

Democratic and Popular Republic of Algeria

وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Scientific Research

Amar Telidji University-LAGHOUAT



Faculty of Technology

كلية التكنولوجيا

Electrotechnical department

قسم الكهروتقني

End-of-cycle project

To obtain a master diploma

Filed: Electrotechnical

ميدان: كهروتقني

Option: Electrotechnical industrial

تخصص: كهروتقني صناعي

Subject:

Study of the innovative ideas in electric cars and the environmental impacts challenges

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2023/2024

أَعُوذُ بِاللَّهِ السَّمِيعِ الْعَلِيمِ مِنَ الشَّيْطَانِ الرَّجِيمِ، مِنْ هَمْزِهِ،
وَنَفْخِهِ، وَنَفْسِهِ

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿1﴾ خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ ﴿2﴾ اقْرَأْ
وَرَبُّكَ الْأَكْرَمُ ﴿3﴾ الَّذِي عَلَّمَ بِالْقَلَمِ ﴿4﴾ عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ ﴿5﴾

**In the Name of Allah, the Entirely Merciful, the
Especially Merciful.**

Recite in the name of your Lord who created (1) Created man
from a clinging substance-Recite (2) and your Lord is the most
Generous (3) Who taught by the pen (4) Taught man that which
he knew not (5)

Al-'Alaq - ماتيسر من سورة العلق

ملخص

لقد قمنا في هذا العمل بدراسة السيارة الكهربائية من ناحية التجديد متمثلة في الافكار الجديدة والمخترعة حديثا, التي ساهمت ومازالت تساهم في تطوير الاداء من ناحية سعة البطارية والراحة للمستعمل, حيث ذكرنا 11 فكرة متضمنة من ناحية مصدر الطاقة وتوزيعها وحتى نقلها وصولا للمظهر الربحي اي فكرة خارج الصندوق مراعاة للتحديات المناخية وتحذيرات المنظمات حول الاحتباس الحراري, وضرورة الانتقال الطاقوي النظيف الذي تضمن اهم تحديات السيارة الكهربائية و المواد المصنعة للبطارية والسوق الاستهلاكي ونقطة الاختلاف بينها وبين السيارات ذات المحركات الاحتراق الداخلي .

الكلمات المفتاحية: سيارة كهربائية، مركبة كهربائية، مركبة كهربائية تعمل بالبطارية، ابتكار، أفكار مبتكرة، تقنية البطاريات، الشحن اللاسلكي، التأثيرات البيئية، نظام إدارة البطاريات،.... وما إلى ذلك.

Résumé

Dans ce travail, nous avons étudié les voitures électriques en termes de renouvellement et les idées nouvellement inventées qui ont contribué et continuent de contribuer au développement de la performance en termes de capacité de batterie et de confort d'utilisation. Nous avons mentionné 11 idées incluses en termes de source d'énergie et de distribution et même de transmission pour atteindre l'apparence de profit de toute idée en dehors de la boîte, en tenant compte des défis climatiques, les avertissements des organisations sur le réchauffement climatique et la nécessité de la transition énergétique, qui comprenaient les défis les plus importants des voitures électriques et des matériaux de batterie et les différences avec les voitures à combustion interne.

Mots-clés: Voiture électrique, VE, VEB, innovation, idées novatrices, technologie des batteries, impacts environnementaux ,charge sans fil, BMS, etc.

Abstract

In this work, we have studied the electric cars in terms of renewal and newly invented ideas that have contributed and continue to contribute to the development of performance in terms of battery capacity and user comfort. We have mentioned 11 ideas included in terms of energy source and distribution and even transmission to reach the profit appearance of any idea outside the box, taking into account the climate

challenges, warnings of organizations about global warming and the need for Energy Transition, which included the most important challenges of electric cars and battery materials and the differences with combustion interne cars.

Keywords: Electric car, EV, BEV, innovation, innovative ideas, batteries tech, environmental impacts, wireless charging, BMS, etc.

Thanks, and appreciation

All thanks and gratitude to our God the Lord of the heavens and earths **ALLAH** الله - سبحانه وتعالى - who granted us the succeed in completing this humble work without my power except his AL mighty. I also want to thank my dear **friend BENAIDA BACHIR** for being a great partner, I couldn't do this without him no forget my classmates, **-2M ELTI-** for all the wonderful times and such an amazing experience we have been through for **5 YEARS** contributed to this modest project.

I also want to thank my distinguished supervisor **Dr. MAHDJOUBI ABDELHALIM** for the carness and his efforts and all the university family, especially my professors since freshmore to senior graduate.

Last but not the least, whoever is not thankful to people is not thankful to ALLAH .

LAGGOUN ABDESSAMED

Thanks, and appreciation

All thanks and gratitude to our God the Lord of the heavens and earths **ALLAH** - سبحانه وتعالى - الله who granted us the succeed in completing this humble work without my power except his AL mighty. I also want to thank my dear **friend LAGGOUN ABDESSAMED** for being a great partner, I couldn't do this without him no forget my classmates, **-2M ELTI-** for all the wonderful times and such an amazing experience we have been through for **5 YEARS** contributed to this modest project.

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Last but not the least, whoever is not thankful to people is not thankful to **ALLAH** .

BENAI DA BACHIR

Dedication

I dedicate this work to my dear mother, who has raised, worked, struggled and bound more than 20 years for these moments and my father as well.

To my deceased aunt, AL HADJA, who always stood and supported me while I am fighting my demons. I wish she could attend this day.

To my beloved sister the keeper of my secrets.

To my elders SAID BEN SAYAH and CHABAB ELNACER .

To my BFF: HAMZA LAOUFI, YOUSEF TABBRAKH, DJELLOUL MEKHLOUFI .

To my mentor PR. AMMAR BENTABET, my family in JILL AL-TARDJIH also my acquaintances, brothers and sisters in HACEEF project.

TO our fighters of the resistance and the 35,709 martyrs in GAZA, occupied PALESTINE .

I hope this work for the sake of ALLAH and contribute to the rise of our civilization May peace and blessings be upon the Messenger of God Prophet MOHAMMED, his companion, wives, followers and those who followed him to the Day of Judgment.

LAGGOUN ABDESSAMED

Dedication

I want to dedicate this work to:

To **my dear mother** who gave me all the support that led me to success and struggled. receive my deep gratitude. God grant you a long live.

To **my dear father** you were the best example of the sacrifices you have always made for us. Thanks for your efforts.

To **my brother and sisters**, thanks for being in my side. may this work be for you an example to follow and encourage you to do better.

To all those who, from near or far, contributed to the realization of this work.

I hope this work for the sake of ALLAH and contribute to the rise of our civilization May peace and blessings be upon the Messenger of God Prophet MOHAMMED, his companion, wives, followers and those who followed him to the Day of Judgment.

BENAI DA BACHIR

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List of Abbreviations

AC (Alternative Current)

BEV (Battery Electric Vehicle)

DC (Direct Current)

EV (Electric Vehicle)

GHG (Greenhouse Gas)

HEV (Hybrid Electric Vehicle)

ICE (Internal Combustion Engine)

kW (kiloWatt)

kWh (kiloWatt-Hour)

V2G (Vehicle-to-Grid)

V2X (Vehicle-to-Everything)

EoL (End of Life)

HV (High Voltage battery pack. voltage is > 60 V and ≤ 1500 V DC or > 30 V and ≤ 1000 V AC root mean square (rms))

LFP (Lithium Iron Phosphate)

LIB (Lithium-Ion Battery)

DIB (Dual-Ion Battery)

LMO (Lithium Manganese Oxide)

mAh (milli Ampere-Hour is one thousandth of an Ampere-hour Ah)

Na⁺ (Sodium ion cell)

NiMH (Nickel Metal Hydride)

NMC (lithium-ion cell that uses a cathode made of lithium Nickel Manganese Cobalt Oxide)

PbA (lead acid battery and commonly used as 12V starter and leisure battery)

SOC (**S**tate **O**f **C**harge is defined as the amount of charge in the cell as a percentage compared to the nominal capacity of the cell in Ah.)

IP (**I**ndicator of **P**rotection)

PTC (**P**ositive **T**emperature **C**oefficient thermistor)

BMS (**B**attery **M**anagement **S**ystem)

PCM (**P**rotection **C**ircuit **M**odule)

PVDF (**P**olyvinylidene fluoride)

USD (**U**nited **S**tates **D**ollar)

CAGR (**C**ompound **A**nnual **G**rowth **R**ate)

CNC (**C**omputer **N**umerical **C**ontrol)

isoSPI (**i**solated **S**erial **P**eripheral **I**nterface communication protocol)

GPS (**G**lobal **P**ositioning **S**ystem)

IEC (**I**nternational **E**lectrotechnical **C**ommission)

RSU (**R**oad **S**ide **U**nit)

MOF (**M**etal **O**rganic **F**ramework)

MAI (**M**ethyl **A**mmonium **I**odide)

FTO (**F**luorine doped **T**in **O**xide)

MDF (dimethylformamide)

V_{os} (**O**pen-circuit voltage)

J_{sc} (**S**hort-circuit current density)

NREL (**T**he **N**ational **R**enewable **E**nergy **L**aboratory)

FHG-ISE (**F**raunhofer Institute for Solar Energy Systems ISE)

ESTI (**E**uropean **S**olar **T**est **I**nstallation)

bioNGV (**b**io **N**atural **G**as **V**ehicle)

CATL (**C**ontemporary **A**mpere**x** **T**echnology)

SDI (Serial Digital Interface)

BYD (Build Your Dreams)

IEA (International Energy Agency)

NZE (Net Zero Emission)

RSU (Road Side Unite)

General introduction

Electric vehicles (EVs) are transforming the way we think about transportation. With the rise of climate change and increasing concerns about air pollution, EVs offer a sustainable alternative to traditional gas-powered cars around the World. Rechargeable batteries power these vehicles and produce zero emissions, making them an environmentally-friendly choice for drivers.

They also offer much cheaper running costs, a smooth and quiet ride, with the benefit of instant torque and acceleration. Whether commuting to work, running errands, taking a road trip, or taking your classic car for a Sunday drive, there's an EV option to suit your needs. And as technology continues to evolve, EVs are becoming more accessible and affordable than ever before.

In this work, we'll explore the benefits of electric vehicles, how they work, and what to consider as well as sample of the innovations that make it comfier more efficient with longer autonomy.

The work was structured as follows:

- Chapter One, which is a bibliographic study of EV from components, most important features, and types of batteries.
- Chapter two was entitled to the most important invention and discovery ideas that developed performance in various fields When it comes to EV and their advantages also if there are any inconvenience.
- Chapter three was about the environmental impact of electric cars, the materials extracted for the manufacture of batteries, and the political and economic impacts of distribution, receipt, and recyclability of batteries towards a cleaner world.

Last but not least a general conclusion with our perspectives.

Chapter I

Generalities in electric cars



I.1. Introduction

The electric vehicles (EV's) act as a possible alternative to the vehicle conventionnels, allowing the vehicle constructors to respond to the demands of vehicle users (performance and carburetor consumption) and atmospheric protection

This chapter is for the purpose of donating all the generation and advanced uses of the scientific community available on this vast domain in which the electric vehicle is located.

I.2. Electric Car

An electric car is a vehicle whose engine works with batteries, supercapacitor. Greener than petrol cars, these cars have existed since the end of the 19th century, but have only been marketed since the end of the 20th century.

I.3. The history of electric cars in detail

The history of the electric car begins in the nineteenth century with a very first prototype made by **Robert Anderson** in the early 1830s. This Scottish businessman, Robert Anderson will develop an electric cart.

Other prototypes were built, including the small electric locomotive of Thomas Davenport and that of Robert Davidson, but it was at the end of the 1850s that the history of the electric car took a decisive turn.

In 1859, the French Gaston Planté invented the rechargeable lead acid battery, which was later improved by Camille Faure in 1881. This innovation laid the foundations for the next prototypes and marked the beginning of the rise of the electric car.

In November 1881, **Gustave Trouvé** presented an electric car, or rather an electric tricycle, at the International Electricity Exhibition in Paris. Nevertheless, it was only a prototype and its use was more than delicate since the conductor had to, thanks to a system of pulleys, immerse metal plates in containers containing acid in order to modulate the current intensity and therefore the speed.

However, a few months later, **William Ayrton** and **John Perry**, two Englishmen, presented their prototype electric tricycle with an engine connected to the right rear wheel. Its range was 20 km at a speed of 15 km/h. The car could also drive at

night since it was equipped with electric headlights. It is this prototype that most historians consider to be the first electric car in history.[1]

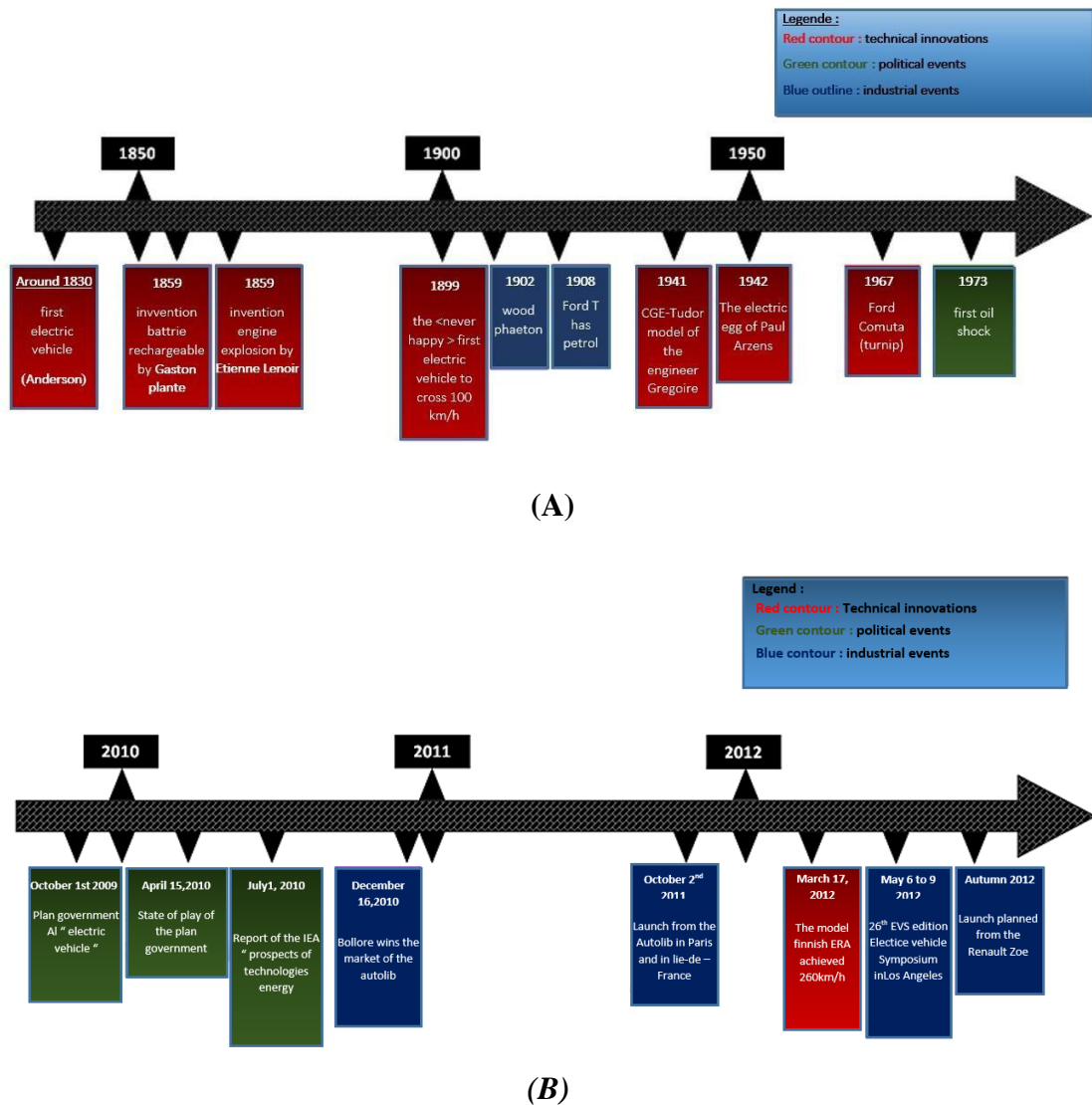


Figure I. 1 : Developement history of electric car

At the dawn of the 2010s, the electric car market seemed to be reborn. In 2008, at the Paris Motor Show, Bolloré announced the release for 2010 of the Bluecar, a small electric city car. This model will be used for the Autolib car sharing service in Paris. On 1 October 2009, Jean-Louis Borloo, Minister of Ecology, and Christian Estrosi, Minister of Industry, presented a national plan for the introduction of 2 million electric and hybrid cars by 2020.

The numerous innovations, the diversity of models on the market (Renault Zoé, BMW i3, Nissan Leaf, Tesla Model S, etc.) as well as government incentives via

ecological bonuses, attract more and more motorists. In addition, people are becoming increasingly aware of the impact of their lifestyle on the environment and the need to change their car use. [2]

I.4. Different types of electric car

There are 2 large families of electric cars:

- 100% electric
- Hybrid

I.5. Components of an electric car

The main components of an EV system are:

- The motor
- The controller
- Batteries
- The transmission

The detailed structure of an EV system and the interaction between its various components are:

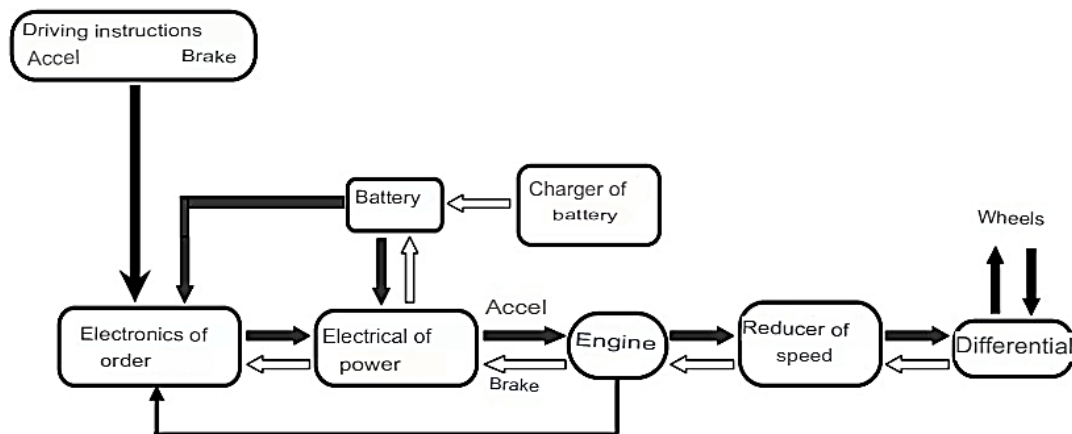


Figure I. 2 : operating process of EV

According to (Figure I. 2), the operating process is as follows

Once the current has passed through the battery packs, it is sent to the car's electric motor. At this stage, a magnetic field is created in the stator. It is this field that drives the movement of the motor's rotor. Unlike an internal combustion engine, the rotor is driven by the wheels. Depending on the car model, it may transmit its movement to the wheels via a reducer.

It has only one gear, which improves its speed of rotation, and it finds the best possible ratio between torque and speed of rotation.

You noticed the electric car does not have a clutch. Also, to have direct current, it is enough for the driver to press the accelerator pedal.

The direct current is transformed into alternating current by the action of a converter, which also generates the electromagnetic field passing through the rotor

Also, there is no gearbox in an electric car, it is the axis of the motor that rotates on that of the driving wheels without intermediary.

In order for a car to drive, it needs a plug or a charging station. A cable with suitable connectors allows you to perform this operation. There are different models, corresponding to the different charging modes.

Driving an electric car allows you to generate electricity when the motor is running without receiving any power (leaving the accelerator pedal or when you brake), it generates power from braking and this energy goes straight into the battery (Recharging).

I.5.1. Motor

I.5.1.1. Different types of electric motor used

The electric car is equipped with several types of motors that transform electric energy into mechanical one:

- **DC motors:** The first electric motors in cars were DC motors brushless BLDC and brushed BDC. The choice of this motor was guided not the ease of speed control with the power electronics allowing to power it very simple because the continuous voltage coming from the battery can be used directly.
- **AC motors:** it is the emergence of new technologies in power electronics that has allowed the emergence of AC motors in electric cars. Indeed, in order to supply the **asynchronous** and **synchronous** motors, the system must include between the battery and the motor a three-phase current inverter. This inverter must be current reversible in order to be able to use the machine in generator mode during deceleration. In order to control these motors, two quantities must be controlled: the voltage and frequency of the

alternating signal provided by the inverter also must include a pulse width modulation (PWM) THE MOST USED ARE PMSM IM

- motor with variable reluctance** this motor is based on the principle of reluctance with a rotor composed only of plates and winding with stator. Their advantage of this type of motor is that its rotor losses are very low, there is very little induced current and the temperature of the bearings is lower.
- Axial flux permanent magnet (AFPM)**
 These motors offer superior power, efficiency, and torque density with their unique flat rotor and stator arrangement. Originally developed for vehicle applications

I.5.1.2. Comparisons between different types of electric motors

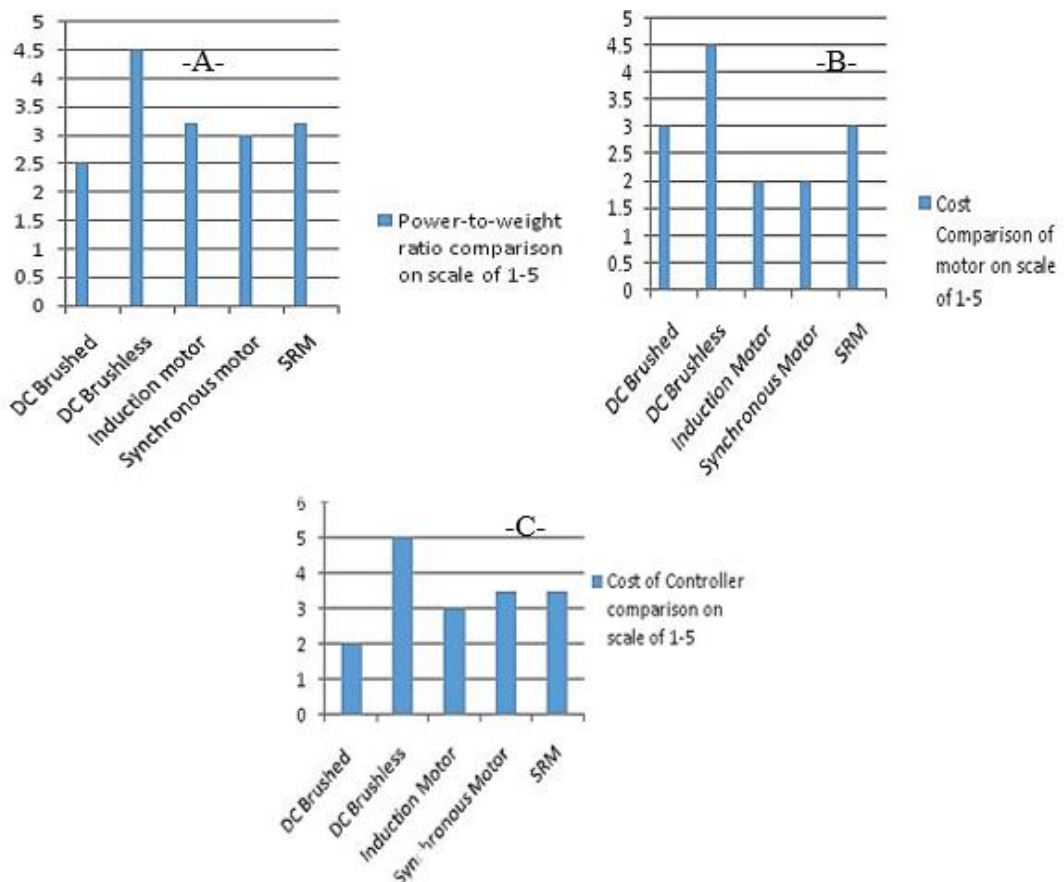


Figure I. 3 : comparing five different electric motors for EVs application on different criterions

Table I. 1 : Efficiency Comparison of Different Electric

Motor Type	Peak Efficiency (Percent)	Efficiency at 10% load (Percent)
DC Brushed Motor	85-90	80-85
DC Brushless Motor	>95	70-80
AC Induction Motor	>90	>90
Synchronous Motor	>92	80-85
Switched Reluctance Motor	<95	>90

we compare five different electric motors for electric vehicle application on different criterions like power-to-weight ratio, efficiency, cost of controller and cost of motor. Comparative evaluation indicates the following.

