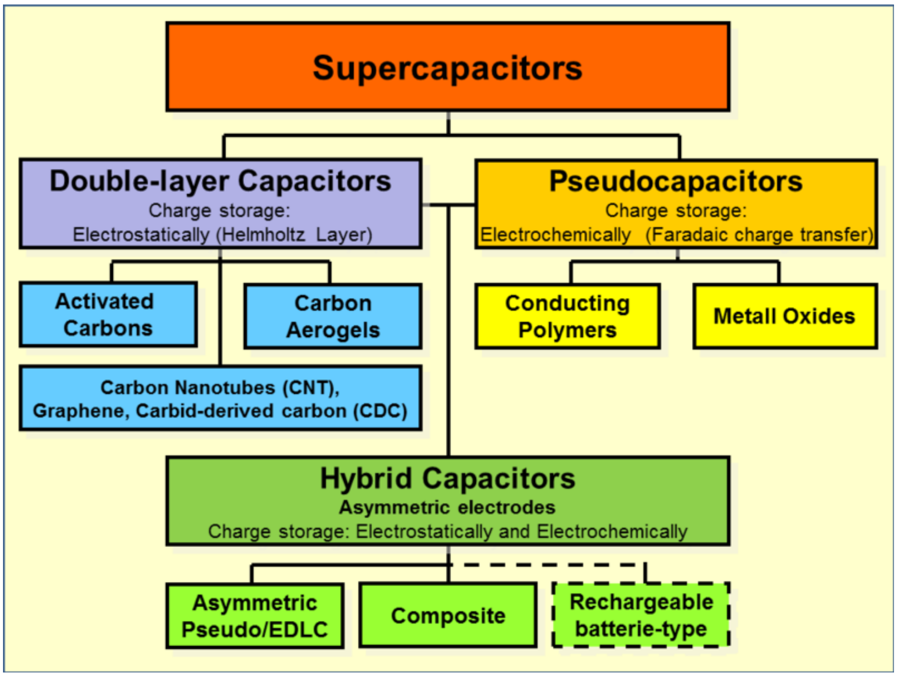


Fig. 20 – Comparison between capacitors and Super capacitors (ELCap, 2012)

2.2.4. Fuel cell

A fuel cell is an electrochemical device converting chemical energy potential from a fuel and an oxidizer into electrical energy through a set of redox reactions. Fuel cells differ from batteries by requiring a continuous supply of fuel and oxygen to sustain the chemical reaction, similar to an engine. Compared to a battery where the chemical energy usually comes from ions or oxides ions included in metals present in the battery sealed structure. Fuel cells will produce electricity continuously as long as fuel and oxidizer are supplied. The first fuel cells were invented in 1838 by Sir William Grove, but it was only after the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932, that the first application was commercially viable. One predominant use of the alkaline fuel cell has been its use in NASA space capsules and satellites since the mid-1960s.

Since then, fuel cells have been used in many other applications – both in stationary applications as primary and backup power supplies, especially in remote or inaccessible areas, as well as mobile platforms - forklifts, automobiles, buses, trains, boats, motorcycles and submarines. Since the first FC vehicle, the 1966 GM Electrovan, it has been considered as a alternative solution to battery power for Electrically powered vehicles. The interest surged following the drive to electrify personal vehciles, albeit battery thecnology couldn’t support the same expected use profile.

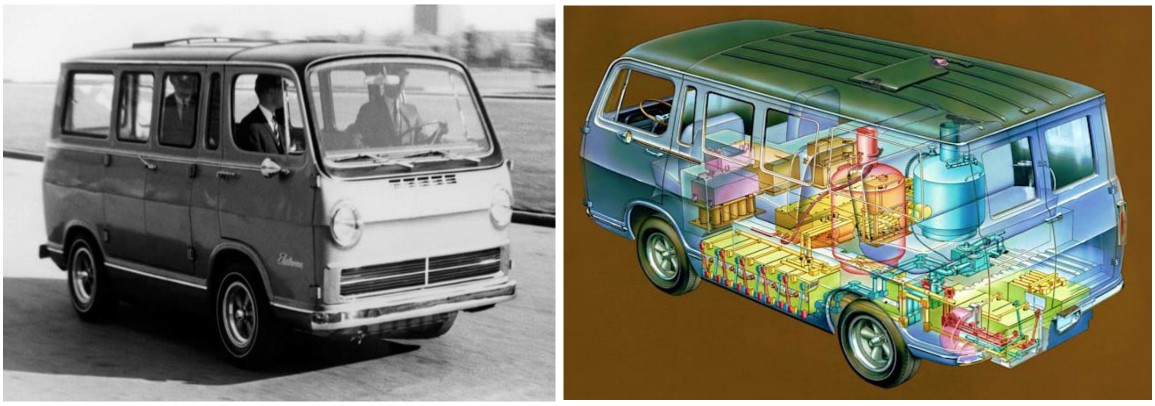


Fig. 21 – GM Electovan, Structural cutout diagram (GM)

Many types of fuel cells exist, all consisting of an anode, a cathode, and an electrolyte that allows ions, positively charged hydrogen ions (protons) in case of a hydrogen fuel cell, to move between the two sides of the fuel cell. At the anode in the presence of a catalyst the fuel undergo oxidation reactions that generate ions (positively charged) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, a different catalyst causes ions, electrons, and oxygen to react, forming water and depending on composition also other products.

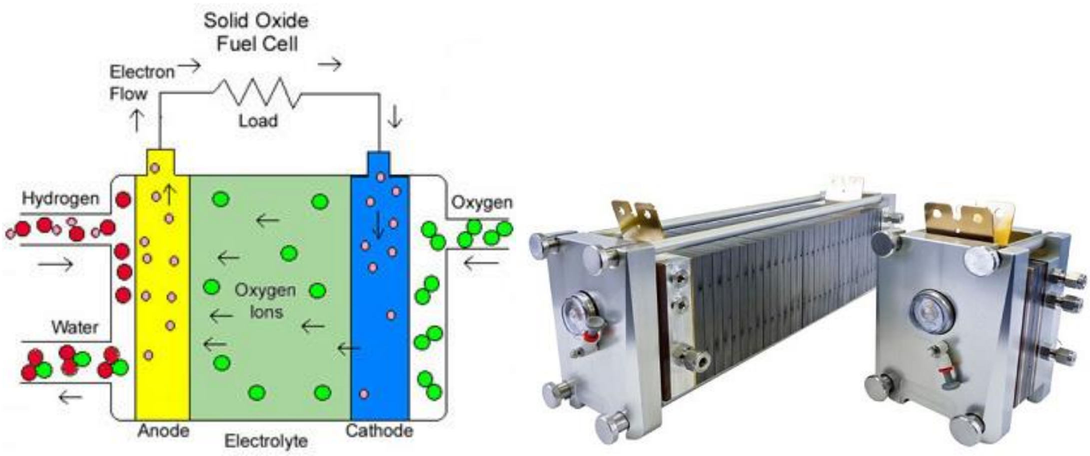


Fig. 22 – Hydrogen Fuel cell structure, modern stack design (FuelCells.com)

Fuel cells are classified by the type of electrolyte they use, most common being Hydrogen Gas, but also Liquid Methanol and Ethanol cells are commercially available. And by the difference in startup time ranging from 1 second for proton-exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). A related technology is flow batteries, in which the fuel can be regenerated by recharging. Each fuel cell produces relatively small electrical potential, about 0.7 volts, it is stacked and serially interconnected to its neighboring cells to create sufficient voltage to meet an application's requirements. Fuel cell reaction by products are water, heat and, depending on the fuel source, very small amounts of other emissions, such as nitrogen dioxide. Typically, the energy efficiency of a fuel cell is between 40 and 60%; however, by capturing the waste heat and diverting it to a useful application, efficiencies of up to 85% can be obtained.