- DC brushed motor are easy to control, provide high torque at lower speeds but have high maintenance cost, large size, low efficiency.
- BLDC motor has higher power-to-weight ratio, but its maintenance cost, cost of controller is high.
- three phase induction motor provides efficiency more than 90% at peak load as well as at 10% load. Three phase induction motor and BLDC motor are the two most widely used motors by electric vehicle manufacturers.
- Synchronous motor has higher efficiency at lower speeds and improves battery utilization and driving range. Synchronous motor is preferred where constant torque is required.
- Switched Reluctance motor provides a great alternative to induction motor and BLDC motor with lower cost of motor and controller, high efficiency at peak load as well as at 10% load, reliability and fault tolerance capability.

I.5.2. Transmission

A gearbox is the transmission of the car, the part of the motor that changes the gears to allow the car to drive comfortably at different speeds and in reverse the electric cars have mechanical transmissions, because every car needs a transmission to move under its power. Whether the car has a transmission or not depends on the type of electric car

The motor of an electric car does not need to change gears for the car to continue running efficiently. Indeed, the motor provide instant power and constant torque at any given speed within a defined range.

Electric cars have automatic transmissions. So, they don't have a clutch or even a gearbox. An electric car is a single-speed car with two pedals one for acceleration and one for braking.[3]

I.5.2.1. Architecture of an EV traction chain

An EV consists of an energy source, control electronics, one or more energy converters, one or more electrical machines and a mechanical connection system (speed reducer.....).

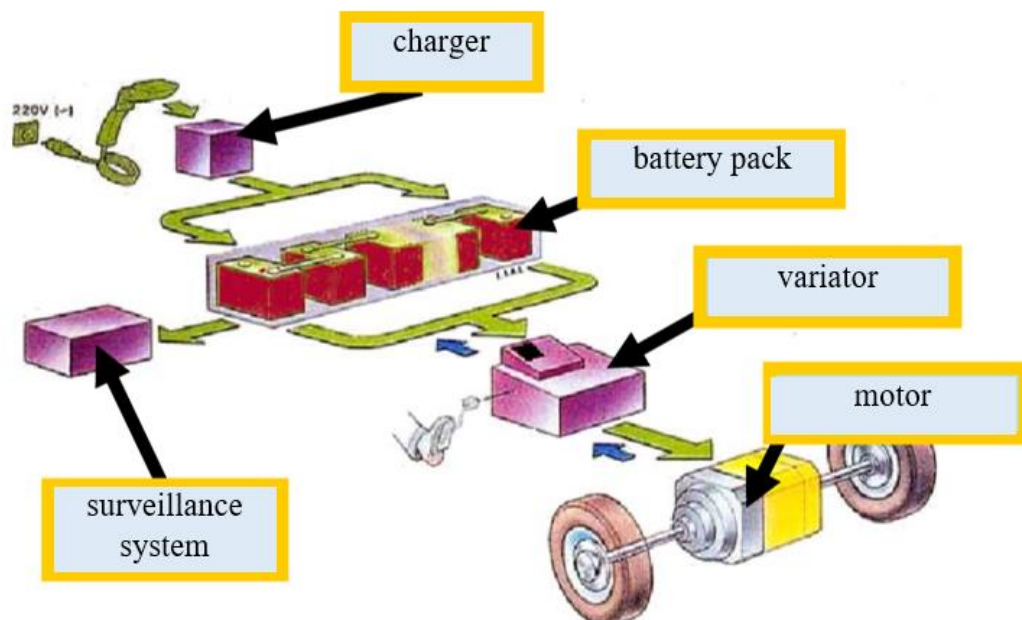


Figure I. 4 : Component of the traction chain of an electric vehicle

I.5.3. Batteries

A battery is an accumulator that converts chemical energy into electrical energy. This technique is ensured during the discharge phase and a small part in heat. For the charge phase, it is the electrical energy that is transformed into chemical energy and another part into heat.

For a Detailed architecture we choose a of VW ID 4 battery:

Battery characteristics:

- Gravimetric Density Energy = 168 Wh/kg
- Usable Energy = 77 kWh to 82 kWh
- SoC Window = 93.9%
- Nominal Voltage = 350.4 V
- Voltage Range = 403.2 V to 240 Min V
- Nominal Capacity = 234 Ah
- Total number of cells = 288
- Configuration = 96s3p
- Pack Internal resistance (estimated from cell data) = 0.05952 Ω
- Main Fuse Rating = A
- Peak Power = 166.7 kW

Structure

- Pack Mass = 489 kg
- Cell Mass = 309 kg
- Pack-Cells = 180 kg
- Cell to Pack Mass Ratio = 63.2 %
- Pack Dimensions = 1820 mm x 1450 mm x 140 mm
- Estimated Volume = 369.46 liters
- Enclosure Materials = Aluminum
- IP Rating = IP6K7

For a VW ID 4 battery. **82 kWh** consisting of **12 modules**, each with an energy density of **6.85 kWh** and **24 cells**. The cells are in **8s3p** configuration while the total cell configuration is **96s3p = 288 cells**. Each module weighs **32 kg**. The total battery weight is **489 kg**.

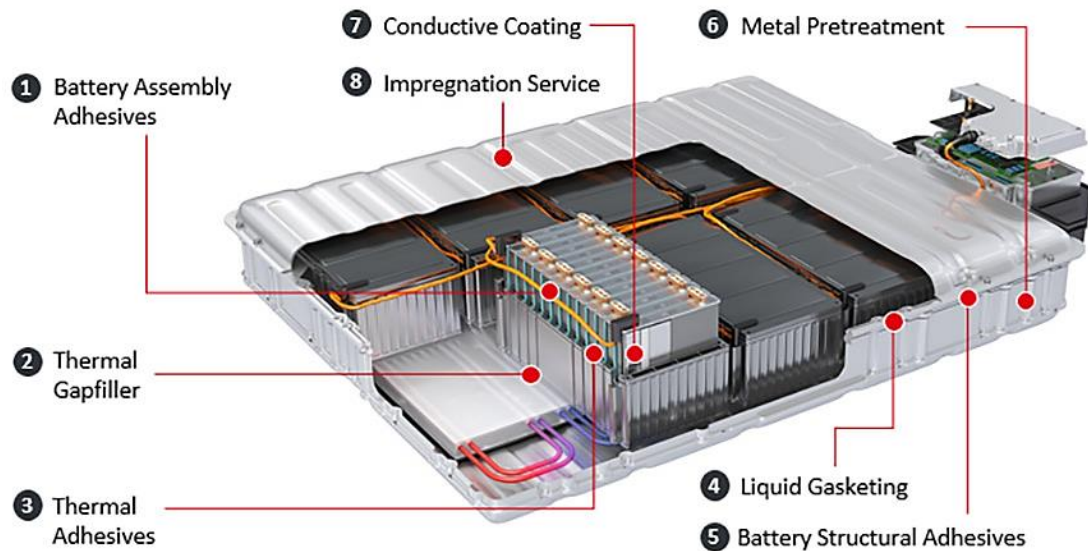


Figure I. 5 : Longitudinal clip of VW ID 4 battery [4]

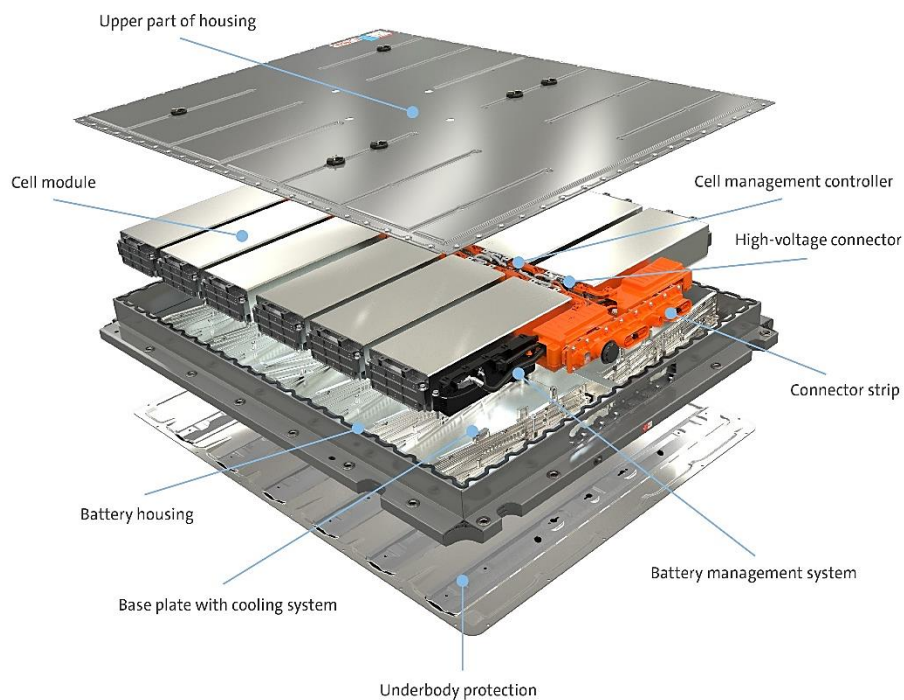


Figure I. 6 : Horizontal clip of VW ID 4 battery [5]

We can see the inlet and outlet of the cooling system (water). Cooling water flows through the aluminum base plate. The cooling plate is composed of two halves with the aluminum plate formed the heating and cooling limits are:

- 8°C (46°F): heating by the PTC Heating Element
- 35°C (95°F) (in vehicle operation): cooling by the heat exchanger or heat condenser
- 30°C (86°F) (during charging): cooling by the heat exchanger or heat condenser

The battery has a heat pump and a normal radiator, thus allowing the system to optimize the thermal energy requirements.



Figure I. 7 : Underside aluminum cooling plate [6]

below (**Figure I. 8**) with cooling channels of the thermal management system brazed and stamped onto the upper base aluminum plate. This is a cut of the entire base plate. The modules also have a thermal paste placed first below the base.



Figure I. 8 : Top aluminum cooling plate [6]

Side and front machined extrusions. These are front, rear, or side collisions. This helps to keep the battery safe. The extrusions are welded together in the corner to form the battery case.



Figure I. 9 : Battery Housing side safety structures [6]

A self-drilling mounting bolt is used to connect the top plate of the case to the battery case. Anaerobic sealing adhesive is also used to prevent leakage

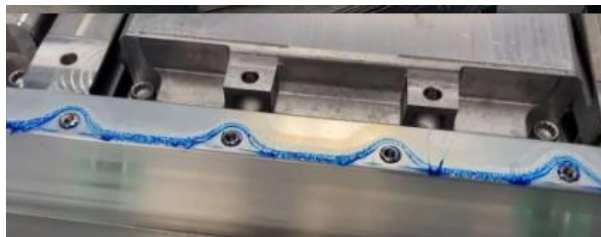


Figure I. 10 : Cross Sections [6]

The underbody protection weighs about 23 kg and is made of aluminum. This prevents stones or other things from entering the battery from below with a thickness of only 1 mm and in case of thermal runaway not a great protection.

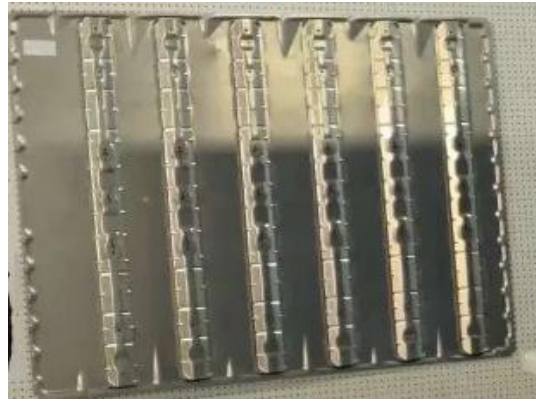


Figure I. 11 : Bottom Cover Tray for Underbody Protection [6]

The central longitudinal extrusion contains 4 cell management controllers (for 12 modules, 1 controller can control 4 modules). The black communication cables connect the 4 cell management controllers to the master BMS. Another connector connects the cell controller to the voltage, current sensors inside the battery module.

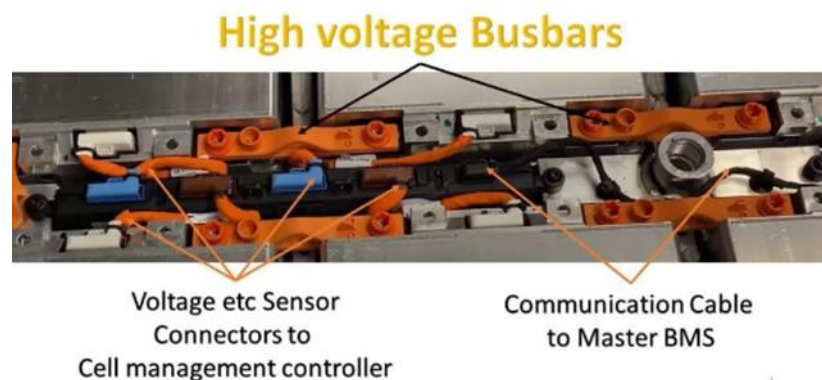





Figure I. 12 : Central channel BUSBAR and BMS connections [6]

The cell controllers are connected to the BMS while the busbars are connected to the HV junction box.



Figure I. 13 : High voltage connector strip [6]

The high voltage connector strip connects the battery to the converter (inverter...

	<p>A battery pack (or battery) is an assembly of modules together to generate a defined voltage. An electronic management system (BMS), sensors and a cooling system are integrated to secure and optimize the operation of the modules.</p>	<p>Number of battery packs in a BMW i3: 1</p> <p>In total, one BMW i3 battery pack includes 8 modules and 96 cells.</p>	<p>Main components</p> <ul style="list-style-type: none"> • cover • Management system electronic • Sensors • Cables • Cooling system
	<p>A battery module is an assembly of cells arranged in series or parallel and protected by a casing against external shocks.</p>	<p>Number of modules in 1 BMW i3 battery pack: 8</p>	<p>Main components</p> <ul style="list-style-type: none"> • cover • Cooling system • Connectors
	<p>A battery cell is the basic unit of a battery pack. A cell consists of two electrodes (the anode and the cathode, which correspond to the poles of the battery), a separator (to avoid contact and short-circuit between the anode and the cathode), immersed in an electrolyte (which ensures the conduction of ions) and connected by current collector</p>	<p>Number of cells contained in 1 battery module of a BMW i3: 12</p>	<p>Main components</p> <ul style="list-style-type: none"> • Electrodes (anode and cathode) • Separator • Electrolyte • Current collector • Housing

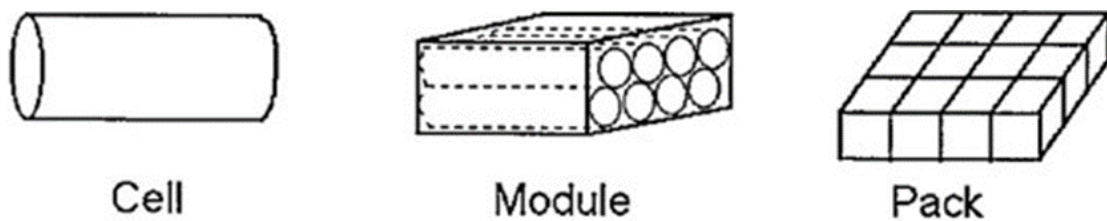


Figure I. 14 : From Cell to Module to Battery Pack [7]

I.5.3.1. The 3 Different Types of Batteries

There are three types of EV battery cells for electric vehicles: cylindrical, prismatic, and pouch. All of these batteries are lithium-ion based with some type of casing. Each type of battery has a specific chemical composition, size, capacity, and lifespan that make them more or less desirable for EVs. Understanding the differences show why a manufacturer may prefer one battery over another.

Cylindrical

➤ **Chemical Composition**

Cylindrical batteries are the classic version of electric vehicle batteries. These batteries are made up with an aluminum or steel casing. The cylindrical shape is created by electrodes and separators layered together and then rolled together.

➤ **Size**

A cylindrical battery comes in a variety of sizes for different applications. For electric vehicles, the sizes of cylindrical batteries are 1850, 21700, and 46800. Compared to the sizing of prismatic and pouch batteries, cylindrical batteries fall in the middle.

➤ **Capacity**

Cylindrical batteries are known for having the highest capacity density with the lowest cost 26,000 mAh

➤ **Lifespan**

Cylindrical batteries have a long lifespan of up to 25,000 cycles.

➤ **Advantages**

- One of the greatest advantages of cylindrical batteries is that these batteries have been made for centuries. Because of this, the production of cylindrical batteries is dependable and experienced. Since the production is standardized, the cost is low for quick production.
- Cylindrical batteries also have high-temperature resistance and can be combined to make a strong battery pack. Notably, Tesla is an advocate for cylindrical batteries.

➤ **Disadvantages**

- Although cylindrical batteries have the advantage of mass production and the ability to combine, these batteries can be weaker than competitors. Because of the cylindrical shape, combining these EV battery cells into a battery pack leaves gaps between cells. The gaps prevent the density from reaching the strength of a pouch or a prismatic battery if those were combined.
- Cylindrical batteries also can be heavy because of their steel or aluminum shells. EVs are known for being lightweight, so cylindrical batteries may have a negative effect.

Prismatic

➤ **Chemical Composition**

Prismatic batteries are made up with an aluminum or iron casing. These types of battery cells get their shape from layered electrode sheets and separators put into a rectangular metal casing.

➤ **Size**

Prismatic batteries are the largest electric vehicle batteries compared to cylindrical and pouch.

➤ **Capacity**

In EVs, prismatic batteries have a high capacity of 20,000 mAh to 30,000 mAh. Because of the rectangular shape of prismatic batteries, they have the ability to combine multiple cells and create a high-capacity battery pack.

➤ **Lifespan**

The lifespan of prismatic batteries is shorter than cylindrical. These electric car batteries have a lifespan of 2,000 cycles.

➤ **Advantages**

- Prismatic batteries have been manufactured for a few decades and are already common in EVs like BMW and Volkswagen. The history of manufacturing means that prismatic batteries are standardized
- Unlike cylindrical batteries, the rectangular shape of prismatic batteries does not leave any gaps when combined for a battery pack. Because of this, manufacturers can easily create battery packs with prismatic batteries that fit their capacity needs.

➤ **Disadvantages**

Although prismatic batteries can reach a high capacity, that is not always optimal. Using a prismatic battery as a battery for an electric car may result in overheating and inconsistencies with density. Additionally, prismatic batteries cost more than cylindrical batteries and do not have as long of a lifespan.

Pouch

➤ **Chemical Composition**

Pouch batteries are lithium batteries with polymer-coated aluminum foil casing, making them different from both prismatic and cylindrical batteries. Pouch batteries contain electrodes and separators layered within a sealed flexible foil container.

➤ **Size**

Pouch batteries are the smallest of the three types of electric vehicle batteries. Pouch batteries are both small in length and weight. They're often used in portable devices like phones but can be used for EVs too.

➤ **Capacity**

Although pouch batteries are small, they are still mighty. They can fulfill the same power as cylindrical batteries with the same capacity. Because of this, manufacturers may choose pouch batteries over cylindrical batteries if space is limited.

➤ **Lifespan**

Pouch batteries have the same lifespan as prismatic batteries, which is 2,000 cycles.

➤ **Advantages**

Pouch batteries are flexible for a range of sizes because of their lightweight and small size. Even more, pouch EV battery cells compete with cylindrical batteries in capacity and prismatic batteries in lifespan. Because of this, manufacturers may choose pouch batteries over alternative electric car batteries because of their lightweight and small size.

➤ **Disadvantages**

Pouch batteries are relatively new to the EV battery world. Because of this, pouch batteries have high costs for production and use. Additionally, pouch batteries have low mechanical resistance, which can be risky when putting these batteries into cars. Critics of pouch batteries often cite the possibility of dangerous overheating, known as thermal runaway, as a reason to not use pouch batteries

The cell is composed of

- A cathode
- An anode
- A separator
- An electrolyte.

- **Anode and cathode**

These two terms are used to define the input and output points of electric current, terminals or electrodes, of a cell or battery. The negative (-) terminal of a battery corresponds to the anode where the oxidation reaction occurs that will supply the electrons. The positive (+) terminal of a stack corresponds to the cathode where the reduction reaction occurs that will consume the electrons.

- **Separator**

It is an essential component of a battery, serving as an electrically isolated membrane between anode and cathode. During the charging process, it facilitates the exchange of lithium ions from anode to cathode, and vice versa during discharge.

- **Electrolyte**

Immersed in a liquid, gel, or solid electrolyte, the electrodes – anode and cathode – react to create an electric current. This electrolyte ensures the transport of electricity by ionic conduction. According to technological progress, its nature is adapted to obtain the characteristics that best fit the use that we want to make of the batteries.