In past two decades many Fuel Cell powered vehicles have been introduced to the market, but with limited refueling infrastructure and technological barriers for the large scale, economical, energetical and environmental production of hydrogen limiting the wide-scale adoption of this technology.

Fuel Cell Type	Polymer Electrolyte Membrane (PEMFC)	Alkaline (AFC)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC)	Solid Oxide (SOFC)
Fuel	H_2	H_2	H_2	H_2/CO/reformate	CO, H_2
Oxidizer	O_2, air	O_2, air	O_2, air	CO_2,O_2, air	O_2, air
Common Electrolyte	Hydrated Polymeric Ion Exchange Membranes	Mobilized or Immobilized Potassium Hydroxide in asbestos matrix	Immobilized Liquid Phosphoric Acid in SiC	Immobilized Liquid Molten Carbonate in $LiAlO_2$	Perovskites (Ceramics)
Operating Temperature	40 – 80 °C	65 – 220 °C	205 °C	650 °C	600 -1000 °C
Typical Stack Size	1kW-250kW	10-100kW	400W	300kW-3MW	1kW-2MW
Efficiency	60% (Transportation) 35% (Stationary)	60%	40%	50-60%	50-60%
Applications	-Backup power -Portable power -Distributed generation -Transportation -Specialty vehicle	-Military -Space	Distributed generation	-Electric utility -Distributed generation	-Auxiliary power -Electric utility -Distributed generation
Advantages	-Solid electrolyte reduce corrosion & electrolyte management problems -Low temperature -Quick start-up	-Cathode reaction faster in alkaline electrolyte, leads to high performance -Low cost component	-High temperature enable -Increase tolerance to full impurities	-High efficiency -Fuel flexibility -Can use variety of catalyst -Suitable for CHP	-High efficiency -Fuel flexibility -Can use variety of catalyst -Solid electrolyte -Suitable for CHP&CHHP -Hybrid/GT cycle
Challenges	-Expensive catalyst -Sensitive to fuel impurities	Electrolyte management	-Pt catalyst -Long start up time	-High temperature corrosion and breakdown of cell components -Long start up time -Low power density	High temperature corrosion and breakdown of cell components

Table 2 – Comparison between Fuel cell technologies. (BatteryUnivesity)

2.2.5 BMS

Modern battery technology, especially Li-Ion requires controlling of various function of the battery cells in order to keep the battery pack within its safe and best performing conditions. First and foremost, to prevent safety hazards (Bursting of the outer shell, toxic gas venting, Overheating, fire) and to keep the battery cells from degrading, caused by improper charging and discharging cycles.

The BMS main functions are:

- Protection – Undervoltage, overvoltage, overheating, - shutting down the battery, disconnecting it from the main circuit.
- Battery cells connection management to load, discharge control.
- Controlling charging, diverting energy between cells/packs for cell balancing, controlling the energy flow from regenerative energy recovery.
- Communication-data transfer to other modules, ECUs. Error reporting. Control input from chassis and motor ECUs.
- Monitoring and data collection – Voltage, current, temperature, etc.

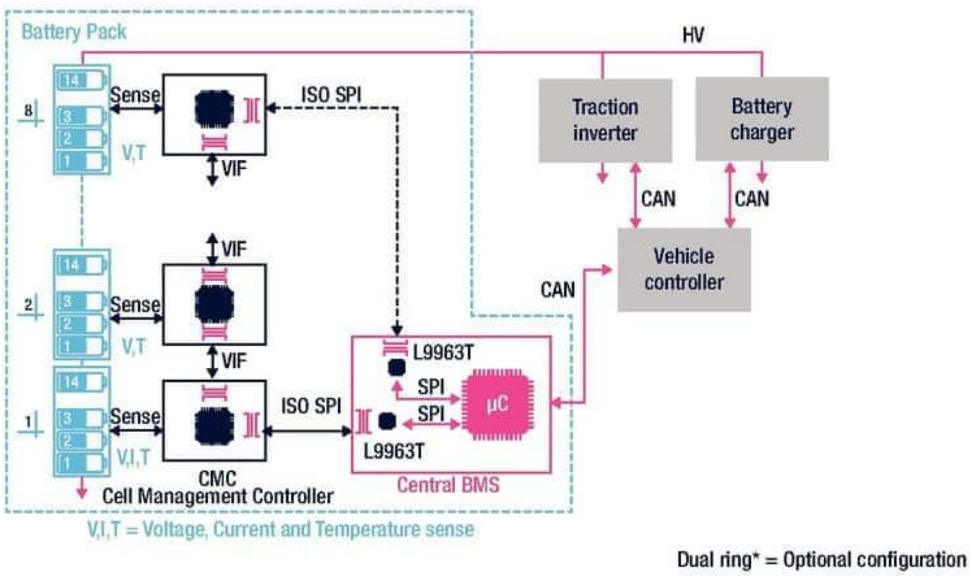


Fig. 23 – Typical BMS topography and major components. (ST)

2.3. Conclusion of literature review

EV propulsion and applicability for current and future vehicles is only as good as the energy storage and generation solutions implemented in them. While innovative design and manufacturing solutions are revolutionizing the construction of these vehicles, energetic solutions and technology seems to lag and follow conservative approaches.

Innovative approaches to packaging, modularity and standardization of energy storage solutions will enable a rethink of how the vehicles of the future are conceived, designed, and sold. Global targets of de-carbonization and sustainability require the wide-spread acceptance of EVs as a viable replacement for ICE vehicles, with capabilities, features and pricing that is comparable to the phased-out platforms. This is of highest importance for emerging and developing markets, which will be the epicenter in growth in years to come.

By combining the best features of different energy storage solution, modular packaging, compatibility with future upgrades, driven by shifts in battery technology – several key roadblocks can be dismantled – addressing the scarcity of key materials, environmental impact of manufacturing and future-proofing the drivetrains, reducing the reliance on recycling solutions that are a major missing piece in the EV puzzle.

3. MATERIALS AND METHODS: DESIGNING THE UNIFIED BATTERY ARCHITECTURE

The aim of the proposed system is to be a competitive alternative system architecture to the current standard architecture common in the EV market. Building upon the technological knowledge base gathered in the previous chapter's literature research, a set of concepts and main ideas is devised. These must provide preferable attributes as well as to address limiting factors.

3.1 Design concepts

In order to have an effective energy storage solution suitable for use in EVs, it must follow these concepts:

- Lower raw materials utilization per vehicle.
- Modular system comprising of multiple modules of specialized capability
- Standard module size to accommodate variable internal components.
- Ability to add further modules according to intended use profile.
- E-vehicle can be sold separately from its battery pack. Lowering the initial investment, in costs and materials.
- Ability to easily mount-dismount modular battery modules.
- Standardized modules allow for interchangeability between platforms, both mobile and stationery based.
- Large fleet users, with dynamic fleet utilization, can interchange units between individual vehicles, boosting their capabilities according to intended use, Overall battery raw materials can be greatly reduced.
- Design towards the automotive sector, following automotive standards and guidelines.
- A common, "unified" form factor, that will suit the different modules design constraints.
- End-user handling
- Nice to have optional feature - Hot-swapping/Autonomous module swap.
- Large scale production enabling competition and price reduction.