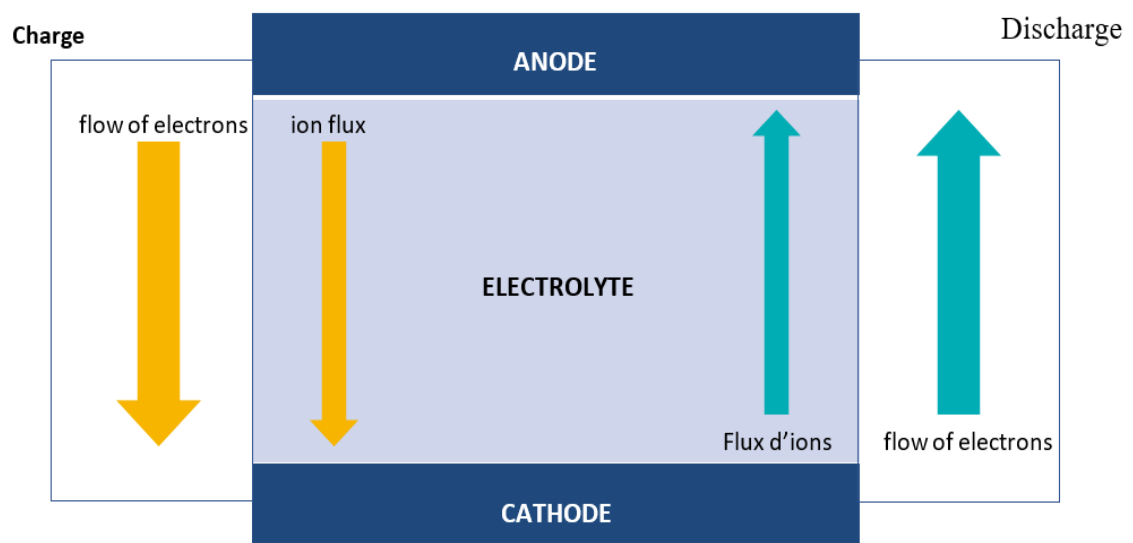


Figure I. 15 : Operation process of battery

1.5.3.2. Notions of electrochemistry and electronics

Batteries, like electric cells, are electrochemical generators. In other words, they produce electricity from chemical reactions. They are studied and developed in a scientific discipline called electrochemistry, which focuses on the relationship between chemistry and electricity. Electrochemistry describes the reactions and phenomena that take place at the interface of two conducting systems, at the level of atoms. These are chemical reactions and phenomena coupled with reciprocal exchanges of electrical energy.

These energy exchanges, both electronic and ionic, take place when one or more electrons transfer their charge, producing electricity.

I.5.3.3. Comparison of different battery technologies

The technical elements of comparison are:

- **Energy density:** The energy density of a battery is used to determine the amount of electrical energy (Watt hour) it contains per volume or per unit of weight. Two units of measurement are used: Watt hours per liter (Wh/L) or Watt hours per kilogram (Wh/kg).
- **Lifetime:** Battery life is also a key criterion for comparison. Indeed, their performance deteriorates over time and some technologies are much more enduring than others. The criterion used is the number of charge and discharge cycles. In other words, the number of times you will be able to «refuel» before having to replace the batteries. Lifetime, an essential factor, reaches or exceeds 1500 cycles and more of the available technologies.
- **Fast charging:** In mobility-related applications this factor is becoming increasingly important. The most advanced technologies accept higher and higher load currents to reduce the downtime of cars. The charging time is expressed in hours or minutes for the fastest technologies to power.
- **Environmental performance:** for electric cars to assess its advantages and disadvantages, The aim is to improve the future ecological performance of electric cars to get out of the dependence of fossil fuels like gasoline.

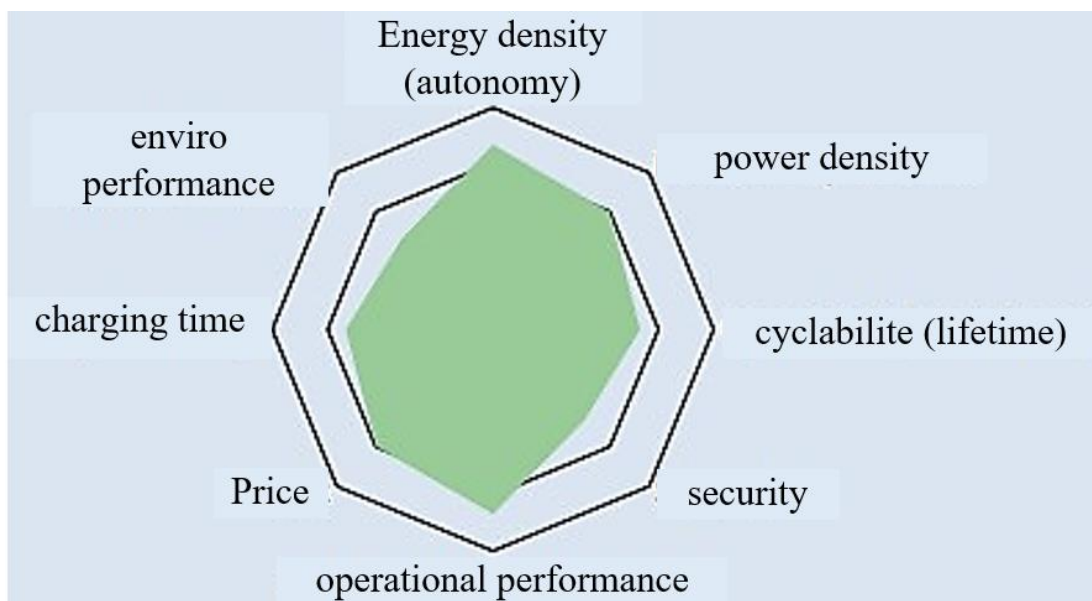


Figure I. 16 : Technical elements of comparison

I.5.3.4. Main electrochemical materials of batteries

Are:

- Lead-acid battery
- Nickel/Cadmium (Ni-Cd)
- Nickel-metal hydride (Ni-Mh)
- Lithium/Ion (Li-Ion)
- Lithium/Polymer (Li Po)
- Lithium/iron/Phosphate (LFP)
- Lithium/Metal Polymer (LMP)
- Nickel/Manganese/Cobalt (NMC)
- Nickel/Cobalt/Aluminum (NCA)
- Lithium/Cobalt/Oxide (LCO)



Figure I. 17 : Different type of materials in battery

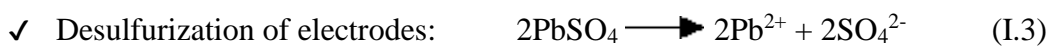
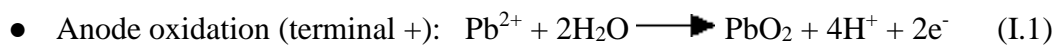
Research has focused on batteries that can hold as much energy as possible in the smallest possible volume, while being the lightest and, of course, the cheapest to mass-produce.

I.5.3.4.1. Lead-acid battery

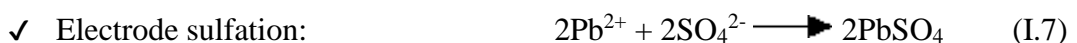
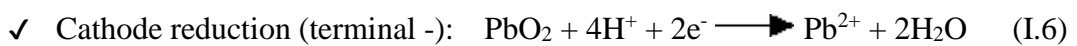
This technology offers high throughput performance, moderate performance at low and high temperatures, easy indication of state of charge and good charge retention for intermittent load applications. There are few disadvantages such as: low energy density and long charge time, heavy and it requires careful maintenance.

The charge in the lead-acid battery forms the solids in the electrodes and the H⁺ ions in the electrolyte.

Lead sulfate PbSO₄ disappears from the electrodes



The discharge of the lead-acid battery consumes the solids in the electrodes and the H⁺ ions in the electrolyte (the acid concentration decreases and the pH increases).



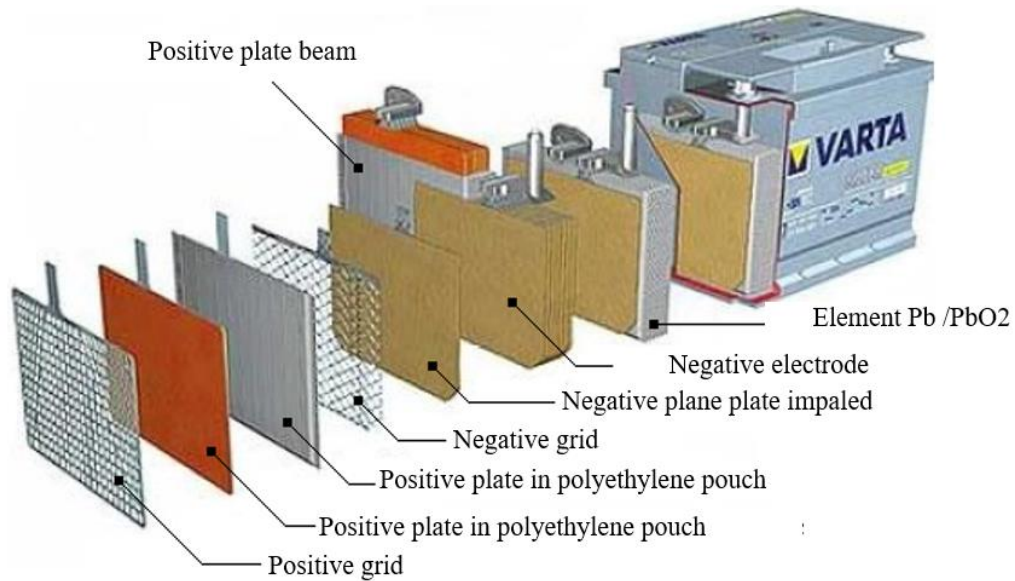


Figure I. 18 : Scheme of a flat, pasted, grid type accumulator.

I.5.3.4.1.1. Manufacturing process

- Method of manufacturing a negative plate:

for lead acid battery including the steps of: addition of a polymer binder to a paste comprising tribasic lead sulfate crystals having a desired crystal morphology and bonding of the polymer-containing paste to a grid where the paste is dried to form a battery plate for a lead-acid battery acid, characterized in that the morphology of the crystals of the active material of said battery plate is appreciably formed before bonding and in that no steam proofing or curing step is required.

Positive plate manufacturing process

For lead acid battery including steps of

a) mixing and reacting oxidised lead powder, water and sulfuric acid in a closed reactor to produce a paste comprising crystals of tetra-basic lead sulphate having a desired crystal morphology

b) adding a polymeric binder to the paste obtained in step 'a' and bonding the polymer-containing paste to a grid where the paste is dried to form a battery plate for a lead-acid battery, characterised in that the crystal morphology of the active material of said battery plate is substantially formed prior to bonding and in that no steaming or curing step is required.[8].

I.5.3.4.2. Nickel-cadmium

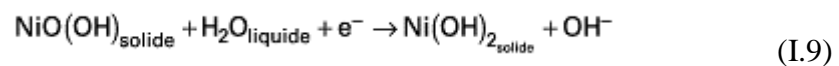
Nickel-cadmium (Ni Cd) batteries are an important part of rechargeable battery technology, using nickel oxide-hydroxide for the positive electrode, cadmium for the negative electrode and an alkaline electrolyte. These batteries have a well-defined production process, offer a wide range of applications, exhibit efficient discharge, extended storage life and require responsible environmental practices.

I.5.3.4.2.1. Manufacturing process

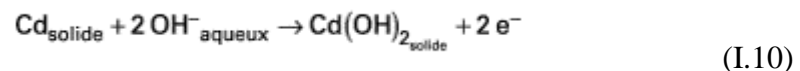
Ni Cd batteries are built using nickel oxide-hydroxide and cadmium as the main active materials. Production involves the preparation, assembly and sealing of the electrodes in an alkaline electrolyte. The process focuses on precision to ensure appropriate chemical reactions, leading to stable and efficient battery performance [9].

The electrochemical half-equations describing the discharge reactions are:

for the positive electrode:



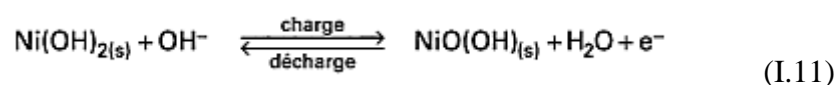
for the negative electrode:



I.5.3.4.3. Nickel-metal hydride (Ni-MH)

Nickel-metal hydride (Ni-MH) batteries have an energy density 1.5 to 2 times higher than that of Ni-Cd. They have a high-power capacity, an overload/discharge tolerance, as well as environmental compatibility and safety, this makes them suitable for portable power tools and VHE.

The negative electrode, which is a mixture of metal hydrides, consists of a potassium hydroxide electrolyte and a positive electrode whose active material is nickel hydroxide. The reaction can be written as:



The negative electrode reaction occurring in a NiMH cell is



On the positive electrode, nickel oxyhydroxide, NiO(OH), is formed:

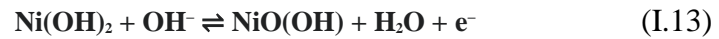


Figure I. 19 : High power Ni-MH battery of Toyota NHW20 Prius, Japan [10]

I.5.3.4.3.1. Manufacturing process

Equipped with a safety device and metal housings and covers, both of which are insulated with a gasket. The lower part of the casing is the negative terminal, and the upper part is the positive terminal.

In all forms of design, whether for cylindrical, prismatic or button cells, the cathode is either sintered or bonded.

The positive electrode of the cylindrical Ni-MH cell is a porous sintered substrate or an impregnated or bonded nickel substrate that is then converted to active material by electroplating.

The substrate serves as a mechanical support for the sintered structure and acts as a current collector for electrochemical reactions that occur in porous plates. It also ensures mechanical strength and continuity during manufacturing processes. Perforated strips of nickel-plated steel or pure nickel are used in continuous lengths, or screens woven of nickel wire or nickel-plated steel. A common perforated type can have a

thickness of 0.1 mm with 2 mm holes and a vacuum zone of about 40%. Expanded metals and perforated sheets are less expensive, but their ability to achieve high rates is poor. Sintered structures are much more expensive but are suitable for high discharge performance.

Foams have generally replaced sintered plate electrodes similarly the negative electrode is also a very porous structure using a perforated nickel sheet or grid on which is applied the active hydrogen storage alloy with plastic binder. The electrodes are separated by a synthetic non-woven material, which serves as an insulator between the two electrodes and a support to absorb the electrolyte. [11]

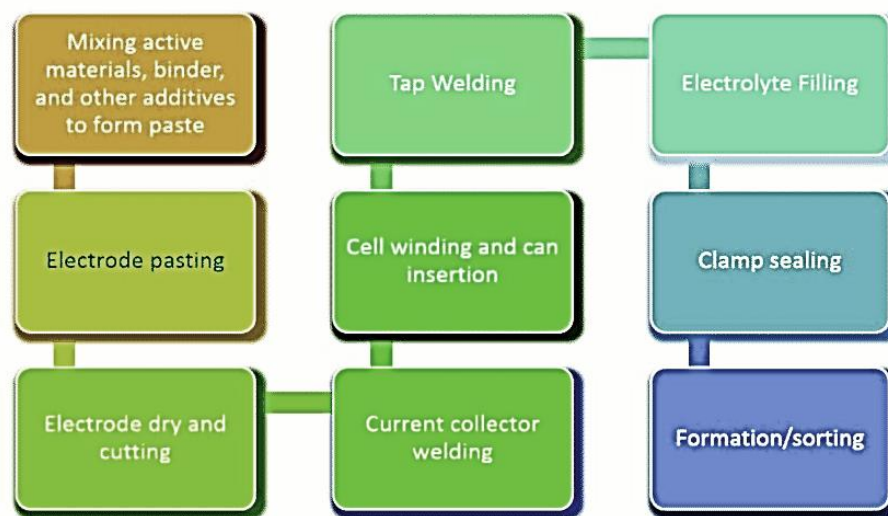


Figure I. 20 : Schematic diagram showing the supply chain for the nickel/metal hydride (Ni/MH) battery industry.

I.5.3.4.3.2. Memory effect

This phenomenon occurs mainly on the nickel-cadmium battery or accumulator (NiCd), which was widely used on battery tools. On this accumulator, the effect is caused by the formation of crystals on the cadmium cathode. If the battery is not fully discharged before recharging, crystals tend to form in the part that is not discharged.

The voltage decreases as the size of the crystals increases, as the crystals reduce the conductivity of the material. Similar phenomena are observed in nickel-metal hydride (NiMH) batteries to a lesser extent.

When recharging a NiCd battery or accumulator, micro-crystals of cadmium are formed. If the battery is slightly discharged repeatedly, micro crystals become larger crystals in the part that has not been discharged.

Since larger crystals have a smaller surface area than micro-crystals of the same mass, they react less well during discharge, in other words, the available voltage decreases. [12]

I.5.3.4.4. Lithium-ion

The idea of the lithium-ion battery was first proposed in the 1970s, when British chemist **Stanley Whittingham** invented a battery that could recharge itself over time.

In the 1990s, Li-ion technology began to gain popularity, rapidly increasing its popularity. What lithium metal batteries have higher energy density, Li-ion battery is very safe when charged and discharged according to specific safety guidelines. [13]

The lithium battery separator moves lithium ions from the cathode to the anode and vice versa through the electrolyte.

When lithium ions move, they activate the free electrons in the anode, which creates a charge at the positive current collector. Then, this electric current flows through the VE system to the negative current collector. The flow of electrons inside the battery is blocked by the separator.

The reduction takes place on the cathode side. Here, cobalt oxide combines with lithium ions to form lithium and cobalt oxide (LiCoO_2). This gives half-

Oxidation takes place on the anode side. There, the graphite intercalation compound (LiC_6) forms graphite (C_6) and lithium ions.

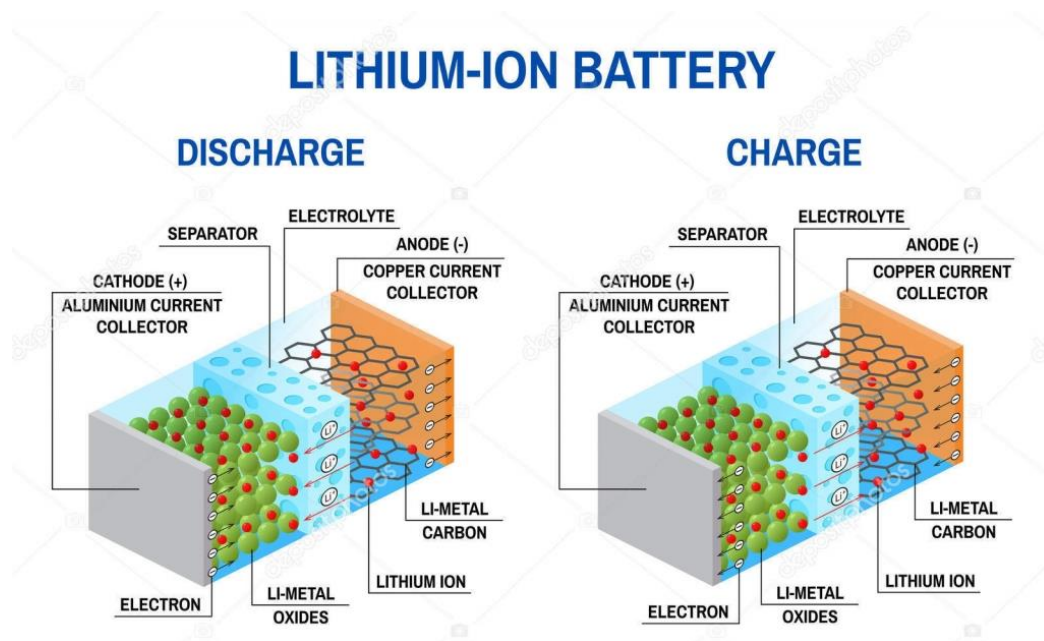


Figure I. 21 : Li-ion battery diagram [14]

The key manufacturing processes are performed under vacuum. Our vacuum solutions are used in major lithium-ion battery manufacturing sites worldwide. They are renowned for their reliability at all stages of lithium-ion battery manufacturing.

Vacuum is essential in all stages of lithium-ion battery manufacturing. From mixing, drying, filling, degassing to sealing. Without the vacuum, many steps would not even be possible.

Suspension mixing

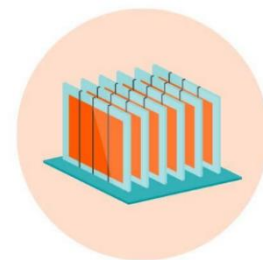
The initial mixing process of the suspension with lithium metal oxides, adhesives and solvents takes place under vacuum. This prevents air bubbles from entering the process and ensures a pure and homogeneous paste.



Suspension drying

Vacuum is used in the drying process to gently remove moisture and other solvents.

Vacuum drying can be done in batches (single chamber) or online (multi-chamber system, typically seven to nine chambers). [15]



Electrolyte filling

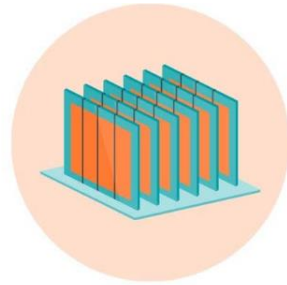
The cell is vacuumed to ensure there is no moisture or air left. Then, the electrolyte is also filled under vacuum for uniform distribution of the electrolyte in the cell. [15]



Impregnation of the lithium-ion battery cell

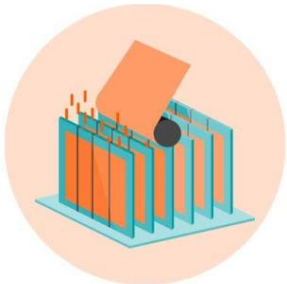
Contact between the electrode and the electrolyte is essential for the operation and efficiency of the battery cell.

The vacuum assists this process to ensure a vacuum-free contact. [15]



Degassing of the electrolyte

The electrolyte is degassed under vacuum to eliminate air bubbles. This allows lithium ions to move freely, allowing the battery to be charged and discharged efficiently. [15]



I.5.3.4.5. Lithium/Polymer (Li Po)

Lithium-ion polymer (Li Po) (also known as Li-Pol, lithium-poly and other names) is a type of Li-ion battery with a polymer electrolyte instead of a liquid electrolyte. All LiPo batteries use a high conductivity polymer gel as the electrolyte. Lithium polymer cells have evolved from lithium-ion and lithium-metal batteries. The main difference between lithium-ion and Li-Pol is that instead of using a lithium salt liquid electrolyte (such as LiPF_6) contained in an organic solvent

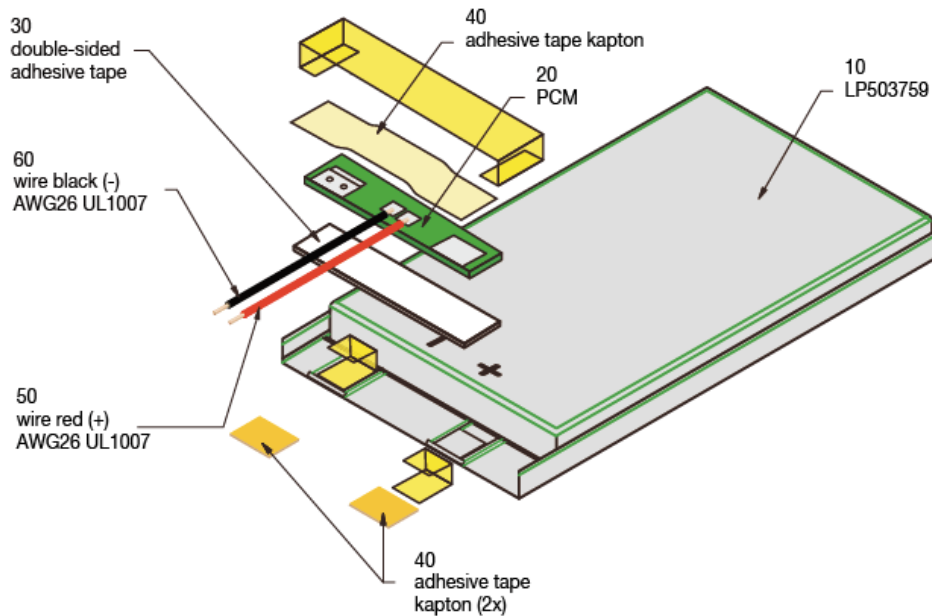


Figure I. 22 : *Lithium Polymer Battery [16]*

Lithium ion moves from one electrode to another, and technologies differ in the construction of electrodes that will absorb (and stabilize) lithium.

The anode (the negative pole) almost always consists of graphite, which easily absorbs lithium ions, while the batteries differ only in the composition of the cathode. LFP batteries have an iron phosphate cathode. The electrolyte allows the lithium ion to move from one pole to another.

The electrolyte is liquid but not aqueous: this is important because lithium in its metallic state reacts strongly with water. The semi-permeable membrane only allows the transfer of lithium ions.

I.5.3.4.6. Lithium/iron/ Phosphate (LFP)

An LFP battery, part of the Li-ion battery family, naturally consists of an anode, cathode, electrolyte, separator and other components. The anode is composed of graphite, copper plate, conductor, PVDF binder and additives. Similarly, the cathode is composed of an active material, aluminum plate, electrical conductor, PVDF binder and additives. LiFePO_4 material with olivine structure is used as an active material due to its appropriate performance. This powder active material is coated on an aluminum sheet (Al) at the cathode.

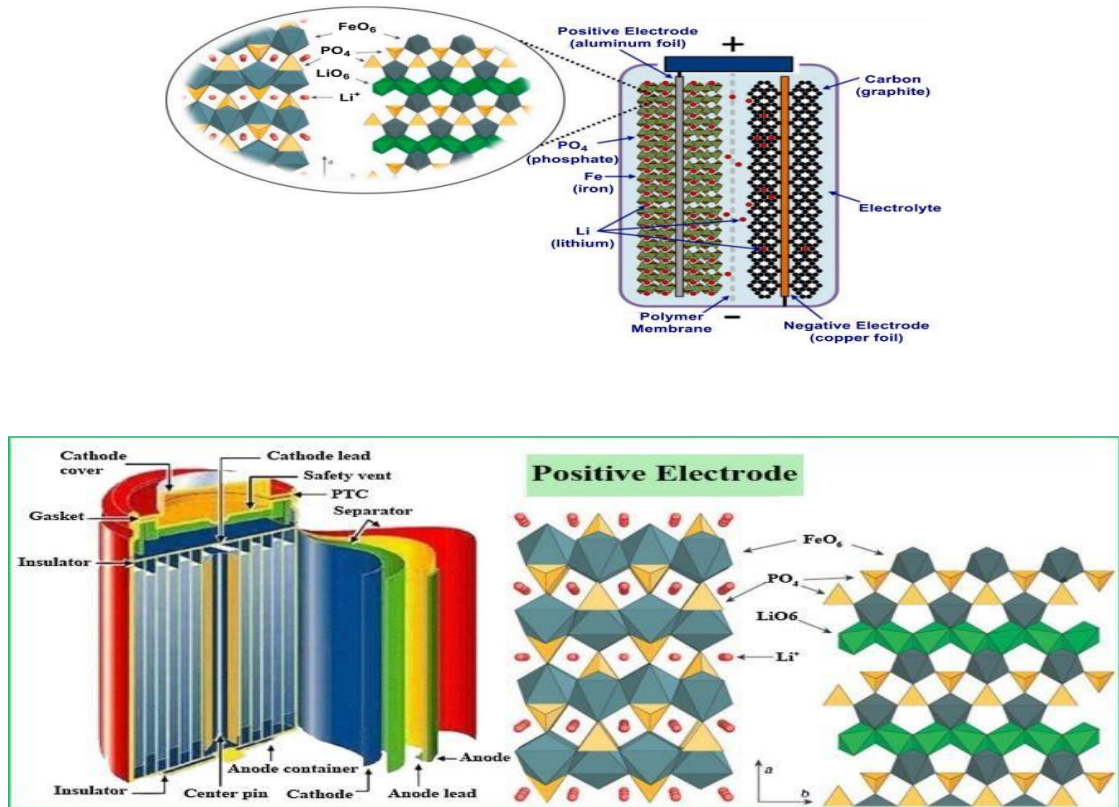


Figure I. 23 : Internal structure of a LiFePO₄ battery

I.5.3.4.6.1. Composition of a LFP battery cell

When LFP batteries discharge, lithium molecules at the negative electrode detach from graphene layers, becoming lithium ions and electrons. Electrons exit the anode when lithium ions move through the separator. Then, lithium ions are integrated into the iron phosphates located at the cathode

During charging, lithium separates from iron phosphates, which generates lithium ions and electrons. The resulting lithium ions and electrons are transferred to the anode, which then integrate into the graphene structure. [17]

Electrode	Electrochemical Reactions
Anode	$\text{Li}_n\text{C}_6 \rightleftharpoons \text{Li}_0\text{C}_6 + n\text{Li}^+ + n\text{e}^-$
Cathode	$\text{Li}_m - n\text{FePO}_4 + n\text{Li}^+ + n\text{e}^- \rightleftharpoons \text{Li}_m\text{FePO}_4$
Overall	$\text{Li}_n\text{C}_6 + \text{Li}_m - n\text{FePO}_4 \rightleftharpoons \text{Li}_0\text{C}_6 + \text{Li}_m\text{FePO}_4$

I.5.3.4.7. Lithium/Metal Polymer (LMP)

LMP batteries are one of the current technological variations that use lithium in the service of electromobility, these are solid state batteries because the electrolyte is solid. At the heart of the cells, the electrodes are separated by an electrolyte composed of a mixture of lithium salt and a solvent. The anode contains metallic lithium, the cathode a compound of vanadium oxide, carbon and polymers. This technology has a major difficulty: MRLs must be maintained at a temperature of approximately 60°C. [18]

This almost imposes to keep them in charge by leaving the electric cars that operate them connected to the sector when they do not drive

It comes in the form of a thin film rolled up. This film, with a thickness of about a hundred micrometers, is composed of

- ✓ Anode: lithium strip
- ✓ Electrolyte: composed of polyoxyethylene (POE) and lithium salts
- ✓ Cathode: composed of vanadium oxide, carbon and polymer

I.5.3.4.8. NCA Battery

At a 9% share of the international market which is quite low, NCA batteries share many similarities with NMC batteries, as they both have a layered cathodic structure. However, in NCA batteries, aluminum replaces manganese from NMC technology.

This has the effect of improving the specific energy and lifetime compared to NMC batteries. NCA batteries also have a high gravimetric capacity of 200 mAh*g⁻¹ compared to LMO and LFP batteries at 148 mAh*g⁻¹ and 170 mAh*g⁻¹, respectively. [19]

The main disadvantage of NCA batteries is that they are not as safe as other types of batteries. They require special monitoring measures for their safe use in applications such as EVs. NCA technology is historically favored by Tesla: the giant of electromobility

I.5.3.4.9. NMC battery

NMC batteries lead the world market with 41% Li-ion batteries, The combination nickel-manganese-cobalt provides a high energy density and mass power compared to Li-ion batteries.

These qualities are at the origin of the application of this technology in the automotive sector (BMW, Audi, Nissan, Renault, etc.). There are different combinations of nickel-manganese-cobalt (molar ratios): NMC111 (one-third nickel, one-third manganese and one-third cobalt), NMC523 (50% Ni, 20% Mn and 30% Co) or NMC622.

NMC technology has improved life cycle, thermal stability and energy density compared to LFP batteries. [19]

I.5.3.4.10. LCO battery

According to AEB (2020), LCO technologies occupy 11% of the Li-ion battery cathode production market.

They have an excellent charge/discharge rate and high power and energy densities: hence their common use in portable electronic devices

However, OCH cathodes do not have good thermal stability and cobalt is a toxic material. [19]

Therefore, this type of batteries does not have the performance required for applications such as hybrid electric cars (HEVs), plug-in hybrid electric cars (HEVs) and EVs.

I.5.3.5. Comparison of different EV battery technologies

There are several battery technologies with different characteristics for each type, we will see the advantages and disadvantages of each model Let's start with the

Table I. 2 : Comparison of different EV battery technologies

12	lead	Ni-Cd	Ni-MH	zebra	Li-phosphate	Li-Ion	Li-polymer
Mass energy [W/kg]	30-50	45-80	60-110	120	120-140	150-190	150-190
Energy density [Wh/liter]	75-120	80-150	220-330	180	190-220	220-330	220-330
Mass power [W/kg]	To 700		To 900	200	To 800	To 1500	To 250
number of cycles	400-600	2000	1500	800	>2000	500-1000	200-300
self-charging per month	5%	20%	30%	12% per day	5%	10%	10%
nominal voltage [V]	2	1.2	1.2	2.6	3.2	3.6	3.4
temperature	-20 to 60° C	-40 to 60° C	-20 to 60° C	-20 to 50° C	0 to 45°C (charge) - 20 to 60° C (discharge)	-20 to 60° C	0 to 60° C
Advantage	Low cost	reliability and performance	very good energy density	good energy density, good cyclability	very good energy density cost cyclability	excellence energy and power	thin battery
disadvantage	low energy	relatively low	cost of basic materials high	limited self-	charge a temperature positive	security cost	cost-limiting

	sudden death	energetic pollutant	danger under high temperature	consumption			performance
Cost [dollar/kWh]	300 to 250	800 to 1200	2000 to 2500	1000 to 1500	1500 to 2000	2500 to 3000	2000 to 2500

A classical representation consists in comparing them on a Ragone diagram according to the specific powers and Energy they can offer. Most of them are represented in the form of a band, because they can be designed by being rather oriented “power”, “energy”, or a trade-off between the two.

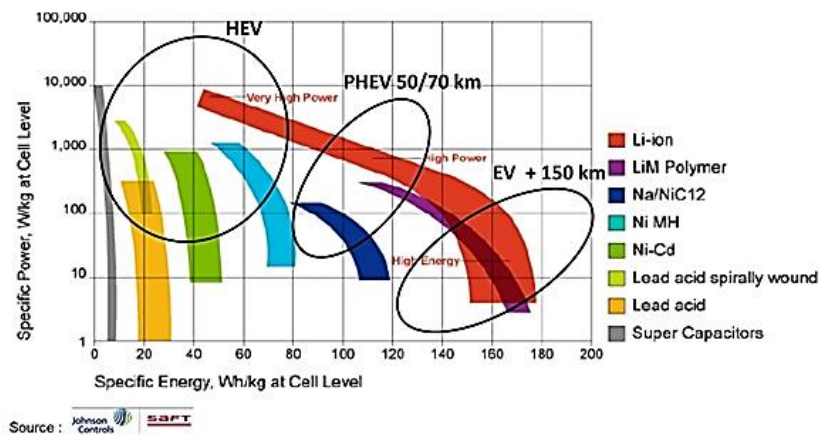


Figure I. 24 : the Ragone diagram shows the main performances of these different battery torque.[20]

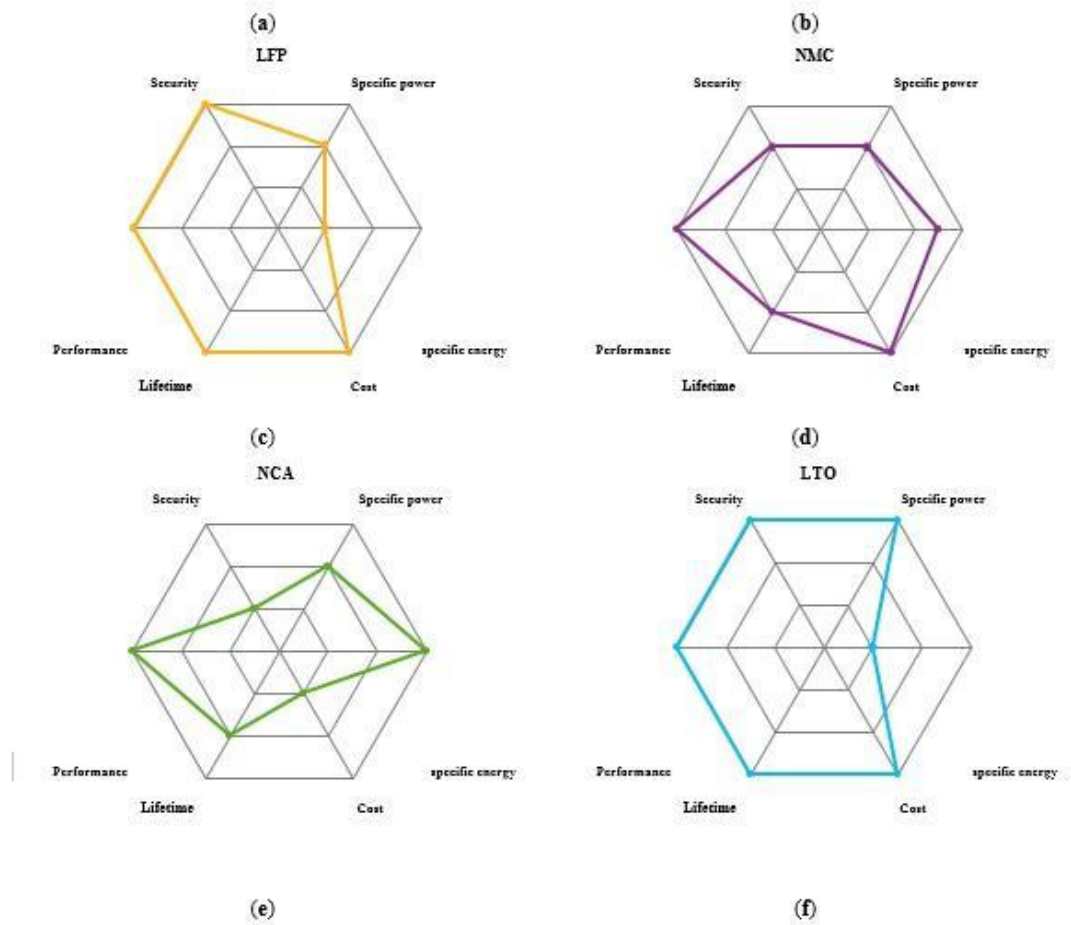


Figure I. 25 : Comparison of lithium-ion (Li-Ion) technology. (a) LCO; (b) LMO; (c) LFP; (d) NMC; (e) NCA; (f) LTO.

I.6. Conclusion

In this chapter, we presented a general overview of electric vehicles. We cited a historical overview of EV and then we presented the architecture of the EV powertrain, emphasizing the different battery technologies available in details.

We can note that the development of batteries effect positively on EV, so those can the main key of competitive car constructors.

Chapter II:

The innovative ideas



II.1. Introduction

We predict that several million electric vehicles will be in circulation by 2050. To boost the car of tomorrow and open up even more possibilities, we are discussing and showcasing the most innovations that will allow a real boost to this sector.

In this chapter, which is concerned with new and innovative ideas related to the development of electric cars, we focused on batteries and the extent of development in their performance by virtue of the battery's monopoly of 30-40% of the price of the EV, as well as the significant spatial space, and other ideas related to the energy distribution system.... were mentioned.

II.2. Criteria for evaluating new ideas

The main avenues of research for the battery of the future focus largely on 4 areas: increasing performance in terms of energy and power, and lowering the price of batteries. At the same time, manufacturers are striving to improve the safety and reliability of their solutions, while improving the environmental impact of their products and their supply chain (Corporate Social Responsibility).[21]

- **Lower battery prices**
- **Increased performance**
- **improving security**
- **Improving CSR** (Corporate Social Responsibility)

see following (*Table II. 1*):

Table II. 1 : Strategic Research Agenda for batteries [22]

Active Materials Generation		Type of chemistry	Market launch
1	Cathode: LFP, NCA Anode: 100% carbon	Li-ion cell	Marketed
2a	Cathode: NMC111 Anode: 100% carbon	Li-ion cell	
2b	Cathode: NMC523 to NCM622 Anode: carbon	Li-ion cell	

3a	Cathode: NMC622 to NMC811 Anode: carbon (graphite) and 5 to 10% silicone	Optimised li-ion cell	2020
3b	Cathode: high-energy NMC (HENMC), high-voltage spinel (HVS) Anode: silicon / carbon	Optimised li-ion cell	2025
4a	Cathode: NMC Anode: silicone / carbon Electrolyte: solid	All-solid-state Li-on	2025
4b	Cathode: NMC Anode: lithium metal Electrolyte: solid	All-solid-state Li-on	after 2025
4c	Cathode: high-energy NMC (HENMC), high-voltage spinel (HVS) Anode: lithium metal Electrolyte: solid	Advanced all-solid-state Li-on	2030
5	Lithium-air / metal air; Lithium-Sulphur; Sodium-ion, aluminum-ion, manganese-ion	New cell; New conversion chemistry; New insertion chemistry	after 2030

- The price of batteries is at the heart of the race by manufacturers in the sector to conquer the automotive market.** The difference in price between an internal combustion vehicle and an electric vehicle is one of the main reasons for not buying one. Batteries account for between 30% and 40% of the price of an EV, making them one of the main cost reduction areas targeted by manufacturers.

- **Between 2010 and 2019, the average price of an automotive battery pack has fallen by 87%**, thanks to the innovative efforts of the industry. The main levers for reducing costs are innovation (in cell chemistry as well as product design and the industrialisation of manufacturing processes) and the race for volume, particularly via mega-plants, to achieve economies of scale.

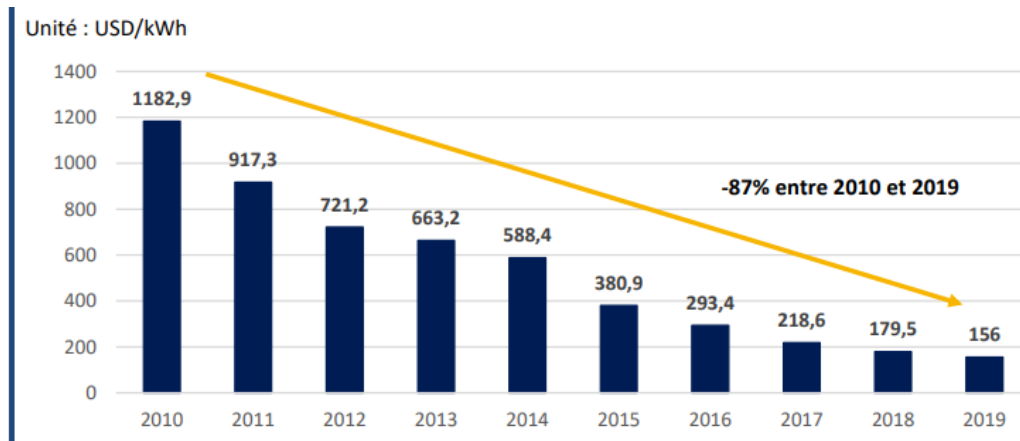


Figure II. 1 : Evolution of li-ion battery price [23]

Lithium-ion chemistry has been the focus of much of the effort devoted to developing future batteries using new cathode, anode and electrolyte materials. A technology roadmap has been regularly updated since 2017.

- **Patent filings for the 5 main types of lithium-ion battery cathode (NMC+, LCO, LMO, LFP, NCA) have risen sharply:** 2,184 international patent families were filed between 2014 and 2018, compared with 1,445 between 2009 and 2013. This strong growth is driven by NMC technology.
- The total number of patents filed for this type of cathode rose by more than 100% between the two periods, while the number of patents filed for NCA jumped by 187%. These two technologies are of interest to the automotive industry because of their high mass energy density. By contrast, filings for LFP fell by more than 12%.
- **One of the main avenues of development is to reduce the proportion of cobalt used in the manufacture of cathodes,** in particular NMC, which is an expensive mineral with decried socio-environmental performance, but whose presence improves battery life (cyclability).

- This is one of the key issues in the transition from one battery generation to another. After generation **2a**, which contained a third of cobalt (NMC111), generation **2b**, which has been deployed on the market, has reduced this proportion to 30% (NMC523) and 20% (NMC622). The currently deployed **3a** generation has decreased this share to 10% (NMC811) and ongoing R&D work is trying to increase this share to 5% (NMC955).

II.3. Idea 01: Solid state battery

A solid-state battery is a battery technology that uses a solid electrolyte instead of the liquid electrolyte that forms the basis of lithium-ion technology.

The internal structure of a solid-state cell, however, is very different, as all its elements are solid. While traditional lithium batteries use a liquid electrolyte, solid-state cells are made up of: A cathode (or positive electrode), which can be made with the same components as a lithium-ion battery (for example LFP, NMC, LMO, etc.). A separator, usually made of ceramic or a solid polymer, which also acts as an electrolyte.

- An anode made of lithium metal (pure lithium)

Solid-State Lithium-Metal Batteries

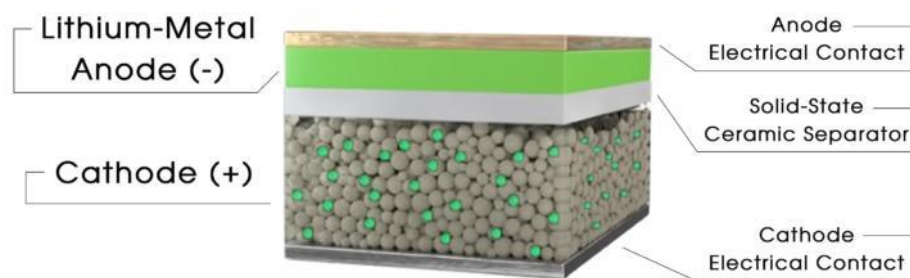


Figure II. 2 : Solid-state lithium-metal battery [24]

The central grey layer is the solid-state separator which, on its own, acts both as a separator between the anode and cathode and as an electrolyte. It therefore becomes the intermediary through which the ions move and also has the properties of electrical

insulator and mechanical separator between the anode and cathode. Having this solid, resistant support means that the graphite structure on the anode can be eliminated and the lithium in metallic form can accumulate directly on the anode (there are also semi-solid solutions in which the electrolyte is made of gel).