3.2 Main ideas

The main ideas behind the architecture are:

- Universal approach for battery pack sub-units, according to prevailing commonly available components and electrical specifications
- Ability to deliver comparable performance to volume and weight to commonly used battery pack designs.
- Modular system comprising of - Carrier frame and quick detachable modules.
- Specialized modules design, comprising of battery, capacitor and F.cells modules.
- Module structure made for mass production, using lightweight polymer technology, injection molding and ultrasonic welding, similar to commercial lead acid production.
- Ability to mix and match battery technology on a single vehicle.
- Safe and ergonomic for End-User handling, mounting and dismounting.
- Isolated-Protected connections for HV, protected LV connections. Contacts visible only upon insertion of the module, not allowing user access.
- Integrated BMS unit
- Integrated cooling circuit, with leak-free connections.
- Double safety on mounting interface – two discreet lock to keep the module into the car mount.
- Weight lower then 25kg per module, for one-person manipulation.
- Each module structural integrity to keep 20% of vehicle weight.
- Sealed module, with pressure-controlled venting for thermal cycling.

3.3 Specs and system integration

On the basis of these main ideas and concepts we are able to compile a set of technical specifications needed of such a system.

- System Voltage – 350V nominal, 400V fully charged. According to common market practices.
- Carrier featuring set of common locking geometry and Electrical interfacing features, variable in size and overall design, according to vehicle requirements.
- Carrier material choice – steel for low cost to aluminum-titanium for high performance applications.
- Modules to Carrier interface – Safe-Secured on both sides when disconnected, Insertion initiated uncovering, Leak-free quick connection for coolant circuit.
- Modules use common commercial cells. 2170/4680/Prismatic equivalent, 60x138mm Supercapacitors, Light duty 60-100w PEM fuel cells (ex. Protium)
- Module size: 535 x 175 x 220 – Minimal size to house the various cells in unified form factor.
- Module weight – max 32kg.
- Material – Casing HDPE, Retention features – 304 stainless.
- IP rating – IP68 – Dust ingestion, water jet.
- Structural maximum load Y-direction(Laying flat-top-down)– 250kg

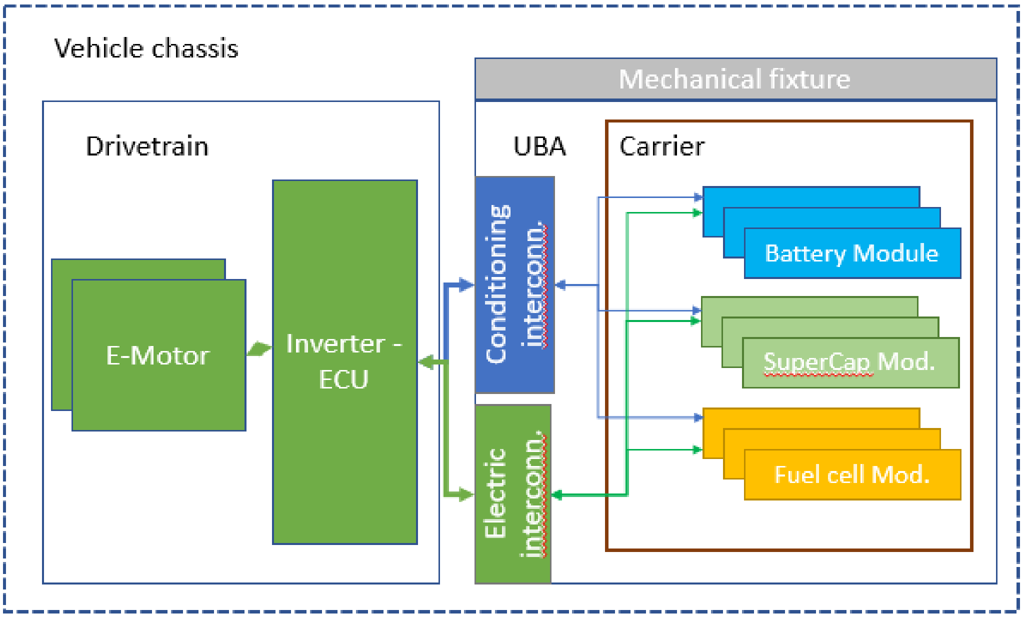


Fig. 24 – system diagram (DanielTM)

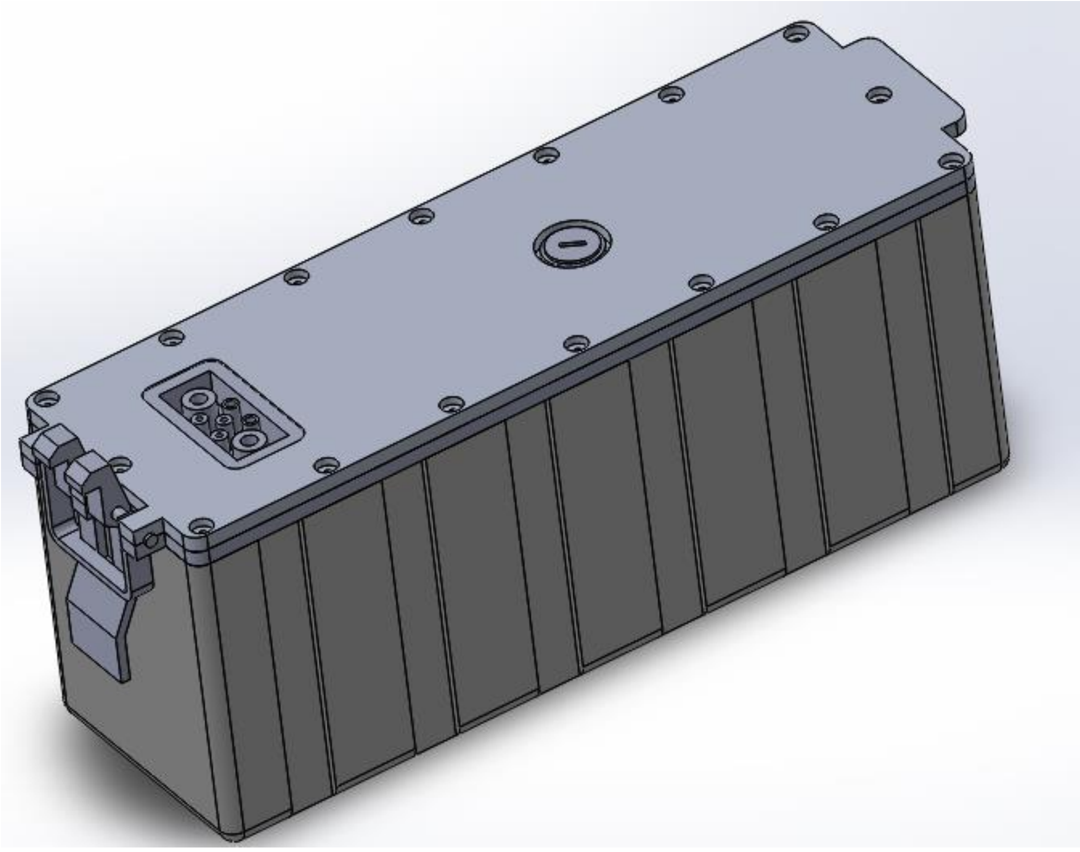


Fig. 25 - Rendering of a module unit (DanielTM)