II.3.1. The working principle of a solid-state battery

When the cell is charged, the lithium particles move away from the cathode, passing through the structure of the atoms that compose the separator, and are then placed between the separator and the electrical contact of the anode, forming a solid layer of pure lithium. In this way, the anode is composed solely of the lithium particles and is smaller than the anode of lithium-ion technology, which contains the graphite structure. [25]

II.3.2. Benefits and inconvenient

Solid-state batteries promise many improvements over batteries currently available on the market: solid electrolyte seems to be able to offer **higher energy density, longer life, greater resistance to dendrites, ultra-fast charge times, faster production** and **greater safety**, all in a reduced volume.

However, it is important to remember that this technology is still in the development phase and that to date: **Stability problems, A separator that performs only at high temperatures, Life cycles that are still low, High cost.**

Li ion batteries are still the best performing technology on the market. In fact, they have a number of chemical formulas, each adapted to different purposes, which are immediately available and produced on a large scale. For this reason, we have compared the solid battery with Li ion

II.3.3. Comparing between solid state and li-ion

Table II. 2 : Advantages of all-solid lithium battery technology over lithium-ion technology [26]

Note: 0: lower than li-ion, 1: equivalent to li-ion, 2: higher than li-ion, 3: significantly higher than li-ion

Batterie tout-solid, anode Li-metal	Critter	Note
<p>The radar chart displays performance metrics for all-solid lithium batteries. The criteria and their scores are: Cost (1), Gravimetric density (3), Volumetric density (3), Availability of materials (1), and Life span (1). The 'Level of technological maturity' is indicated as 5/11.</p>	Cost	1
	Gravimetric density	3
	Volumetric density	3
	Availability of materials	1
	Life span	1
	Level of technological maturity	5/11

II.4. Idea 02: Lithium-air battery

The lithium-air battery is identified as **the 5th** generation of batteries. But a number of other technologies are also being developed, such as **sodium-ion technology, developed in France by Tiamat, and lithium-air... [27].**

The quantity of energy that can be stored depends in particular on the volume of the reservoirs, which can be easily resized thanks to a radically different design from lithium-ion batteries.

Like all galvanic cells, the cells of a lithium-air battery require two electrodes and an electrolyte that transports the ions (electrically charged atoms) and thus conducts the energy. In this respect, the lithium-air battery is similar to a lithium-ion battery. However, there are some key differences in its construction compared with conventional lithium-ion technology:

- While conventional lithium-ion batteries have a graphite anode and a cathode based on various lithium metal oxides, a lithium-air battery has only a lithium negative electrode (anode). This metal is characterised by a particularly high

electrochemical potential, which is essential for achieving very high energy density.

- The positive electrode (cathode) is made of carbon in a nano grid structure to create as large a reaction surface as possible. The oxygen required for oxidation is taken from the ambient air.

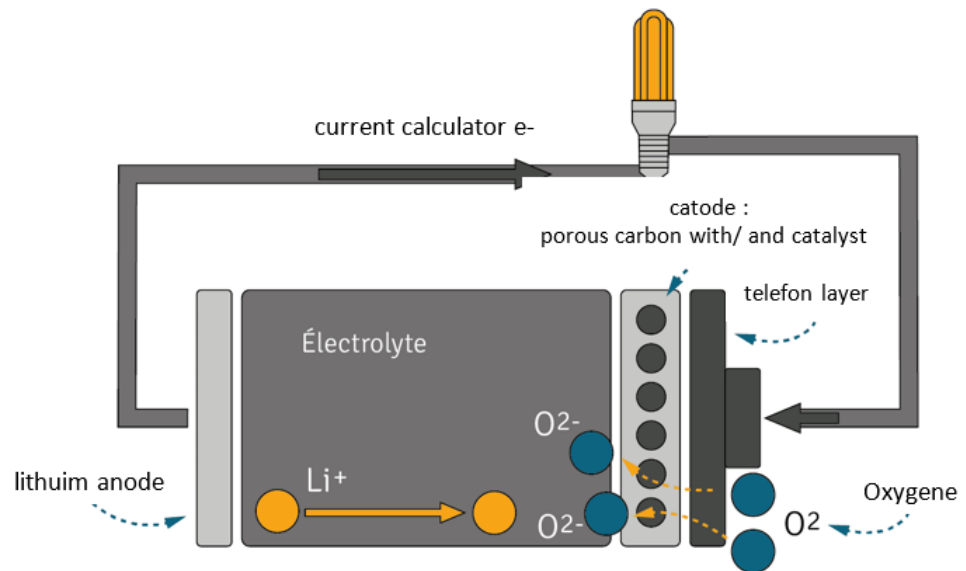


Figure II. 3 : Schematic of lithium battery function [28]

The schematic (*Figure II. 3*) representation of the lithium-air battery shows how it works:

- **During discharge**, the electrolyte transports the lithium ions from the lithium anode to the carbon cathode, where they react with the oxygen in the ambient air.
- **During charging**, lithium ions are transported from the cathode to the anode, and oxygen is again separated and released to the exterior.

the two reactions in the lithium-air battery produce according the following reaction equation:



the reaction equation is modified as follows:



Research is currently focusing on the best electrolyte for the lithium-air battery. In addition to dissolved substances, gaseous ceramic or polymer-based solid bodies may also be considered as electrolytes (solid-state batteries).

Different experiments are currently being carried out to test optimum service life and reduced charging times.

II.4.1. Innovation in lithium-air

« Their new Li-air battery cell can be recharged 1,000 times and produce high currents, with negligible energy losses and high efficiency. » .[29]

The first is a new low-cost catalyst (**trimolybdenum phosphide**) in the cathode, which is particularly effective, acting both to accelerate the formation of lithium oxide Li_2O and to dissociate these molecules during recharging. What's more, their new catalyst prevents the formation of undesirable molecules from nitrogen, water and carbon monoxide, which are also present in the air. It is these molecules that foul the cathode and render the cell dysfunctional after a very small number of recharging cycles.

with its new prototype, a mass energy density of 685 Wh/kg, which is three times more than the Li-ion NMC (Nickel, Manganese, Cobalt, 230 Wh/kg) cells most commonly used in today's electric vehicles. But that's just the beginning with these new components, which are not yet optimised. can reach over 1,000 Wh/kg, making Li-air batteries 4 times lighter than today's Li-ion NMC batteries.

Of course, it's a laboratory prototype, and there's still a lot of work to be done before we get to a potential commercial battery. But it's extremely encouraging

If we get a commercial product, this means that electric vehicles (EVs) would be 200 kg to 400 kg or more lighter, depending on the vehicle. The result would be EVs that consume much less energy per 100 km and use fewer raw materials for their batteries. The ecological impact of EVs would be correspondingly smaller.

The other major innovation is the development of a **new hybrid solid electrolyte** that conducts Li^+ lithium ions **15 times** better than the liquid electrolytes that have been tried in the past. This solid electrolyte also prevents oxygen from

reaching the anode. And they put a protective layer of lithium carbonate on the anode, which blocks everything except lithium ions.

II.4.2. Manufacturing process

Molding is one of the techniques commonly used to prepare polymer films and their composites, and is applied in a variety of fields. In a typical preparation method, a polymer is dissolved in a suitable solvent with a salt and inorganic materials to prepare a slurry, then cast onto a substrate to make the HSE film. Films can be obtained after drying the slurry in an oven (under vacuum) under certain conditions.

Obtain a high-performance solid-state battery. As a result, a cell with such a structural design could provide an initial capacity of 125 mAh/g to further solve the interface problem, isostatic processing, in which equal pressure is applied in all directions on the substrate,

has been recognised as a promising method. Using this approach, good mechanical contact, as well as improved ion transfer, could be ensured. This method is evolutive, as indicated

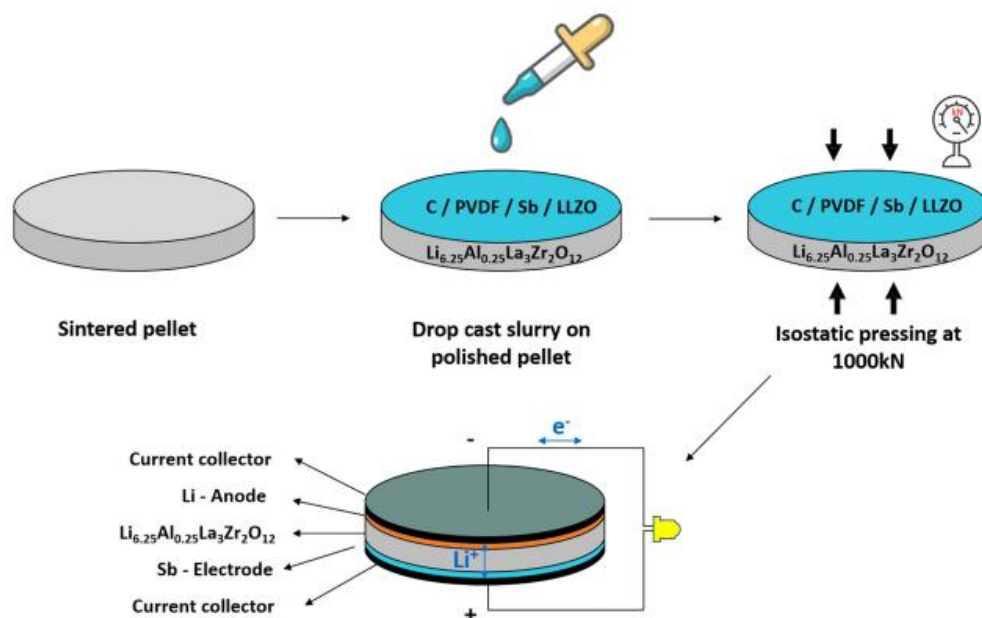


Figure II. 4 : Schematic image showing the manufacturing new low-cost catalyst (trimolybdenum phosphide [30])

II.4.3. Comparison between Li-air and Li-ion

Note: 0: lower than li-ion, 1: equivalent to li-ion, 2: higher than li-ion, 3: significantly higher than li-ion

Table II. 3 : Advantages of lithium-air battery technology compared with lithium-ion technology [31]

Lithium-air	Critter	Note
	Cost	1
	Gravimetric density	3
	Volumetric density	3
	Availability of materials	2
	Life span	1
	Level of technological maturity	1-2/11

II.5. Idea 03: Na-ion battery

In these times of climate and energy crises, this is a very exciting innovation. Professor Bao-Lian Su's team at UNamur has come up with a new kind of battery. Faced with the limitations of conventional lithium batteries, lithium ions have been replaced by sodium ions. At the same time, an innovative material has been developed to store sodium ions faster and in greater quantities. And that's not all: a completely new concept, known as dual-ion batteries, has been developed, doubling the amount of energy stored and increasing the stability of the battery. **Sodium to replace lithium** [32].

Sodium batteries are energy storage devices whose main material for the chemical reaction that generates electricity is sodium. Like lithium-ion batteries, which are widely used in electronic devices and electric vehicles, sodium batteries are designed to store and release electrical energy in a controlled manner.

II.5.1. Operating principle

The operating principle of sodium-ion and lithium-ion batteries is virtually identical, and many of the electrode materials used in sodium-ion technology have been borrowed from lithium-ion technology.

In both technologies, ions are responsible for transporting and storing energy. Sodium ions migrate from the positive electrode, the cathode, to the negative electrode, the anode, through the electrolyte and separator carried by the electric current during the recharge phase. During the discharge process, the ions return to the cathode and a flow of electrons - i.e., an electric current - circulates in the external circuit in the opposite direction to recharging. .[33]

II.5.2. Problem

From a purely chemical point of view, there are significant differences between the two elements: the atomic radius of the sodium cation is 0.3 \AA greater than that of the lithium cation. This means that it has **more than 3 times** the **atomic weight** and **mass** of lithium.

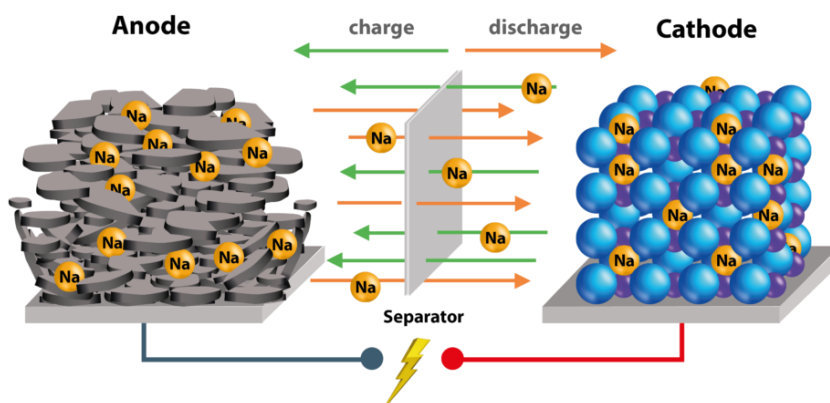


Figure II. 5 : Principal of operation [34]

Sodium, on the other hand, is much plumper than lithium. « This characteristic makes its migration and insertion much more difficult. Finding a suitable component to make efficient electrodes was a major challenge. »

This problem will be solved by scientists and will lead us to a new innovation of a material to receive the Na atom.

II.6. Idea 04: Titanium di-selenide (TiSe₂)

The innovative material, titanium di selenide (TiSe₂), absorbs sodium quickly and efficiently. This allows a large number of sodium ions to be stored, and therefore more energy to be stored. What's more, because sodium migration is made much faster, the battery's charging speed is also higher.

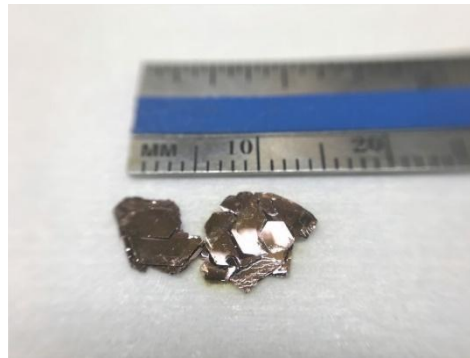


Figure II. 6 : Titanium

Titanium di-selenide is a chemical compound with the formula **TiSe₂**, which is of academic interest for the development of new electrical accumulators because of its good electrical conductivity and its intercalation properties within its crystalline lattice[35].

These first two innovations have been joined by an even more important one.

II.7. Idea 05: Positive and negative ions are on the move (DIBs)

« In conventional lithium-based batteries, only lithium ions migrate from one electrode to the other. Storage capacity is totally dependent on this single element.».[36]

This **new battery** was the obvious choice. While it still has two electrodes - a positive one, the cathode (made of titanium Di selenide), and a negative one, the anode (made of graphite) - it stores energy by inserting two types of ions into its electrodes. While positive ions, sodium ions, are inserted into the **titanium Di selenide** electrode, negative ions, in particular phosphorus hexafluoride ions and **tetra chloroaluminate** ions, present in the electrolyte, are inserted into the graphite electrode. This trick makes it possible to generate twice the electrical capacity of conventional batteries.

Dual-ion batteries use the simultaneous insertion (intercalation) of anions into the cathode and cations into the anode during the charging process and, conversely, the de-intercalation of ions into the electrolytes during the discharging process.

Cations and anions are extracted and released into the electrolyte. The anode can be a metal (such as Li, Na, K, etc.) or any material that can facilitate the reversible insertion of cations. The cathode comprises materials that can facilitate the reversible insertion of anions, such as graphite or organic compounds.

A **TiSe₂-graphite Na-DIB** with fast kinetics and excellent cycling stability is proposed for the first time by combining a TiSe₂ Na-ion anode with an anion-storing graphite cathode. Compared to other Na-DIBs, TiSe₂-graphite Na-DIB significantly improves Na-ion insertion kinetics with superior cycling stability.

The storage capacity of this new battery is double that of a lithium-ion battery, and its volume will be at least halved.

- **Advantages:** an abundance of sodium, making it easy to supply. More affordable and less likely to ignite. Less complicated to recycle, given the materials used in its design [37].
- **Disadvantages:** in its marketing infancy. Heavier than the lithium-ion battery. Low energy density - can store much less energy than a lithium-ion battery of similar size [38].

II.7.1. Reaction mechanisms for DIB

It is worth noting in particular the intercalation of anions in the cathode during charging, the reaction mechanism of **DIBs** differs considerably from that of conventional **LIBs**. (*Figure II. 7*) illustrates the charge-discharge mechanism of a conventional LIB using graphite as the anode and **LiCoO₂** as the cathode. Only **Li⁺** reversibly shuttles between two electrodes, specifically during the charging process, **Li⁺** depletes from the LiCoO₂ and intercalates into the graphite intermediate layers through the electrolyte.

Whereas for the discharge process, **Li⁺** depletes from the graphite anode and intercalates into the LiCoO₂ cathode.[39].

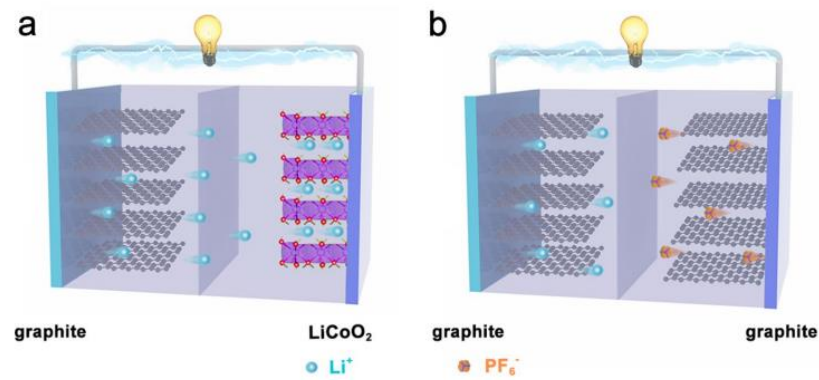


Figure II. 7 : Schematic diagrams illustrating a traditional LIB and b a dual-graphite DIB [40]

The migrated Li^+ is generally supplied by the cathode materials, and the electrolyte is not involved in the electrochemical energy storage process itself.

However, for DIBs, the anions and cations in the electrolyte participate in the charge storage reaction. Taking the double graphite DIB as an example, during the charging process, the cation (e.g., Li^+) and the anion (e.g., PF_6^-) are intercalated simultaneously in the double graphite anode and cathode. During the discharge process, the intercalated Li^+ and PF_6^- remove the insert from the graphite and re-diffuse it to the electrolyte

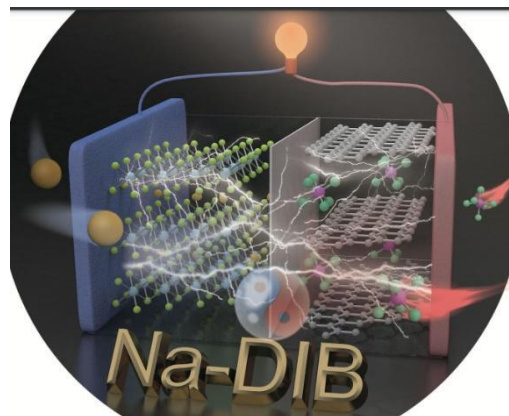


Figure II. 8 : Illustration of the novel dual ion battery [41]

Dual-ion batteries offer high voltages and high energy densities, making them promising energy storage systems. However, the concentrations of anions and cations in the electrolyte vary during the discharging operation of dual-ion batteries. Since the

electrolyte provides charge carriers in dual-ion batteries, power and energy density can be limited by the electrolyte.

An overall improvement in the design of the dual-ion battery and the optimisation of all the constituent components (such as electrodes, separators and electrolytes) are among the approaches being taken to achieve high-energy-density dual-ion batteries. .[42]

Unlike conventional sodium ion batteries (Na-DIB), energy can be stored or released during charging and discharging thanks to the new material that Prof. Su's team analysed. "As can be seen from the diagram, the use of this material, titanium Di selenide (TiSe_2), is innovative because of the large spacing between its layers, allowing rapid diffusion and abundant active sites for hosting sodium ions", says Prof. Su. "Compared with other Na-DIB batteries, the new battery significantly improves the insertion kinetics of Na ions with superior cycle stability", he continues. In other words, this means that energy production is greater, as is storage capacity, with greater stability.

These dual-ion sodium batteries (Na-DIB) have an emerging potential compared to traditional lithium batteries for the next generation of electrochemical energy storage systems due to their high voltage, high energy density, their low cost and respect for the environment. [43]

In addition, this new battery, based on a different assembly allowing two types of ions to travel, would delay the occurrence of the safety problems typically found in batteries (explosion, combustion).

- **From lab to industry**

While this innovation is very exciting, it is still at the experimental stage. "In the laboratory, a button cell offers excellent performance in terms of charge/discharge cycles. It could go up to 500 cycle and this battery that in the experimental phase, many industries make collaborations are envisaged to manufacture the first dual-ion batteries based on sodium and TiSe_2 , not yet industrial size, but prototypes to test them in various devices, including in electric cars.[44]

Table II. 4 : Dual-ion batteries Market Report Highlights

Aspects	Details
Market Size By 2031	USD 1.6 billion
Growth Rate	CAGR of 16.4%
Forecast period	2021 – 2031
By Application	<ul style="list-style-type: none"> • Electric Vehicles • Portable Electronics • Renewable Energy Storage • Medical Devices • Others
Key Market Players	Prieto Battery, Tiamat Energy, Jenax, Solid Energy Systems, Custom Cells Itzehoe GmbH, Qing Tao Energy Development Co., Ltd., Sion Power, Ionic Materials, Faradion Limited, Excellatron

II.8. Idea 06: sodium-base-algae battery

Scientists are therefore trying to develop equally efficient alternatives, in particular sodium batteries. "Due to its high theoretical capacity and abundance, sodium is the most attractive alternative to lithium as an anode material for cost-effective, energy-dense energy storage systems," explain the researchers in Advanced Materials.

With a theoretical capacity of 1165 mAh/g, sodium-metal batteries are one of the most promising high-performance, low-cost energy storage systems. However, one of the main obstacles to their development is the uncontrolled growth of dendrites, solid sodium 'spikes' that perforate the separating membrane between the two electrodes and cause short circuits. Another drawback is their lifespan. The reactions...

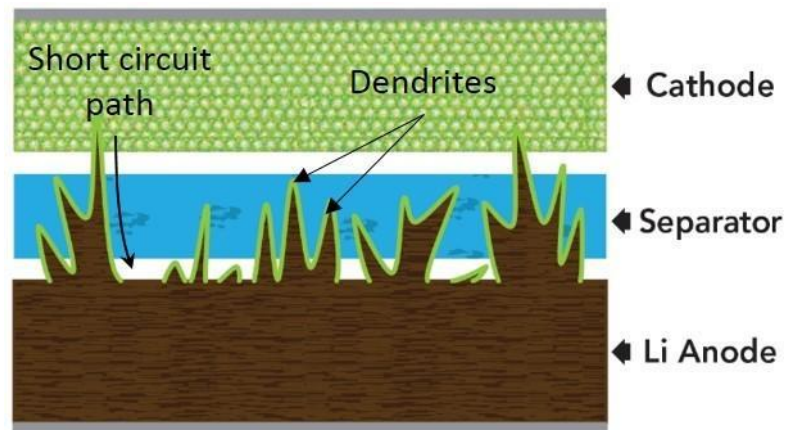


Figure II. 9 : Dendrite growth in lithium battery leads to failure [45]

The electrochemical processes on which the charge/discharge cycles are based slow down much faster than in lithium batteries. Secondary reactions occur, the electrolyte is depleted and the battery loses its capacity. Researchers are now providing a solution to the problem.

The aim of a battery separator is to separate the functional parts of the system (the positive and negative ends) and allow the charge to be transported freely,

This separator is based on **cellulose nanomaterials derived from brown algae**. This approach avoids the problems mentioned above: the fibers containing these nanomaterials not only prevent the crystals from the sodium electrodes from penetrating the separator, but also improve the storage capacity and efficiency of the batteries. [46]



Figure II. 10 : Brown algae for separator [47]

II.8.1. Principle of manufacturing

To make this new separator, the researchers impregnated polyetherimide fibers with cellulose nanocrystals (extracted from algae) measuring around 10 nanometers in diameter and 200 nanometers in length.

This composite material was then transformed into extremely fine charged wires by electrospinning. These wires form a much stronger separator. It should be noted that cellulose nanocrystals can be extracted from other materials (wood, flax, etc.), but those from algae have the advantage of being relatively long.

This approach increases the lifespan of sodium batteries - an essential element for powering devices such as mobile phones for much longer,

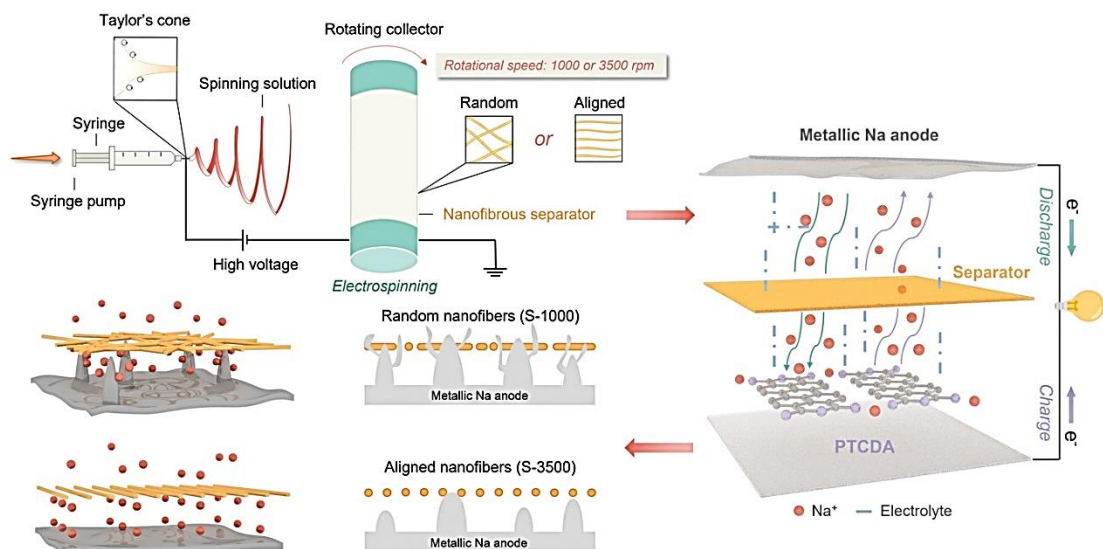


Figure II. 11 : Schematic of the fabrication of electro spun CNC/PEI nanofibrous membranes and Na deposition behaviors with S-1000 and S-3500 separators for Na-metal batteries [48]

II.8.2. Positives

With this idea, they are innovatively developing bifunctional, mechanically flexible and low-cost CNC/polyetherimide (PEI) electro spun nanofibrous separators derived from brown algae, with desirable merits for large-scale applications of low-cost, safe and credible, high-energy products (see **Figure II. 11**). their material design incorporates the following advantages: Regulate the Na ion flux and nucleation behavior to homogenize the Na electrodeposition on the anode surface: Mechanically

block the growth of Na dendrites or the perforation of Na dendrites to inhibit the short circuit;

- Easily adapt the alignment and thickness of high-thermal-stability separators, combined with renewable organic electrodes to promote the total safety and durability of a cell configuration. .[49]

II.9. Idea 07: Dual chemistry battery

Functions on the principle of a cell without an anode, eliminating the use of graphite. This technique is not generally used because the lifespan is shorter than for traditional cells, but here it serves as a range extender for another technology.

ONE's trick is to use a dual chemistry in its cells, one geared towards everyday driving and the other adapted to longer journeys. The integration of these two techniques makes it possible to reduce peak current and cycle constraints, making the whole unit usable in a rechargeable automotive electric battery [50].

II.9.1. Operating principle

To make the dual-chemistry battery work, we first had to develop an exclusive high-efficiency DC-to-DC converter, which manages the battery's two chemistries.

- A first battery configuration, called the main battery pack (MBP), is made up of cells with the beneficial properties of high cycle index and low impedance that are applied to the high-power requirements associated with accelerating from a stop and the high cycle rate of stop-and-go traffic that discharges the battery and then charges the battery from regenerative braking. Because this the first battery configuration also has the undesirable properties of high weight and high cost, the size of the first battery configuration is large enough to satisfy the most frequent needs nominal range travelled of an electric vehicle, part of the nominal driving profile of the electric vehicle that would need these beneficial properties.

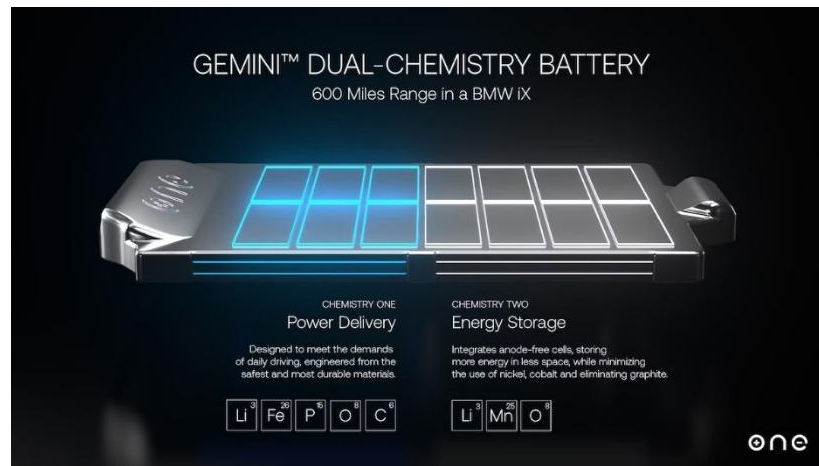


Figure II. 12 : Dual-chemistry battery [51]

- A second battery configuration, called a supplementary battery pack (SBP), is constructed from cells with beneficial high specific energy and low-cost characteristics that are intended to meet the less frequent demands of extended driving beyond the nominal profile. Therefore, the second battery configuration is designed to be larger in size than the first battery configuration because of the higher energy output for extended range driving.

Because the second battery configuration is made up of cells of lower specific power, it builds more cells in parallel to meet energy requirements, resulting in a larger battery form factor. As a result, both the first battery pack and the second battery pack are individually capable of delivering the power and energy required by the load. Finally, because the second battery configuration is made up of a high-impedance cell, it consequently generates more heat. [52] the second battery configuration is managed by a discharge and charge algorithm that directs all possible battery cycling to the first battery configuration, using the second battery configuration. [52]

Only when the first battery configuration is inadequate or depleted. Thus, the discharge and charging algorithm will rely mainly on the discharge and charging of the first battery configuration, or main battery, for the lion's share of using the battery and cycling in an electric vehicle.

- The MBP and SBP can be configured to discharge in a number of different modes depending on their design compromises and current state, as well as the needs of the system. MBP and SBP typically operate in series or sequentially, i.e., one after the other, with the main battery doing all or most of the cycling

until it has no charge left, as they both have adequate power and energy for charging. [52]

- However, the multiple batteries, MBP and SBP can also operate in parallel in a less frequent scenario where the SBP is in deficit and temporarily unable to supply the nominal or maximum current required e.g., the EV motor as can be seen, there are about twice as many anode-less battery cells as LFP cells in the battery pack. As the anode-less cells also store more energy in the same volume, they can provide around three quarters of the range.



Figure II. 13 : ONE Gemini Is a Truly Hybrid Battery Pack with Its LFP and Anode-Free Cells [53]

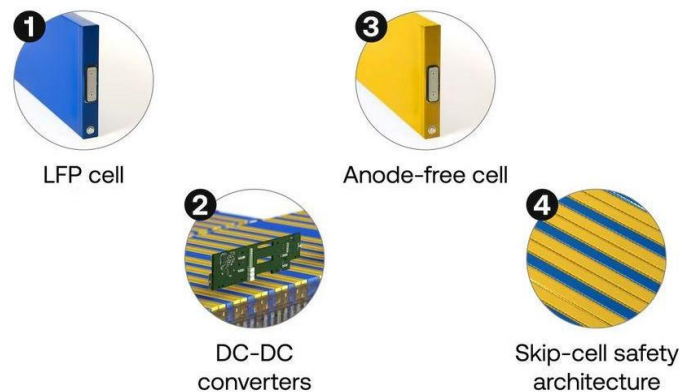


Figure II. 14 : Battery pack [53]

ONE claims that Gemini is the battery pack for electric vehicles with the longest range and can fit into the 300 to 400 liters of space usually available in a vehicle for energy storage, and we have also obtained positive test results on a BMW iX equipped with a prototype of its new Gemini dual-chemistry battery, which travelled 978.5 km on one charge. [54].

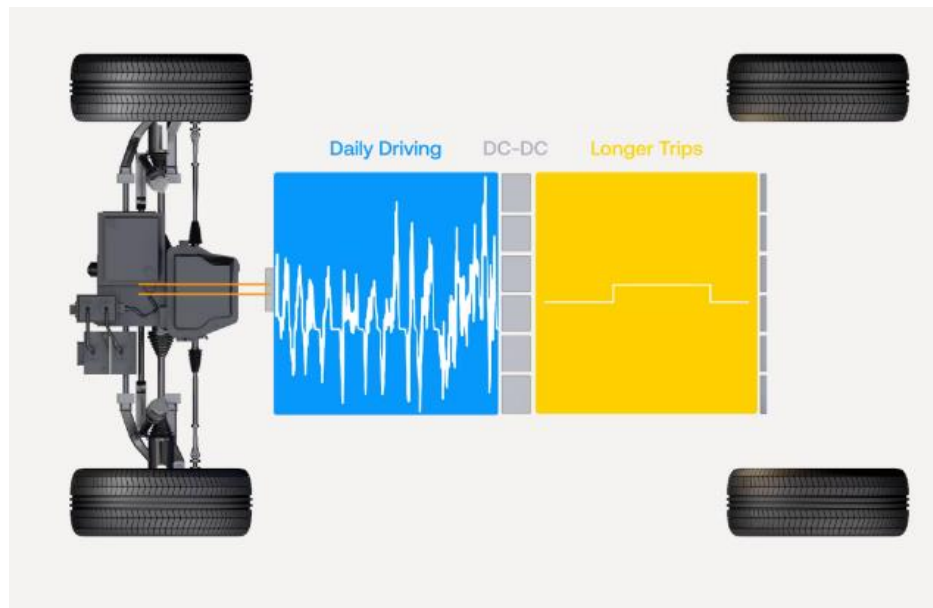


Figure II. 15 : schematic Dual chemistry battery [55]

LFP lithium iron phosphate cells (**blue-*Figure II. 15***) power the motor and meet the demands of 99% of daily journeys with a range of 241.4 km. For longer road trips, the Gemini uses high energy density anode-less cells (**yellow-*Figure II. 15***) to provide an additional 724.2 km of range by transferring energy via ONE's exclusive high-efficiency DC-DC converter.

Coupled by the DC-DC converter, the two cells work together to offer over 965.6 km on a single charge.

The dual chemistry battery reduces the use of valuable battery materials (compared to a standard solution with the same energy content).

Lithium	↓	20%
Graphite	↓	60%
Nickel	↓	75%
Cobalt	↓	100%

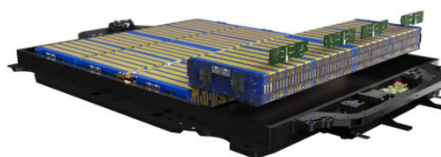


Figure II. 16 : Materiel battery [56]

Indicates that the battery could contain 20% less lithium, 60% less graphite, 75% less nickel and no cobalt (*Figure II. 16*)

Table II. 5 : characteristic of a dual chemistry battery [56]

Energy	GED	VED
185+ kWh	260 Wh/kg	450 Wh/L
Cell-to-pack efficiency	System configuration	Dimensions
70%	204S3P	2.640 x 1.490 x 128 mm
Mass	Volume	Voltage
710 kg	441 L	748 V
Peak power	Continuous power	Cycle life
345 kW	130 kW	>402336 km

II.10.Idea 08: BMS

Battery Management System (BMS) controls the battery pack and declares the status of the battery pack to the outside world. An introduction to the BMS gives a high-level overview and connections to the system.

The Battery Management System (BMS) is the hardware and software control unit of the battery pack. This is a critical component that measures cell voltages, temperatures, and battery pack current. It also detects isolation faults and controls the contactors and the thermal management system. The battery management system protects the operator of the battery-powered system and the battery pack itself against overcharge, over-discharge, overcurrent, cell short circuits, and extreme temperatures. The BMS protects the battery from damage, extends its life through intelligent charging and discharging algorithms, predicts the remaining battery life and keeps the battery in an operational state. Lithium-ion battery cells present significant challenges, requiring a sophisticated electronic control system. In addition, the risks of fire and explosion are significant. A BMS therefore requires advanced silicon to meet all performance, safety and cost criteria.

In general, the three main challenges that each designer strives to meet are optimizing autonomy, reducing costs and improving safety.

II.10.1. The working principle of a BMS

A distributed BMS architecture (*Figure II. 17*) has a modular structure and typically consists of three main subsystems: Cell Monitoring Unit (MCU), Battery Control Unit (BCU), and Battery Disconnect Unit (EDR).

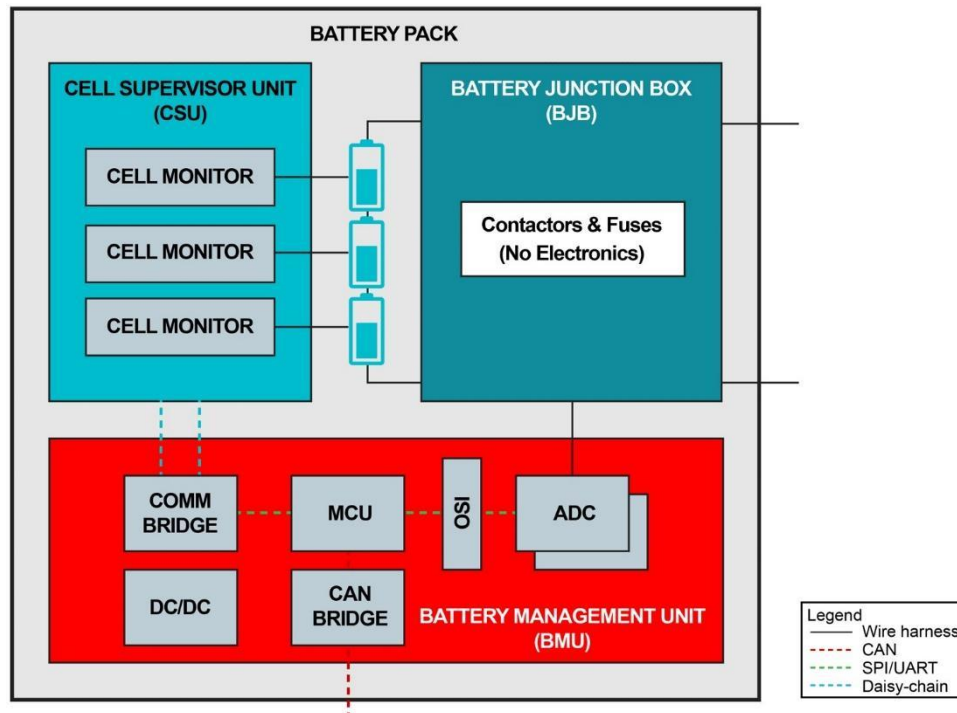


Figure II. 17 : Architecture of BMS operation [57]

The CSU collects parametric information from all battery cells by sensing the voltage and temperature of each cell. The CSU helps compensate for inconsistencies between battery cells by performing cell balancing. The BCU must incorporate the parametric information from the CSUs and must also detect the voltage and current of the battery pack to perform pack management. According to all collected voltage, current and temperature data, the BCU is responsible for allocating how to charge and discharge the battery according to the overall condition of each and every battery cell. Continuous monitoring of the condition of the batteries occurs through calculations of state of charge, state of power and state of health. Intelligent protection control is also an important feature of the BCU, as it must perform insulation monitoring, control the contactors in the event of a crash or short circuit, continuously monitor the temperature

sensors, and perform diagnostics to check that all incoming parameters are indeed valid. The information is transmitted to the automobile vehicle control unit or electronic control unit through Controller Area Network (CAN) communication. .[58]

II.10.2. Wireless BMS

Wires are the de facto method of implementing a BMS today. In many cases, it is the most reliable way to achieve Automotive Safety compliance because functional safety capabilities are built into the daisy-chained wired communication protocol. Wires have their disadvantages, however: cable failures, warranty repairs and battery cell replacements are expensive.

In a wireless BMS, each module is interconnected via a wireless connection instead of a CAN Bus cable or an isoSPI twisted pair. Today, Linear Technology is demonstrating the industry's first wireless automotive battery management system (BMS) concept car. This wireless BMS concept car combines the LTC battery stack monitor with Linear's Smart chips wireless mesh networking products replacing the traditional wired connections between the battery packs and the battery management system uses resonant electromagnetic induction to transmit

One advantage of a wireless BMS, shown in (*Figure II. 18*) is the simplicity associated with assembly and production of the battery pack – which can save costs and increase efficiency during production. Production line technicians can simply assemble the battery pack and get instant readings, whereas a wired BMS requires technicians to plug cables into every battery module. .[59]

Another advantage of a wireless BMS is that cable harnesses and connectors can be one of the leading causes of failure in a battery pack. A wireless BMS reduces low-voltage cabling and has the potential to save original equipment manufacturers (OEM) from significant warranty claims.

A wireless BMS helps reduce weight, and perhaps more importantly, there is now more space in the battery pack. With the increased space, a battery manufacturer or OEM can add more battery cells to the pack. Increased cells plus lower weight can lead to extended driving ranges.

A wireless BMS can also help save component costs because of its inherent isolation, so automotive manufacturers can save money by not having to use transformers, capacitors or common-mode chokes to achieve isolation. And cell balancing Fundamentally there are two approaches to cell balancing.

- Passive balancing
- Active balancing

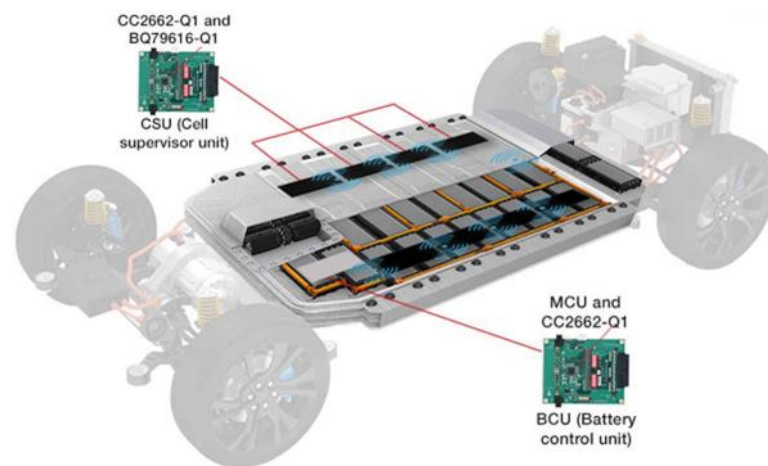


Figure II. 18 : A wireless BMS technology contains TI's automotive-qualified CC2662R-Q1 Simple Link™ wireless microcontroller unit (MCU) includes a 48-MHz Arm® Cortex®-M4 processor and is capable of running a 2.4GHz proprietary wireless BMS protocol [60]

Cloud BMS is critical for improving battery lifetime, charging, and safety. Despite next-generation battery chemistries emerging, current battery technology has room for growth. Intelligent software, advanced models, and better data analytics within cloud BMS can unlock potential performance gains. This technology is crucial for optimizing battery operations, ensuring safety, and advancing the field of battery management and electric mobility.



Figure II. 19 : . Smart Mesh Wireless Sensor Network [57]

- **Creating a complete battery test environment ecosystem**

In order to validate and test a BMS, automotive manufacturers use a hardware-in-the-loop (HiL) system (*Figure II. 20*) which creates a safe environment to test all functionality before connecting to real, potentially dangerous battery cells.

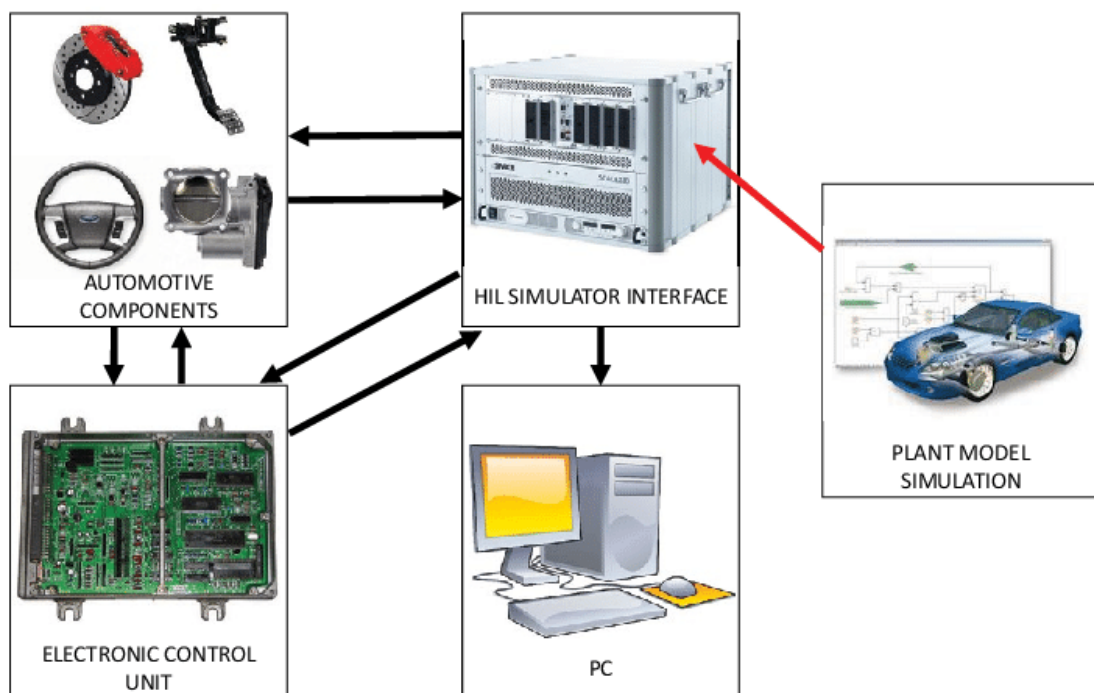


Figure II. 20 : Different part of HIL simulation [61]

The battery cell simulator offers a mix of modules for BMS testing with scalable variants and different functions. The flexibility of this simulator has enabled the engineers to implement systems in different sizes to help meet design needs.