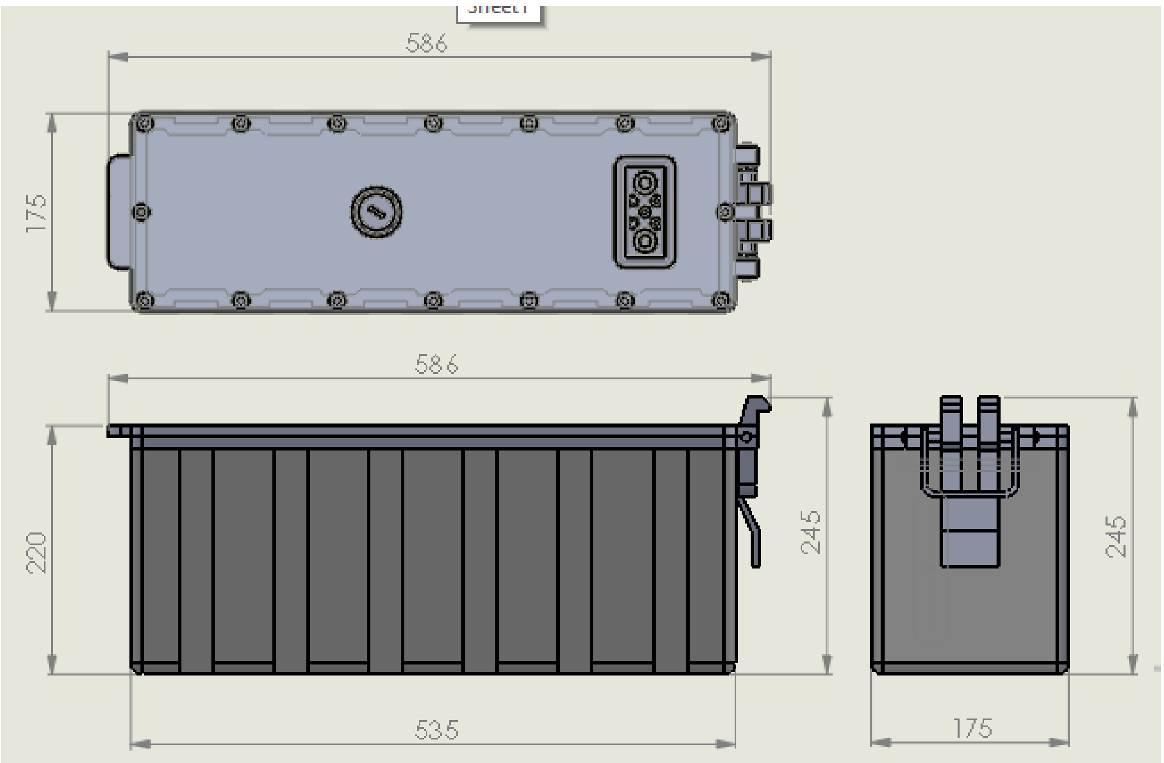


Fig. 26 – Dimensioned drawing of the battery module (DanielTM)

3.4 Description of system components

The basic elements of the system:

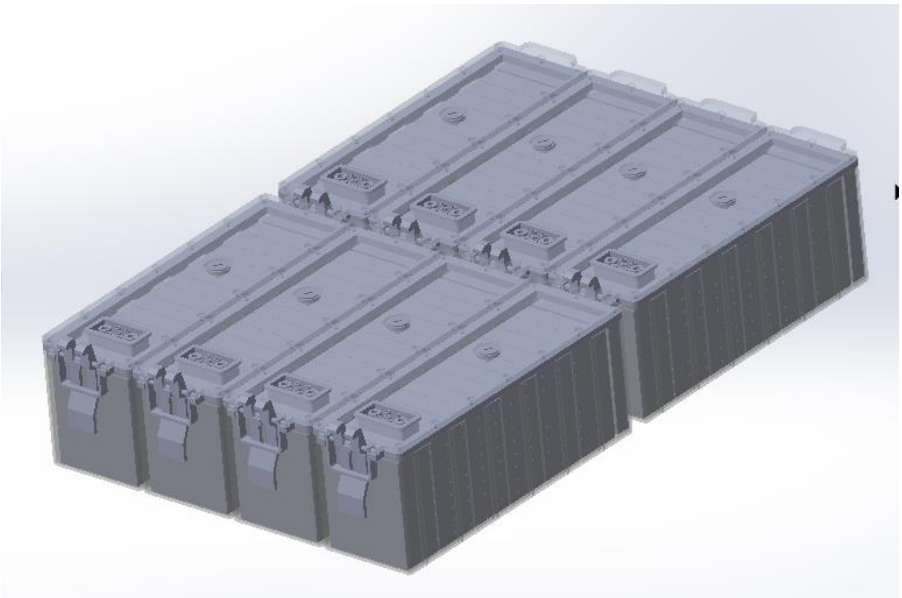
1. UBA-C – Carrier-interface mechanical mounting for the modules + cooling + electrical connections
2. UBA-M-B-xxx – Battery module – variable battery Gen\Tech – Li-Ion\Molt-Salt\...
3. UBA-M-C – Supercapacitor module
4. UBA-M-FC – Fuel cell module

Following is a thorough description and function of each component type:

3.4.1 UBA-C – Carrier

The carrier interface needs to:

- Allow the standardized modules to securely mount to and handle the electrical and cooling quick couplings.
- Interface with the EV vehicle infrastructure and thus will be a proprietary unit to suit the needs of various vehicles\manufacturers needs.
- Preferably should be mounted and accessed externally but can also be internally mounted in the vehicle.
- All connections to the modules must be of a safe type, obscured/sealed/covered until the module is inserted into place.
- Cooling connections are of a double sided self-sealing type(No-leak type), to prevent the egress of coolant(Glycol based) to the environment.



Fig, 27 – CAD Render of a battery pack of 8 Modules – 52kWh (DanielTM)

3.4.2 – UBA-M-B-xxx – Battery module

Standardized battery module, at the core of the system design, must allow:

- Function – main energy source for the traction motor, allow for regenerative breaking recharging. Influenced by the desired vehicle range and (to lesser degree, when Capacitor module is used) by performance-power.
- Size – 535x 175x210mm(LxWxH)
- Battery modules should be compatible with various battery technologies- Li-Ion, Li-FePo, Li-Po, Ni-MH, Molten Salt (Zebra), allowing mixing of dissimilar battery technologies when beneficial for the EV operation cycle. As the technology evolves, the modular system architecture allow easy integration and retrofitting of new batteries and battery technology into older generations of EVs, extending their useful lifetime.
- Composition - 384(96S4P) - 2170 cells, or 26 72Ah prismatic Li-Ion cells, while keeping excess space to minimum but some space for future fitting of 4680 cells or comparable.
- Energy capacity – 96S4P 4000mAh 4.2 2170 cells – 6.45kWh
- Energy performance (Li-Ion module, 2170 cells) – 400V, 40A nominal, 140A max (for 250 cycles), Charge time 1h. Good for 1500Cycles.
- Includes all that is needed to operate the battery cells in a standalone suit – Electrical connections between the cells, Pyretic fuse, BMS, Cooling circuit.
- Electronic connections of the safe type obscured/sealed/covered when not mounted to the vehicle. A feature on the carrier initiated the uncovering of the connections only when the connection interface is considered safe (No chance of operator gaining access to the connections), alternative approach is to electrically isolate the terminals until fully seated I the carrier.
- Cooling/conditioning (Heating-cooling) circuit integrated into the module according to the necessities of the battery cell technology. Quick connections (to the carrier) are of the leak-free type. Limiting spillage of the cooling media to the environment.

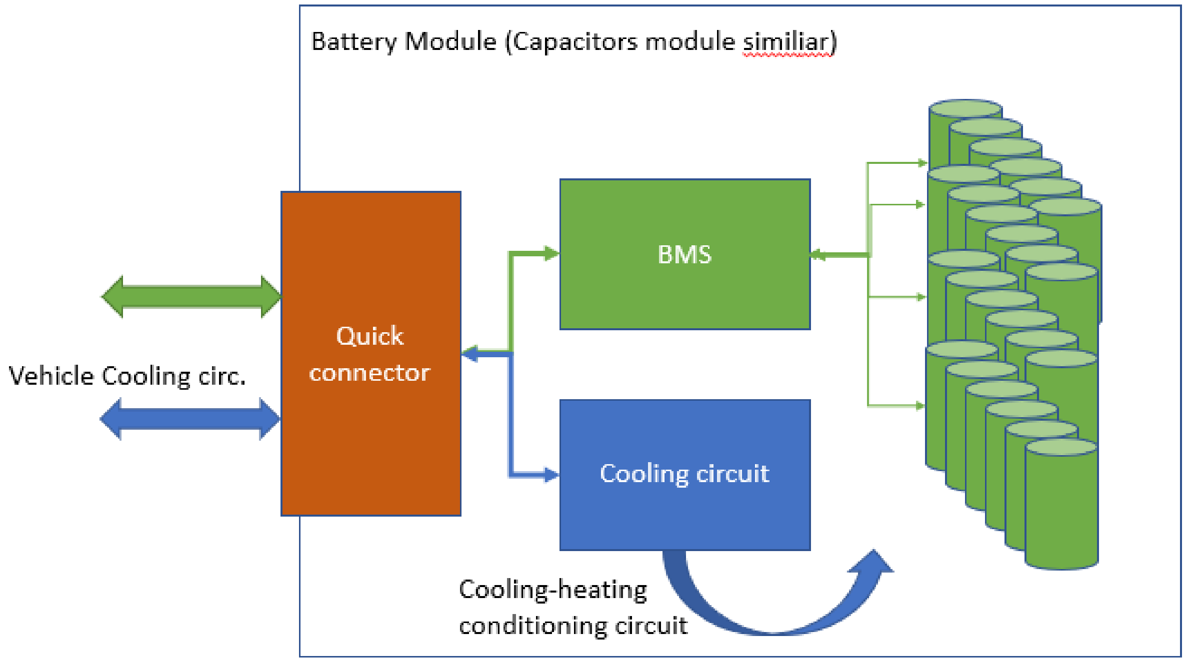


Fig.28 – block diagram of a Battery/Capacitor module (DanielTM)

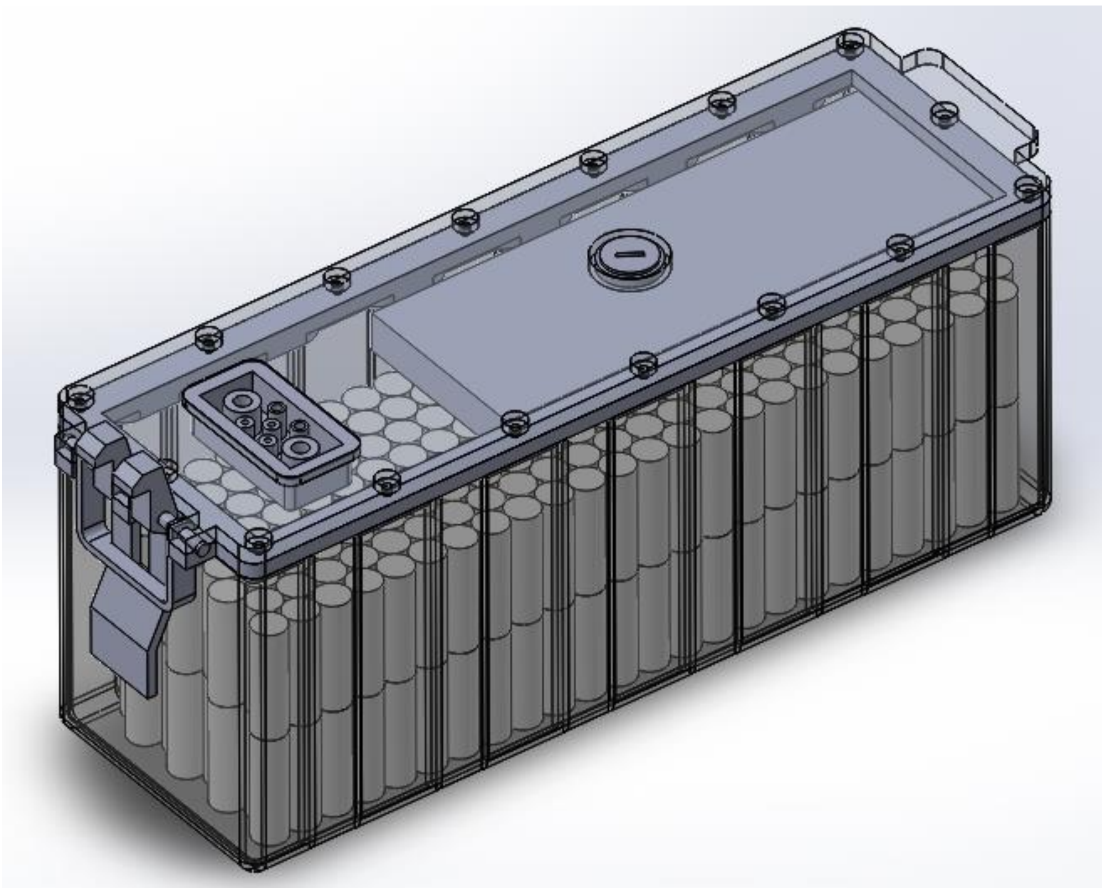


Fig. 29 – CAD render of a 384 2170 cell battery module (DanielTM)

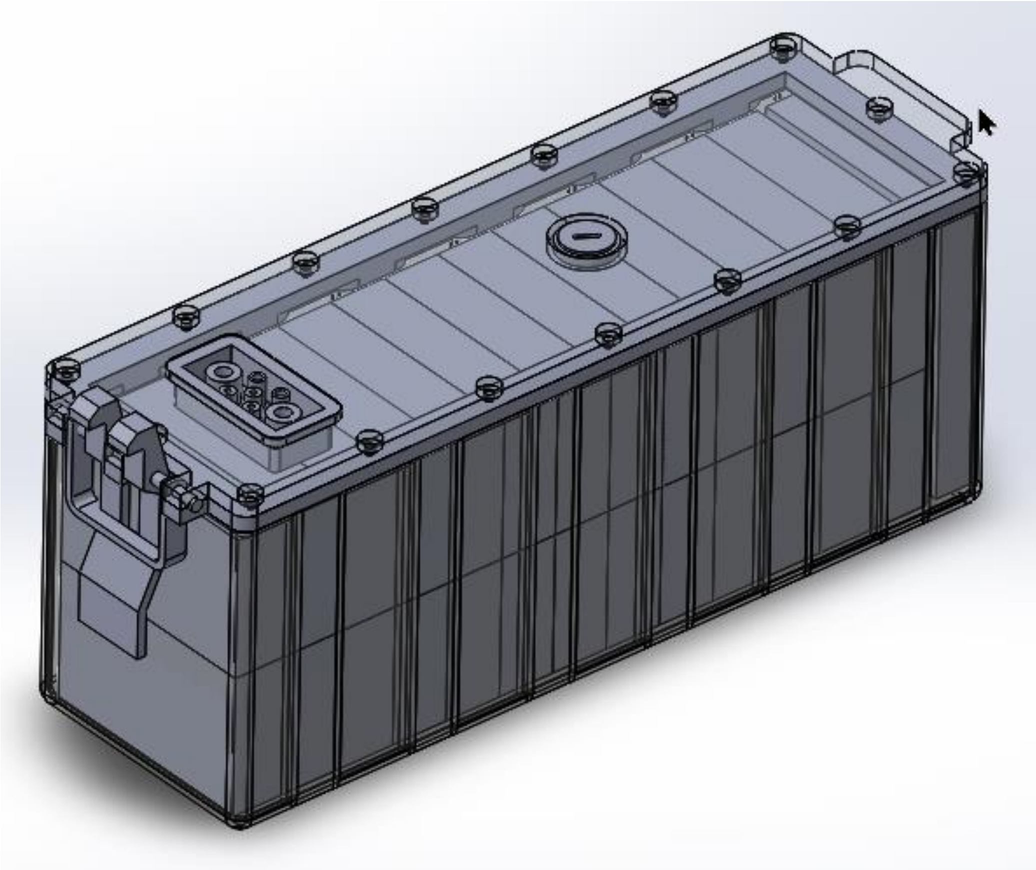


Fig. 30 – CAD render of a 26 Prismatic 72Ah battery module (DanielTM)