- **Self-healing Algorithms:**

Self-healing algorithms play a crucial role in ensuring battery longevity and reliability. These algorithms detect and address issues such as battery degradation, optimizing performance over time. By continuously monitoring the health of the battery, self-healing algorithms contribute to the overall durability of electric vehicles. [62]

II.11. Idea 09: Wireless Charging System

This system frees an electric vehicle (EV) of the need for a cable when charging, further advancing the convenience of EVs for charging at home or work. As the car can be parked always in a designated location, the steering can be operated automatically

Like your phone, wireless EV charging uses resonant electromagnetic induction to transmit electrical current, a process that is also known as inductive charging. Your phone has a magnetic coil inside that receives electricity from the magnetic coil inside the charging pad.

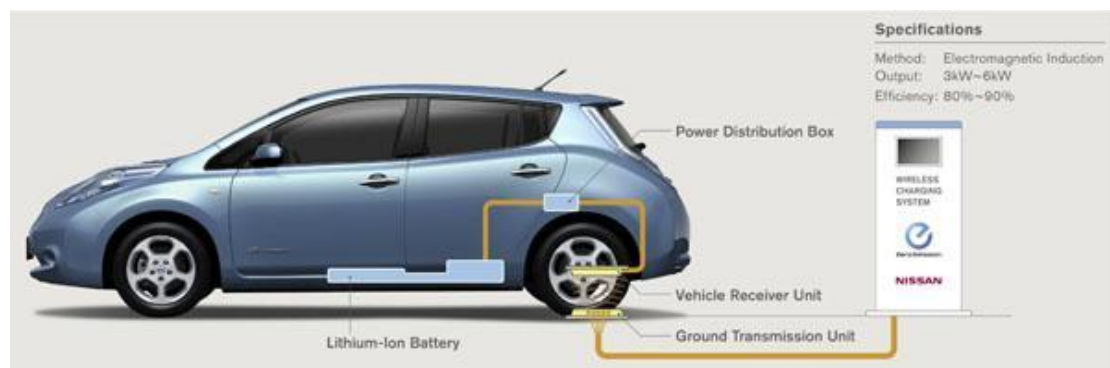


Figure II. 21 : *Wireless (inductive) charging systems and smart charging controls [63]*

Wireless charging for EVs works the same way, with a magnetic coil in the charger that sends current to a magnetic coil on the car's underside. When the two pads align, charging begins.

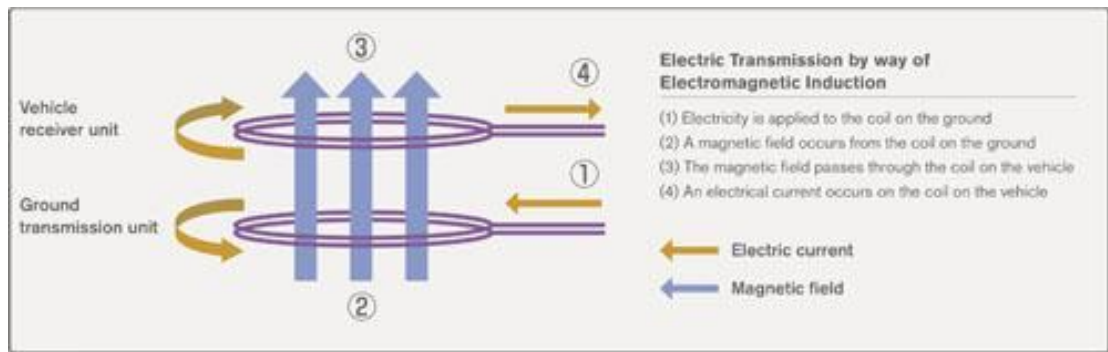


Figure II. 22 : Electric transmission by way of electromagnetic induction [63]

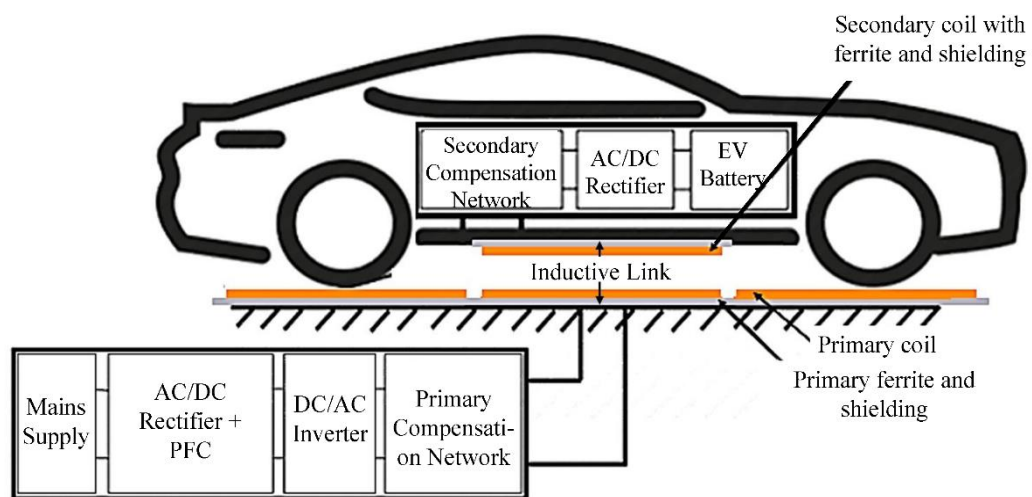


Figure II. 23 : Dynamic EV charging system using G2V power transfer [64]

Starting from the primary side, electrical power from the mains supply is first rectified into a DC voltage to maximize its real power using an AC/DC rectifier and a power factor correction circuit (PFC).

This DC signal is then input into a high-frequency inverter to be up-converted to the operating frequency of interest. Compensation networks are then required to help operate the inductive link in resonance conditions.

On the secondary side, an AC–DC rectifier is utilized after the LC compensation, in order to convert the coupled AC power to DC power that can charge the EV battery.

Between the rectifier and the battery, a DC/DC converter may be used to aid in the output power control process. .[65]

II.11.1. Wireless EV Charging Options

Wireless EV charging comes in two types: static EV charging, which is the most similar to what EV owners do now, and dynamic EV charging, which takes place on the open road.

II.11.1.1. Static EV Charging (Home or Office Charging Station)

Static EV charging simply means the EV is not moving while charging. Rather than plugging in, the wireless-equipped EV is parked over the installed wireless charging coil in the designated space. [66]



Figure II. 24 : Wireless charging EV [67]

II.11.2. Dynamic EV Charging (Roads and Highways)

Eventually, induction charging is expected to be built into the roadways so that owners can charge their EVs continuously as they go. It will work similarly to regular wireless charging and is expected to operate smoothly at speeds up to 65 mph, allowing EV owners to drive long distances without having to stop for a charge or risk running out of power. [68]

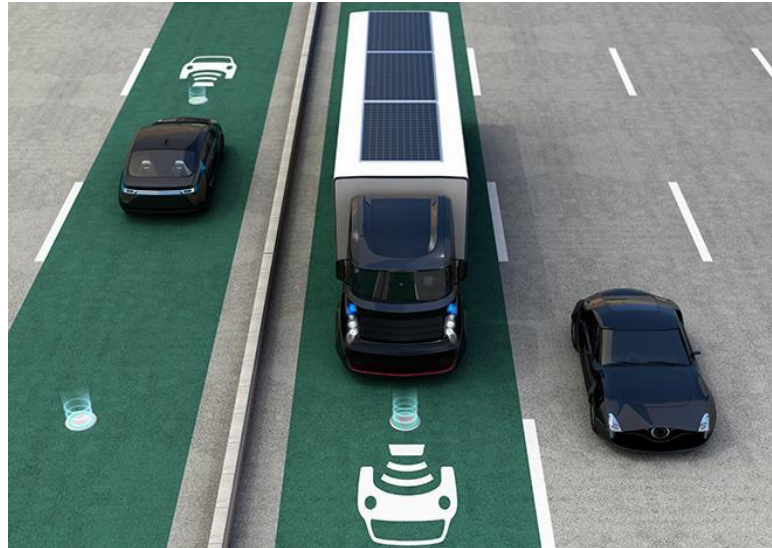


Figure II. 25 : Highway with DWCS in both lanes. [69]

II.11.3. V2V

The proposed V2V system is primarily designed for two applicable scenarios: one is plug-in EVs charging through a wireless V2V charging integration system, as shown in (*Figure II. 26*) Another is called the vehicle assistance system, as shown in (*Figure II. 27*).

II.11.3.1.Plug-in with wireless V2V charging system

At present, the biggest drawback of plug-in charging systems is the limited number of charging stations. In addition, charging stations require regular maintenance and service to ensure the equipment is working properly. The plug-in with wireless V2V charging system can help to solve the above issues. (*Figure II. 26*) structure of the system. The transmitter coil and receiver coil are embedded in the front and rear of the car. The first car can automatically charge wirelessly to the car behind it. [70]

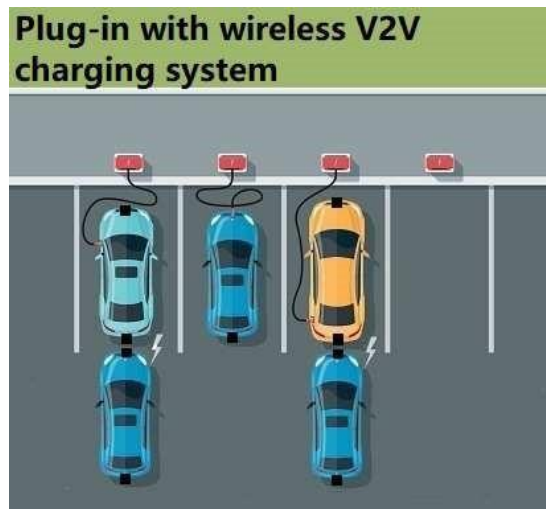


Figure II. 26 : Plug-in with wireless V2V charging system [71]

II.11.3.2. Vehicle Assistance wireless charging system

(*Figure II. 27*) shows the vehicle assistance charging system. When the vehicle's battery runs low, the driver can request the help of other EVs on the road to wirelessly charge the vehicle. In this process, there are several auxiliary technologies, such as vehicle-to-vehicle communication, GPS, and battery state of charge detection

The driver can find suitable vehicles using an application on their smart device that indicates available donor vehicle energy, pricing, distance, and other factors. This concept can reduce the potential EV buyers.[72]

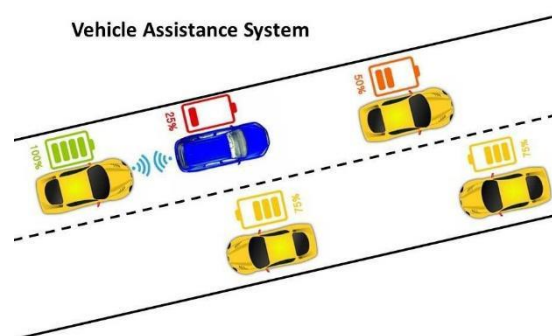


Figure II. 27 : Vehicle Assistance System bases on wireless charging [71]

II.11.4. Integration of different Electric Vehicle charging management

The integration of the aforementioned EV charging solutions within the city infrastructure is expected to increase EV adoption by ensuring ubiquitous charge availability and improving the convenience levels for EV owners. This contributes to the establishment of an internet of electric vehicles (IoEV) in which EVs are considered as intelligent entities equipped with multiple on-board sensors and actuators, and can communicate and exchange information securely with one another and with the surrounding infrastructure to enable driving and charging coordination, energy management, and traffic optimization [73]. A smart city infrastructure model demonstrating the integration of different EV charging infrastructures in an EV is shown in (*Figure II. 28*)

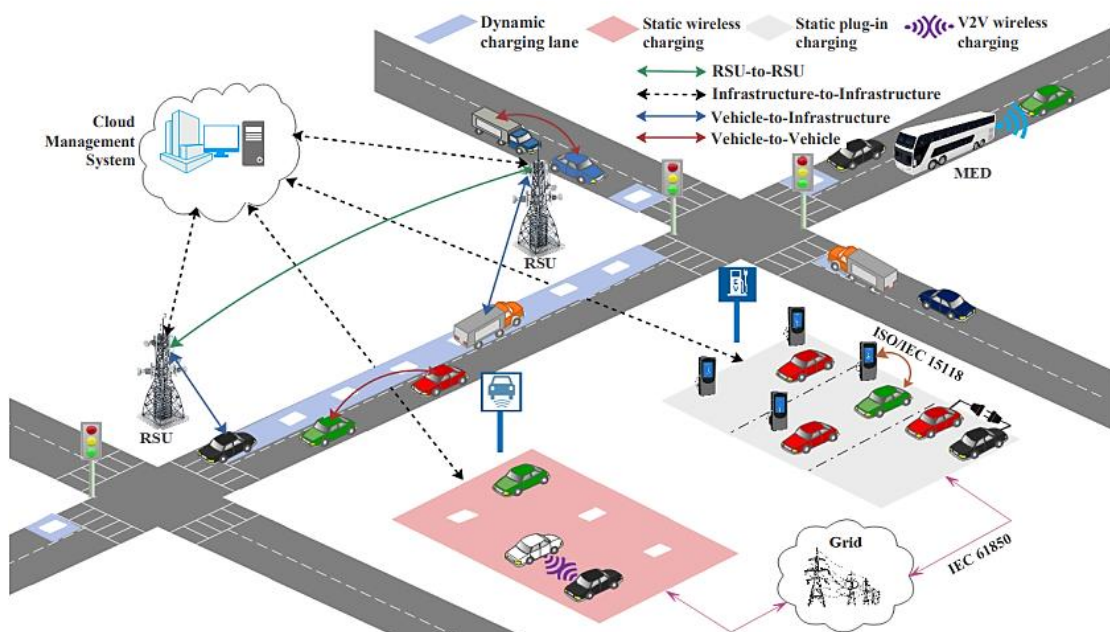


Figure II. 28 : Overview of EV charging solutions in an EV within a smart city infrastructure [74]

In order to enable effective EV charging coordination and management in an IoEV, effective communication strategies need to be implemented, in which a communication link is established between the EV and the charging infrastructure, i.e., vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communication, as well as between neighboring EVs, i.e., vehicle-to-vehicle (V2V) communication. This is because the lack of communication and coordination between EVs within the city

infrastructure is expected to cause congestion, inefficient energy distribution, imbalanced loads, and other adverse effects on the operation of the grid. In contrast, smart charging coordination, involving massive data exchange between the different network entities, is expected to solve these issues by utilizing advanced information and communication technologies (ICT) to build a communication infrastructure that enables load balancing, charge scheduling, and reliable authentication and billing services.[75]

II.11.5. Wireless EV Charging Benefits

Although charging cables have advantages, they also have limitations. Wireless EV charging offers several benefits, particularly for commercial vehicles.

- **No Wire**

By definition, the number one benefit of wireless EV charging is that there are no wires. EV owners do not need to carry heavy charging cables or plug their cars in at every charging station, alleviating range anxiety.

- **Lower Accident Risk**

EV charging cables can become damaged over time, particularly in extreme heat and cold areas, which can be hazardous to the vehicle and its owner. No wires mean less risk, and replacing cables is expensive, too.

- **More suitable**

Wireless charging is simply more convenient, even when only available as static charging – and imagine the suitable if and when dynamic charging becomes a reality

- **Save Time**

Although wireless charging is no faster than regular EV charging, you save a little time by not having to get out of the vehicle to plug in, etc. And again, once dynamic charging becomes a reality, the amount of time saved on charging could be substantial.

II.12. Idea 10: Electric Vehicle Rental Service

In the early-stage EV market, electric car rental services allow drivers to trial an EV for a short time. This experience with EVs increases awareness and facilitates diffusion of the technology. That is why projects like the Okinawa Electric Vehicle (EV) Rental Service are so significant. One of the first EV projects of its kind in the world, the service is dedicated to supporting the use of electric cars and improving the environmental sustainability of tourism on the island of Okinawa, Japan

II.12.1. The service

The introduction of electric vehicles to Okinawa through the holiday rental service was the first phase of a three-part “Green New Deal” aimed at developing a smarter energy system on the island. A combination of factors makes Okinawa a suitable location: high rates of car ownership, lack of public transportation, and its popularity as a tourist destination – welcoming 5.5 million visitors per year, of which half rent a car.[76]

Originally proposed by professors Hideaki Miyata and Kenji Tanaka from the Department of Systems Innovation at the University of Tokyo, the EV rental service complements the aim of local organizations to improve the environmental sustainability of tourism on the island.

A broad ecosystem of organizations participates in the service.

Researchers at the University of Tokyo designed the business model and conducted the technical and market research.

Travel agencies across Japan are the service’s main distribution channel, as they offer package holidays that include electric vehicle rentals. Three rental service companies provide 200 EVs between them: Nippon Rent-a-car Okinawa, Nissan Rent-a-Car Okinawa, and ORIX Rent-a-car Okinawa. The cars are Nissan Leaf with a range of 160 km. Car hirers either pay to use the 27 fast-charging stations on the island or recharge for free at a slow-charging station, which takes about eight hours for a complete charge.

The fast-charging infrastructure for the EVs is provided by Advanced Energy Company (AEC), a joint venture of 26 companies (*Figure II. 29*)

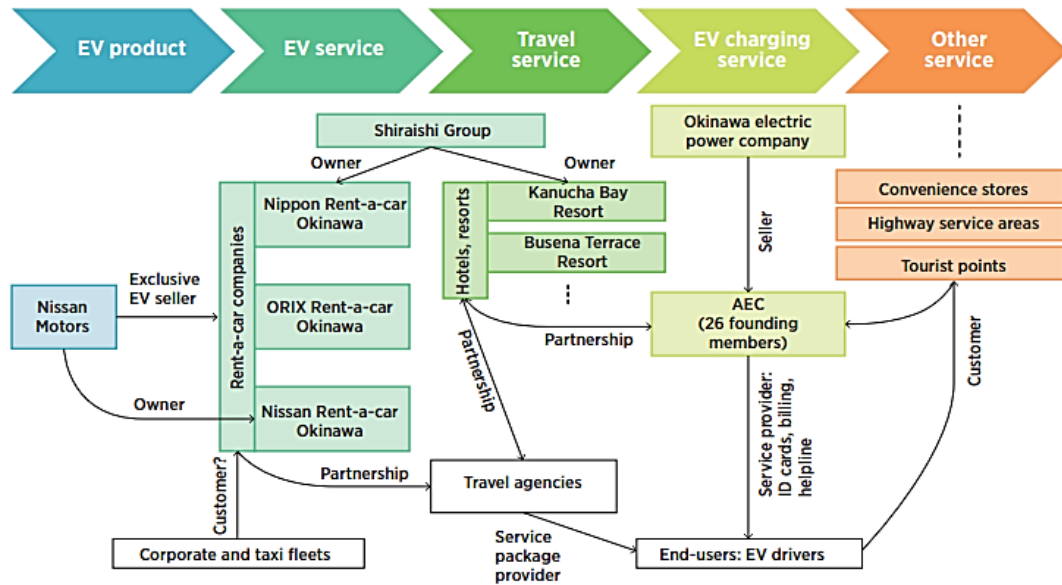


Figure II. 29 : Functional schematic for renting electric cars experience in OKINAWA

Other members of the EV Rental Service ecosystem include the Shiraishi Group, a major financial holdings company, local and federal public authorities, and local companies and tourist site operators that offer slow-charging stations.

II.12.2. Business case

For car rental companies, acquiring a new Nissan Leaf costs about 3M yen. The rental company expected a resale price of 2M yen (\$20,000) after three years of rental. To break even the rental firm must generate at least 1M yen over a three-year rental period. At typical hire prices of 6,300 yen/day, that equates to approximately 18 rentals per car per year, assuming an average rental lasts three days. The target was 100 rentals per car per year.

AEC's business model is based on providing access to the network of fast-charging stations in Okinawa. Regulations governing electricity sales in Japan forced AEC to position itself as an infrastructure provider charging a flat fee, rather than an electricity provider selling kWh. AEC charges a service fee of 2,000 yen (\$20) for unlimited recharging during the EV rental. After a week the service is charged according to the number of times stations are used. The business model was based on an average distance driven per rental of 250 km and the assumption that a fully charged Nissan Leaf would only need one full recharge per average three-day rental.

II.12.3. Challenges

Estimates of usage rates in the original business plans proved to be optimistic. The EV usage rate reached 10.6% in 2012 and 20% overall since the start of the project – corresponding to 60 days usage/car/year.

The car rental companies met with a lack of demand for used Nissan Leaf rental cars in the local market. The average income on the island is too low to create an EV market, even for used cars. Consumers are only willing to pay around 1.5 M yen (\$15,000) per car rather than the 2M yen anticipated by the rental companies.

Another significant challenge is the lack of incentives for travel agents to promote the use of the electric vehicle option over conventional vehicles. Because EV technology is less well-known, travel agents cannot guarantee the performance of the vehicle beyond existing official statistics about range, safety, and ease of charging. Also, they are unable to respond to concerns about the availability of charging on Okinawa.

II.12.4. Strategy turns around

A growing body of evidence suggests that an ecosystem approach is the best way for complex service providers to capture value while offering the best service possible for customers. Approaching the challenges that the Okinawa EV Rental Service faces from a complex service ecosystem perspective, it is possible to make a number of observations about the way the service was conceived, implemented, and operated over its lifetime.

One of the main barriers to acceptance of EVs on Okinawa is the lack of data about the service's EV usage and experience. Consider the moment a potential customer decides whether to hire an EV or conventional car, and the questions they might ask: Given a planned itinerary, how often would the car need recharging? Could they go from A to B to C on a single charge? How often do people tend to recharge and how long does it take them? To date the travel agents are unable to access the data needed to answer these concerns. The vast amount of information collected over four years of operations is fragmented and not readily available to the people who need it. For example, Nissan Motors collects and exclusively keeps all vehicle-related information such as battery performance, driving modes, and GPS

data from travel routes. collects data from the charging stations and can only infer driving patterns and flows from the energy usage data. Travel agencies collect the usual customer information during the package booking, including basic demographic data. The rental companies do not have access to any information on users.

Collaboration between stakeholders to share data (**Figure II. 30**) could help resolve some of the practical issues and customer concerns with the service. Companies in the service ecosystem would have a better understanding of customer habits, which could be used to refine and improve the service business model. The greater the information exchange between the parties in the service ecosystem, the more useful the in-car information is likely to be for the hirer. For example, better in-vehicle information about electricity consumption and recharging related to the intended route would benefit customers.