3.4.3 – UBA-M-C – Capacitor module

- Function – Energy supply buffer, energy burst on acceleration, regenerative breaking main energy reservoir (Instead of recharging the battery modules).
- Supplement the battery modules – reducing the charging cycles count and extending the battery useful life.
- In applications where power demand is high but the range demand is low – supplement the battery modules by pre-charging and supplying the motors with ample amount of power from under-sized battery pack.
- Management circuit to control the capacitors charging and discharging, multiplexed with the battery and motor ECUs,
- Composition – 24S standard 3000F/3V 60x138mm Supercapacitors. Tecate TPLH-3R0/3000SL60X138.
- Energy performance – 0.09kWh, Peak current 2200A@72V, Charging time 700mS, good for 100000 charge-discharge cycles.
- Size – 535x 175x210mm(LxWxH) – Identical to battery modules.
- Weight – 15-16kg

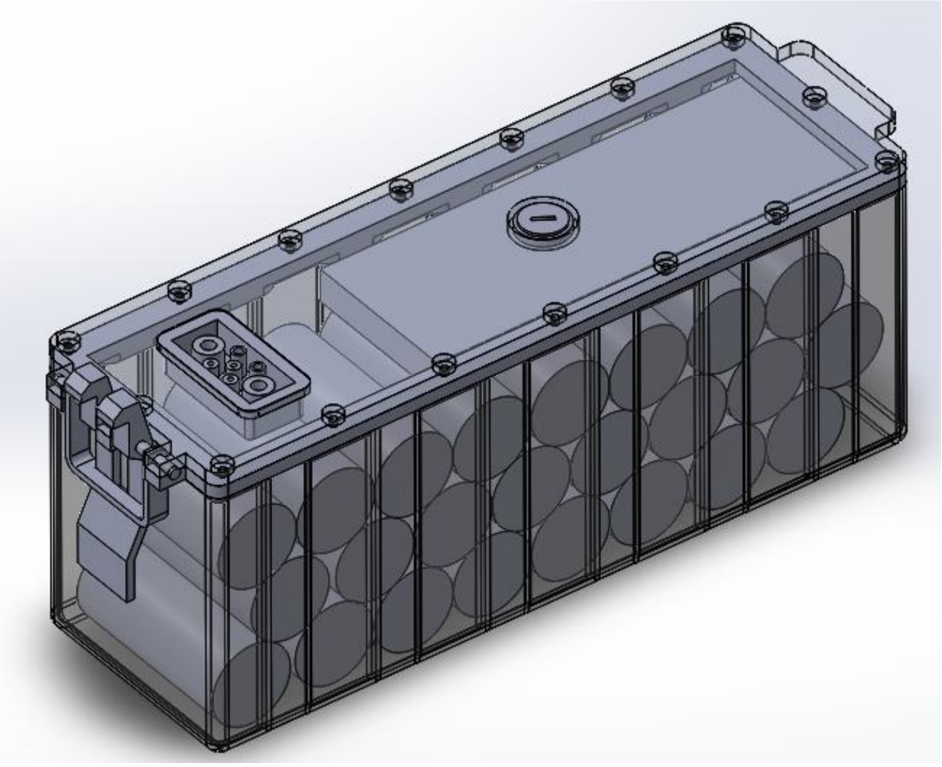


Fig. 31 – CAD render of a 24 3000F/72V 0.09kWh supercapacitors pack (DanielTM)

3.4.4 – UBA-M-F – Fuel cell module

- Function – Trickle charging and range extending module, refillable.
- Supplement the battery modules and extend the total range by recharging the battery modules at a slow rate and when needed the capacitor module.
- Can be procured and implemented in cases where a long-range journey is needed.
- Including an integrated fuel tank for hydrogen\methanol.
- Reusable unit, allowing refueling when removed from the carriage\vehicle.
- Fuel cells – 6x commercial Light duty 60-100w PEM Hydrogen fuel cells (ex. Protium) or Methanol DMFC equivalent.
- Power generation – on Hydrogen – 5A@72VDC 360w, Fuel consumption – 0.6Lpmin@0.3Bar, Tank operation duration – 10h.
- Hydrogen Tank - 4.7liter@700Bar, 0.155kg H2. Equivalent of 5.2kWh.
- Methanol tank - 7.5Liter, Equivalent to 37.5 kWh. In case of Methanol an integrated pump to fill the fuel cells.
- Outside facing, flush, refueling cap/connector.
- Size - 535x 175x220mm(LxWxH)
- Weight limited by the max module weight (25kgs).

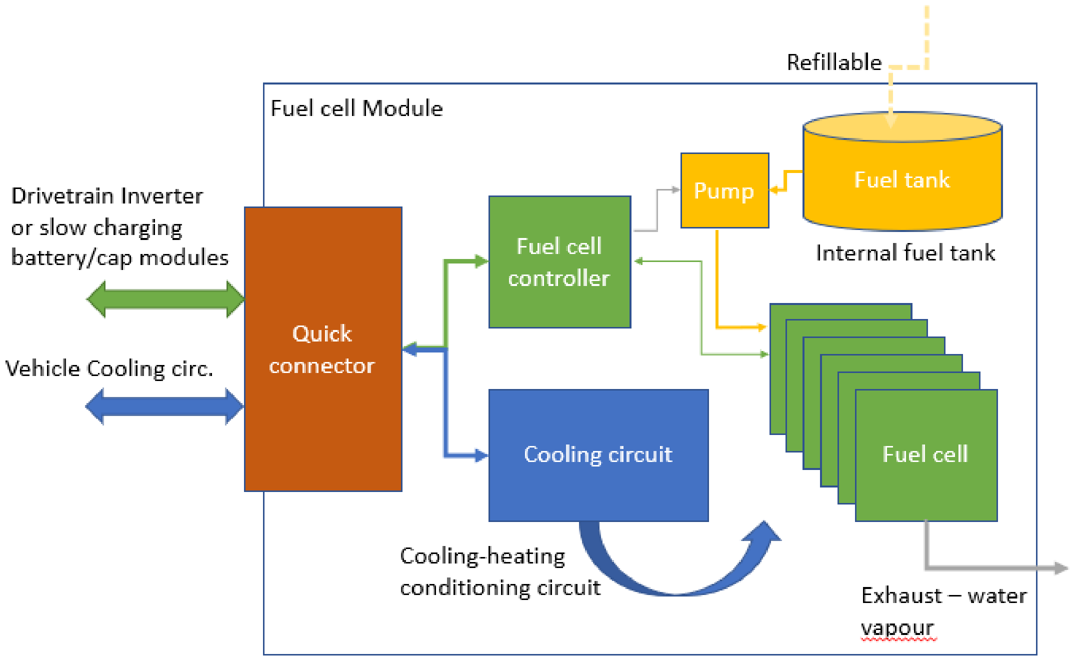


Fig. 32 – Block diagram of Fuel cell module (DanielTM)

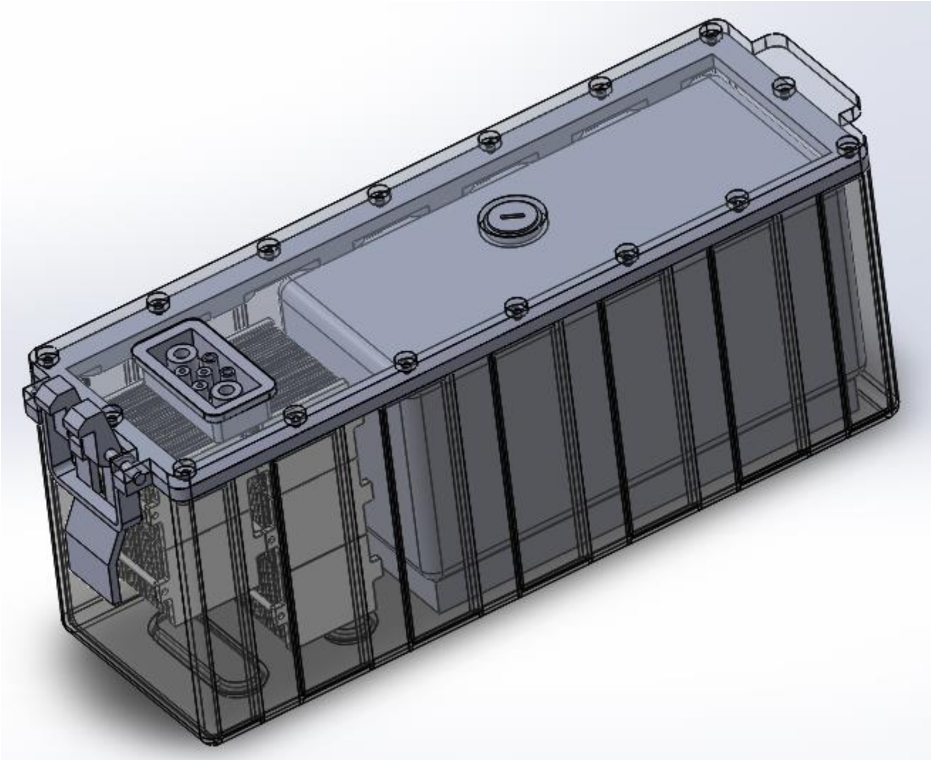


Fig. 33 – CAD render of a 6x DMFC methanol FC module. (DanielTM)

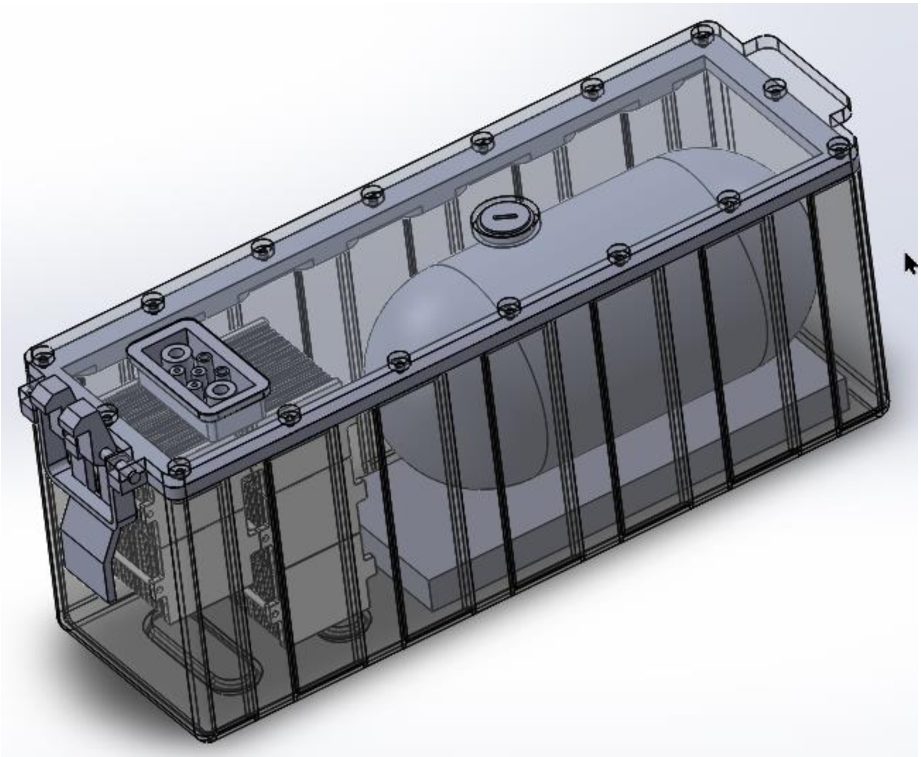


Fig. 34 – CAD render of a Hydrogen PEM FC module (DanielTM)

3.5 Conclusion of third chapter

The proposed design is an alternative and a set off from the common architecture used in the EV market by most of the major manufacturers, that said it has many positive attributes that can revolutionize the concept of EV sales and maintenance. But allowing for a much cheaper Battery mass production, leading for interchangeability, recycling and repair market that can push back serviced units to be used on a wide range of vehicles thus reducing the need for stockpiling and dead stock.

The modular approach makes it possible to future proof todays vehicles and ensure longer service life of the vehicles themselves, and the battery packs. It is clear that wlthogu many different individual components exist, but picking a common domain that can be shared across the board between propulsion technologies is an achievable feat. So while the comprising component are different, ranging from the most commonly used lI-Ion cell to the most advance fuel cell technology, the various modules share the same back bone structure that can be used in various applications.

While designing the modules I took also into consideration various upcoming and currently researched technologies such as Prismatic and large diameter cells, Zinc Iron and Nickel based battery cells, Various designs of fuel cells and their auxiliary components, thus the chosen size factor is a compromise, by having more space to expand it has a slightly larger foot print then a currently used battery pack.

4. PRACTICAL DESIGN ASSESSMENT: COMPERISON BETWEEN UNIFIED BATTERY ARCHITECTURE AND CURRENTLY USED BATTERY DESIGNS.

The performance and feasibility of the proposed system should be thoroughly analyzed and compared to contemporary commercially available design and trends in the EV market, such as the products of the main manufacturers, in particular Tesla, VW, and Toyota. The criteria to be investigated include performance, efficiency, costs (MSRP, PPP), reliability, safety and refinement.

To acquaint the comparison to a common EV user, we can refer to research conducted by the Fuel Institute in the US, concluding that most user profiles include driving ranges of 60kms. In order to allow for an uncharged return trip and accommodate for a variable driving conditions, I suggest taking the length of round trip and add 50% attrition rate, i.e. typical range requirement for the majority of EV users of 180km.

The comparison combined data regarding a common and popular vehicle, Tesla Model 3 with the 50kWh battery, as the smallest range option. To detach the price of the battery packs its assumed that its possible to buy the car without a battery. Then the characteristics of the vehicles are compared, functionally and costs wise, over critical points of its expected use, i.e repairs and recycling included.

Since the system design is hypothetical some figures are taking into account large scale production, acquiring the data from current market reports and prices of components available on the market. The comparison uses both numerical quantitative as well as qualitative approaches to have a better analysis of the overall performance of the proposed system.

4.1 Qualitative analysis of battery pack features

The first approach to evaluate the former to the proposed approaches is by comparison to a common set of attributes, that are major factors in the EV battery usefulness and efficiency. These attributes will get a qualitative score between 0 to 1, according to an objective assessment of the designs ability to fulfill this attribute to its full, detailed in the following table:

	UBA		**Current STA design**	
Attribute	Score	Explanation	Score	Explanation
Scalability – ability to increase the EV battery pack capacity	0.8	Minimal modules are needed. Can be scaled up to a certain max set.	0,2	Only by replacing the complete battery to compatible larger capacity.
Serviceability – ability to remove and repair the battery pack	1	Full serviceability is possible, both in the end-user level.	0.4	Depending on vehicle design. In most cases, it can be done only at the workshop level.
Volumetric and mass packing efficiency	0.4	Volume and mass are consumed also by the module casing, interface	0.9	Ability to maximize the amount of battery cells per volume required less material is needed for housing the cells.
Operational Safety rating	0.8	Modules isolated from each other. Depending on applic. Might need reinforcement	0.5	Better mech. Safety. Failure in a Li-Ion battery pack leads in most cases to a complete thermal runaway of the whole pack.
Adaptability to new technologies – change in cell type, technology	0.7	future integration of different type modules enabled by design. Standard size might need modification in the future.	0.2	Very few battery packs allow for any upgrade in the cell type or composition of the battery pack.
Compatibility with Hot-Swap / Battery changing	0.8	Needs provisions on the carrier, and compatible handling mechanism.	0.3	Battery pack automated swapping was done by BetterPlace in 2008, but since size has grown double, Impossible with structural battery packs.

Table 3 – Qualitative comparison

4.2 Quantitative analysis of battery pack features

Battery pack features can also be assessed in a quantitative manner, using the presumed specs and market knowledge to gain data for comparison. The following table includes the main spec categories, assuming a common use profile, with required range of 180km.

	UBA		**Current STA design**	
Attribute	Score	Explanation	Score	Explanation
Price per car	33500USD	The base vehicle + 4 modules for 180km range(25kWh)	46990 USD (MSRP)	No option to get less the 50kWh battery.
Price (180km profile)	1000-1200 USD/module 4 modules for 180km (25kWh) – 4000USD	On large scale production of modules, price can be brought down to 1000USD. 12k-14.4k for 12 modules (78kWh) comp. Tesla M3	13500 USD	Tesla model 3 battery pack costs according to service invoice published by an owner.
Weight of Battery pack	160kgs	128kg for 4 modules + carrier 32kgs.	545kg	
Battery repl. Time	< 1 hour for 4 modules		13 hours	According to tesla.
Service labor costs 100USD/hour	100USD	Replacement with new modules. 4 modules removal time – 15mins.	2300 USD	According to price list in
Raw materials intake - Lithium	1kg/module, 4kg.	For 25kWh setup	12kgs	75kWh battery
Recycling costs 4.5USD/kgBAT	540USD	120kgs battery mass	6750USD	
Recycling potential – 50%	2- 4kgs Lithium	Possible for the unit to directly fit in other vehicle.	6kgs	Battery packs are not directly interchangeable.

Table 4 – Quantitative comparison

4.3 Combined scoring and normalization

After carrying out both Quantitative and Qualitative comparisons, all scores are

	UBA		Current STA design	
Attribute	Score	Normalized	Score	Normalized
Price per car	33500	**1**	46990	0.4
Price (180km profile)	4000	**1**	13500	0.42
Weight of Battery pack	160	**1**	545	0.415
Battery repl. Time	1	**1**	13	0.08
Service labor costs	100	**1**	2300	0.05
Raw materials intake - Lithium	4	**1**	12	0.09
Recycling costs	540	**1**	6750	0.09
Recycling potential – 50%	4	**1**	6	0.5
Scalability – ability to increase the EV battery pack capacity		**0.8**		0,2
Serviceability – ability to remove and repair the battery pack		**1**		0.4
Volumetric and mass packing efficiency		0.4		0.9
Operational Safety rating		**0.8**		0.5
Adaptability to new technologies – change in cell type, technology		**0.7**		0.2
Compatibility with Hot-Swap / Battery changing		**0.8**		0.3

Table 5 – Combined assessment – Normalized results.

4.4 Conclusion of forth chapter

In this stage, after the introduction of the architecture merits and features, I set out to carry out an educated and unbiased quotative and qualitive assessment of both design approaches, and unsurfaced the main benefits attributed to the UBA architecture. These include major benefits when it comes to costs for the end costumer, the amounts of energy and raw materials input for the production of a vehicle that complies with the market common use profile. Further more, added value in future-proof attributes was demonstrated, with features as upgrades to the battery technology are possible, as well as hot-swapping compatibility.

Serviceability was also improved both in time and costs to the costumer, as well as safety aspect, that while isn't proved in testing, following the specifications and the system design, its believed to have positive effect in regards to thermal runaways and fire, while collision damage can also be mitigated by spreading the deformation on modules that can absorb the forces externally, instead of internally as is common with modern EVS.

The biggest downside, clearly stated here, is the reduction in volumetric packing efficiency compared to common battery designs, reason being, of course, is the individual packaging of the modules, requiring additional space and weight.

5. SUMMARY - CONCLUSIONS AND PERSPECTIVES

In this paper the historic origins and current state of EV battery design were discussed, and an alternative approach was laid out, aim of which is to improve the flexibility, compatibility and scalability of future EV battery architectures and vehicle designs, while reducing the raw materials intake and simplify the reuse/recycle processes related to vehicle and battery end of life. The basic principles of current technology were explored and explained in a way that will enable the exploration of this new approach.
The new approach was then described in detail, including concepts, main ideas and specifications. The design was elaborated into basic CAD designs to emphasize that the concepts have viability in real current and future EV market. Then a thorough comparison was carried out, in order to compare the approaches, their features – pros and cons, and a forecast of the benefits in terms of environmental impact is made.

The overall conclusion of this exercise is that a shift in the main trend in the EV market is worth exploring, either with this proposed architecture or similar manifestations, using concepts and ideas laid out here.

This approach can show future promise in the following paths:

<u>Integrated (Direct-2-Reuse) life cycle between mobile and stationary applications</u>

Widespread dependability on renewable energy generation, from intermittent energy sources such as wind, solar, tidal, etc., requires an efficient and high-capacity energy storage infrastructure. In industrial and heavy-duty applications this is done with either hydro\pressure\mechanical energy storage, but in the residential and small-scale suites its common to reuse EV batteries. The current designs provide many hurdles for this process, requiring the dismantling of the battery packs to the module\cell level and then reassembly into new battery packs. Using modular-unified design will allow a direct reuse path, greatly reducing the complexity of the process, making it cheaper, more reliable, and safer.

By relegating the used units to their second life cycle as stationary application or lower power/energy demanding applications valuable Lithium can be reused removing large straing from the lithium and other rare materials mining and production industries, reducing by product pollution and future proofing Lithium battery technology for years to come.

Enlargement of the OE\OEM battery unit suppliers

Introducing a standardized form factor, will incentivize more manufacturers to join the market, improving competitiveness and reducing prices. Standard units will allow the end-user and the mechanic to be able to choose between offerings, will allow the faster introduction of newer generations of battery technology and reduce the downtime associated with battery service and repair, as a new module can be sourced easily and installed in minutes.

The larger market of supplier and offerings, along easy serviceability, allows for rent-a-battery suites, where the end-user doesn't need to buy and maintain a large capacity battery from the get-go. Instead, the modules can be acquired when needed, and returned to a common battery pool for further use by other road-goers or at stationary applications, greatly reducing the necessary raw materials to sustain the same number of vehicles.

Retrofitting older vehicles

By using a common footprint modules, it is easier to conceive the electrification of older ICE vehicles as well as end-of-life EVs, thus opening up greener options for the electrification and withdrawal from fossil fuel mobility. Larger stocks and common modules, at lower price will make it viable also for developing countries that economic reasons preventing them from migrating to EV propulsion on larger scale.

By retrofitting instead of recycling older vehicles, major pollution source and energetically intensive process, the environmental price of manufacturing new EVs can be saved, reducing the bourdon on landfills and material suppliers, when combined with an industry that supplies other retrofitting features, especially on the safety systems of these vehicles, a new generation of retrofitted EVs can have a competitive edge over newly produced vehicle.

Battery sharing in communities and over commercial enterprises

Common battery architecture will allow the sharing of valuable energetic modules across communities and enterprises, according to demand and use, thus reducing the waste of raw materials associated with modern EVs with fixed batteries, including over-sized battery for most common use scenarios, suffering from heavy mass and lower then optimal efficiency.

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