The current navigation system allows passengers to locate charging stations within a certain radius. However, an improved “intelligent route planner” could make suggestions about which charging stations to use along the journey. A better route planner, both in-car and on personal devices, could help alleviate a customer’s anxiety about range and charging.

Data exchange in the ecosystem would enable travel agents to answer the key questions customers have when choosing a rental car. The smarter use of data would give travel agents greater confidence in recommending the electric vehicle option. Once travel agents know more about the EV service, they might offer an electric vehicle as the default car option in their holiday packages. Customers would have to consider the electric vehicle option, leading to a higher probability of them using the EV service.

The smarter use of data and the resulting confidence in the capabilities of electric vehicles will also enable stronger marketing across the ecosystem. A marketing campaign could raise customer awareness about the EV service at every step of the travel experience: at online booking, on the websites of the island’s hotels and resorts, at the airport, and at the car rental offices.

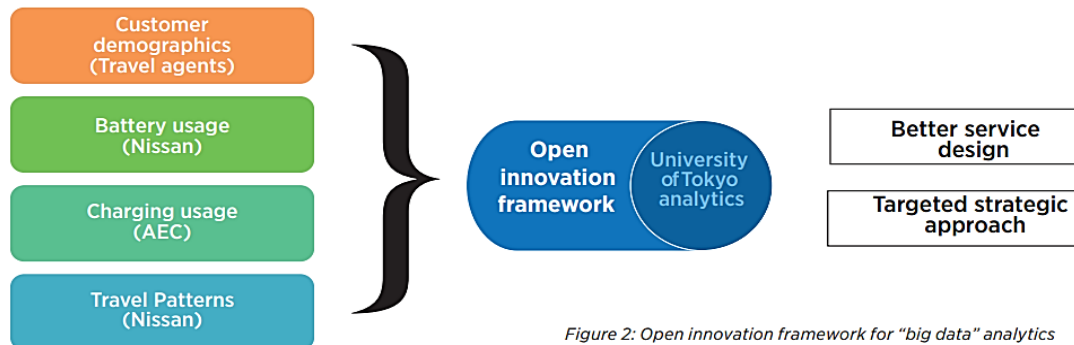


Figure 2: Open innovation framework for "big data" analytics

Figure II. 30 : Data transfer-suggested solution

II.13.Idea 11: Perovskite solar cells

Perovskite solar cells (PSCs) are hailed as the game-changer technology in solar photovoltaics, perovskite solar cells (PSCs) have been introduced as one the most promising emerging photovoltaic (PV) technologies due to their outstanding absorption coefficient, low-temperature processing, and low cost. PSCs are the best alternative source of energy for the future as they are more suitable for large-scale power generation and can achieve higher performances. Their efficiency has risen to 33.9% from 3.8%, proving their impressive growth rate in PV technologies. The short lifetime of PSCs in real-world conditions is a major obstacle to commercialization. Although several different methods have been employed to fix the stability problem of the PSCs, the best stability record of these types of solar cells is far lower than commercial standards, which is more than 25 years. MOFs have been utilized in PSCs as an additive in electron and hole transport layers, interface modifiers, or hybrid perovskite/silicon absorbers. The main purpose of MOFs in PSCs is to enhance their environmental stability, especially in areas with oxygen and humidity resistance.

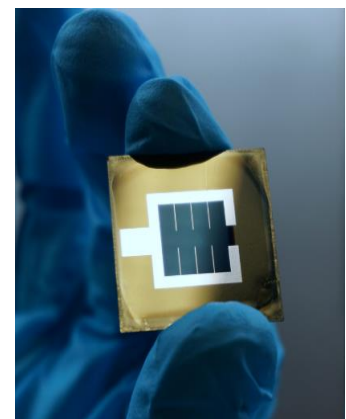
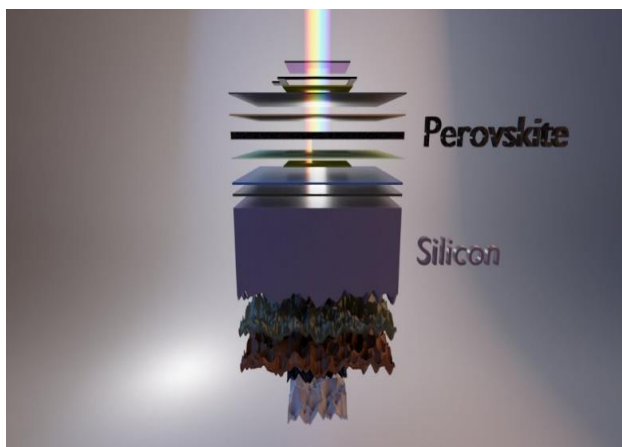


Figure II. 31 : Tandem perovskite / silicon [77]

II.13.1. Manufacturing Techniques of Perovskite Solar Cells

- **blade coating**

It is one of the simple, environment-friendly, vacuum free, and low-cost solution-processed methods for the fabricating PSC at industrial scale using blade coater applicator. Blade coater applicator is a simple coating system which consists of a screw of micrometer size used to adjust the height of the blade with respect to the substrate surface. In this technique, film uniformity and quality can be controlled by controlling evaporation rate of inks by adjusting airflow over the substrate or by heating up the substrate to the boiling point of the solvent. The basic arrangement is as shown (*Figure II. 32*).

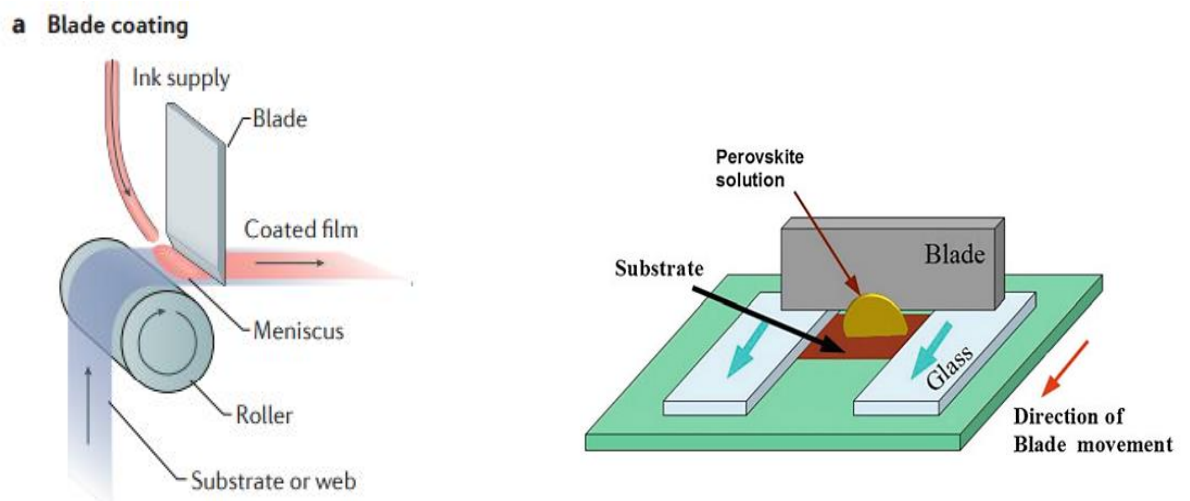


Figure II. 32 : Perovskite solar cell fabrication by blade-coating technique at laboratory scale [78]

- **Slot-die coating**

This technique is highly promising for fabricating large-scale PSCs. This methodology works similarly to blade coating and the main difference is that the scraper is replaced with a coating head composed of two metal sheets, which feeds precursor solution from the narrow gap. In PSC manufacturing, Film uniformity and thickness can be finely tuned by varying the precursor solution concentration and the relative speed of coating head.

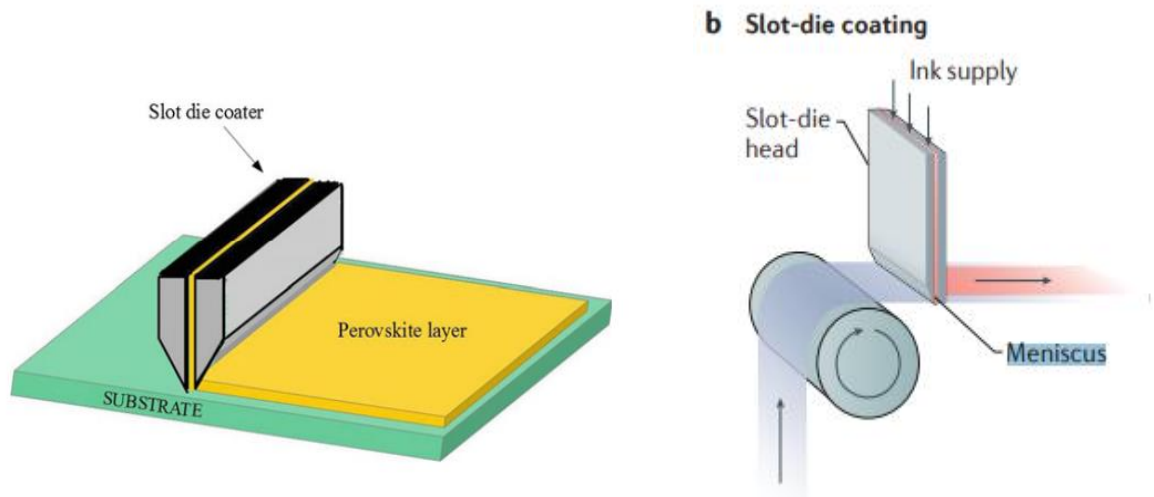


Figure II. 33 : Perovskite layer deposition using slot die coating technique [78]

- **Spray coating**

has become a popular method for producing large-area perovskite films due to its effectiveness. The precursor solution is initially atomized into small droplets, which are then sprayed onto the substrate with the help of a carrying gas, resulting in the formation of a uniform, compact, and continuous wet film, and finally crystallized into a perovskite film upon solvent evaporation by heating. Spray equipment is typically made up of three main components: an atomizing nozzle, an injection pumping system, and a heating plate. Depending on the operating mode of the nozzle, spray equipment can be classified into pneumatic, ultrasonic, and electro spraying, of which the first two types are more commonly used [79]. The quality of the perovskite film fabricated by spray coating can be influenced by a series of processing parameters, which include the distance and relative speed between nozzle and substrate, crystallization temperature, flow rate, viscosity and composition of the precursor solution,

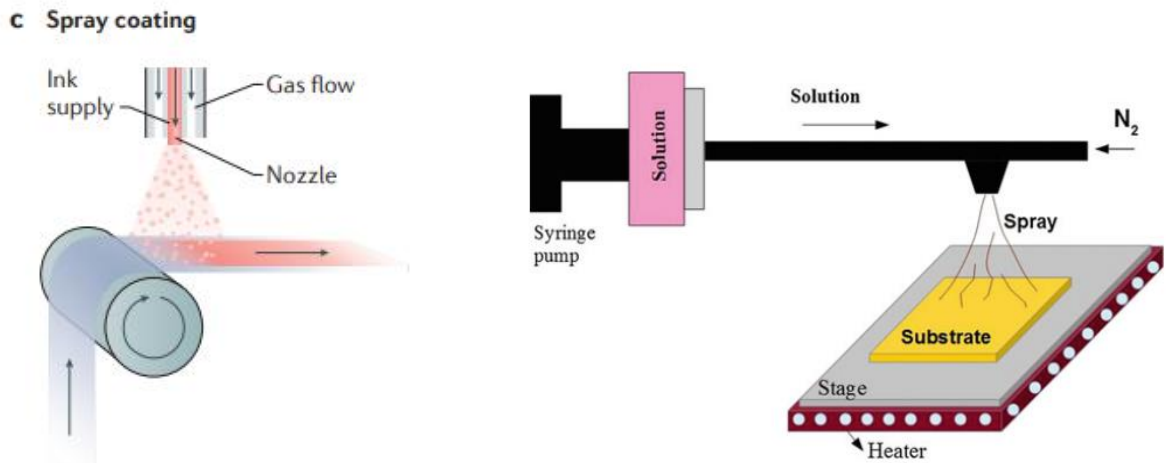


Figure II. 34 : Schematic diagram of ultrasonic spray-coating process [80]

- **Spin-coating technique**

Spin coating is a method of solution processing that is both simplest and cost-effective, and it is used for uniform deposition of perovskite layers on PSCs. This technique is mainly used for producing small-area solar cells. Generally, after spin coating, the film is baked to produce well-crystallized layers of the perovskite, since the baking results in strong adhesion and bonding between metal cations and halogen anions. The film thickness and quality can be improved by optimizing spin speed, acceleration, and time of spin coating. [79][81][82]

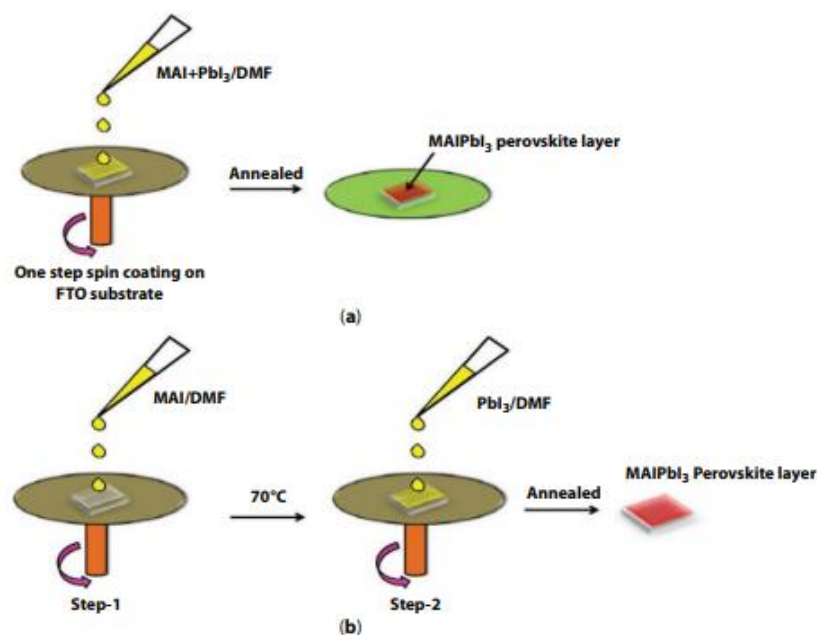


Figure II. 35 : Methods of spin coating (a) one-step deposition and (b) two-step deposition

II.13.2. Development of perovskite

The world has seen a significant development in perovskite solar cells in these recent years, so the (**Table II. 6**) below gives us some of the latest perovskite solar cells: [83]

Table II. 6 : Confirmed multiple-junction terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m²) at 25 C (IEC 60904-3: 2008 or ASTM G-173-03 global). [84]

Classification	Efficiency (%)	Area (cm ²)	Voc (V)	Jsc (mA/cm ²)	Fill factor (%)	Test Centre (date)	Description
Perovskite/Si	33.9 ± 0.3	1.0044	1.966	20.76	83.0	NREL (9/23)	LONGi, 2-term.
Perovskite-2T tandem	33.7	1.0035	1.974	20.99	81.3	(ESTI)	KAUST
Perovskite/perovskite	29.1 ± 0.5	0.0489	2.154	16.51	81.7	JET (12/22)	NanjingU/Renshine, 2-term
Perovskite/Si (large)	28.6 ± 1.4	258.14	1.909	19.11	78.3	FhG-ISE(5/23)	Oxford PV, 2-term

The latest efficiency record for a perovskite/silicon tandem solar cell, an impressive 33.9% set by Longi in 3 November 2023 (**Figure II. 36**), is the current pinnacle of what has been a remarkable leap in photovoltaics. This record, surpassing

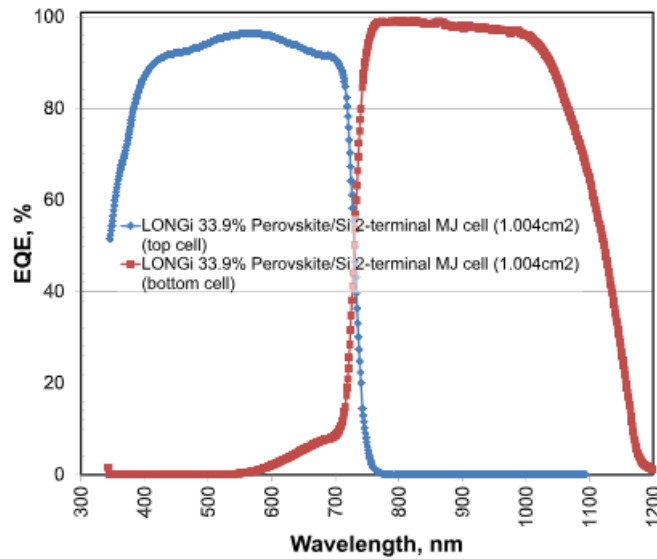


Figure II. 37 : Diagram of tandem perovskite / silicon wavelength

As we can see in (Figure II. 37) the trick is that the perovskite layer uses the entire wavelength range of visible light [380 – 700 nm] and converts it into electric current. Near-infrared light [800 – 2,500 nm], on the other hand, penetrates the perovskite layer, hits the silicon cell underneath and is converted into electrical energy. By working in tandem, the solar cell duo increases its power-conversion efficiency to over 30%

II.13.4. Application for perovskite

Formula:

Mathematical formulas used to obtain efficiency and FF in perovskite solar cells:

To calculate the efficiency and fill factor (FF) of perovskite solar cells (PSCs), several mathematical formulas are used. Here are the key formulas:

- Power Conversion Efficiency (PCE)

$$PCE = \frac{V_{oc} * J_{sc} * FF}{pin} * 100\% \quad (II.3)$$

V_{oc} : Open-circuit voltage

J_{sc} : Short-circuit current density

FF : Fill factor

pin : Incident power

- Fill Factor (FF):

$$FF = \frac{P_{max}}{V_{oc} * J_{sc}} \quad (II.4)$$

P_{max} : Maximum power output of the solar cell

- **Example of tandem perovskite / silicon**

Condition global AM1.5 spectrum (1000 W/m²) at 25 C

Open – circuit voltage : $V_{oc} = 1.966 V$

Short – circuit current density : $J_{sc} = 20.76 \left(\frac{mA}{cm^2} \right) = 207.6 \left(\frac{A}{m^2} \right)$

Fill factor : $FF = 83\%$

$$pin = 1000 \frac{W}{m^2} \quad (II.5)$$

Calculation:

$$PCE\% = \frac{1.966 * 207.6 * 0.83}{1000} * 100\% = 33.87\%$$

Efficiency tandem perovskite / silicon $PCE\% = 33.87\%$

II.13.4.1. Study of power output from perovskite solar cell

Partial solar surfaces - There are quite a few cars with solar cells installed in a small part of the roof or rear spoiler. This option was available in many cars including some Toyota Prius and Nissan Leaf models. As an innovative tip, we are trying to change the type of solar cells through the new technology of perovskite solar cell that gives us the best efficiency

The usable clear area of a Model Y glass roof is **0.6858 m” x 1.0922 m”** and **0.6858 m” x 1.016” m**

$$\text{Roof dimension} = 1.4458m^2$$



Figure II. 38 : TESLA module Y roof dimension

There are additional areas that might be covered by solar cells, but we've left them out for this analysis. For example, solar cells could be mounted on the hood to double the surface area. The problem with the hood is it often gets rock strikes which would shatter the glass. Being lower, objects and the car itself may cast a shadow on the hood in some orientations, reducing the power output. Lastly, European pedestrian safety standards require the hood have some give to reduce pedestrian injuries if struck. A glass hood could never meet these standards.

The rear trunk lid offers a small additional area. It also tends to collect dust and dirt, reducing the performance of cells in this location.

This PV system model is basically a calculation to find the solar energy output. The global formula to estimate the electricity generated in output of PV system is: [86]

$$\mathbf{E = A * r * H * PR} \quad \text{(II.6)}$$

Where;

E: is the energy output (kWh)

A: is the total solar panel area (m²)

r: is the solar panel yield (%)

H: is the annual average irradiation on tilted panels (shadings not included) (kWh/m²)

PR: is the performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)

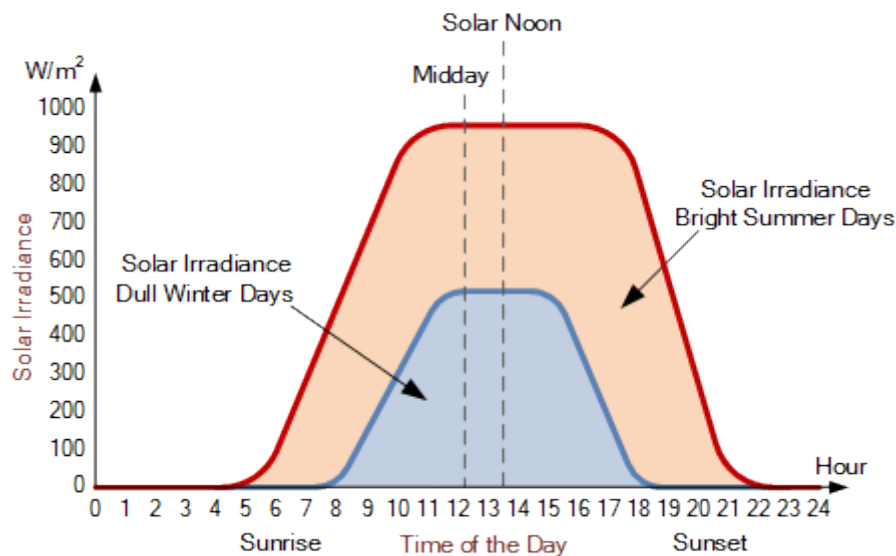


Figure II. 39 : Solar Irradiation During the Day [87]

We can see from our daily example, that the solar irradiance available and brighter sunnier are in summer days and it is greater than winter days. So, the peak sun hours available during the summer is clearly longer than the winter period allowing a PV panel to operate at its peak rated output longer.

So, for example, if the average solar energy which falls on a surface during the summer months is 1000 W/m² and is available for a full 6 hours per day, the daily amount of solar irradiance received during the summer months will be: [88]

1000 W/m² for 1 m²

1445.8 W/m² for 1.4458 m²

$$1445.8 \text{ W/m}^2 \times 6 \text{ hours} = 8674.8 \text{ Wh/m}^2 \text{ or } 8.6748 \text{ kWh/m}^2$$

Thus, from above, we can see that if **1.4458 kWh/m²** is equal to one Peak Sun Hour (PSH), then **8.6748 kWh/m²** is equal to **8.6748 peak sun hours, or 8.6748 PSH.**

$$E = 1.4458 * 0.339 * 8.6748 * 0.75 = 3188 \text{ W} = 3.188 \text{ kWh}$$

So, for example, if the average solar energy which falls on a surface during the winter months is 500W/m^2 and is available for a full 2 hours per day, the daily amount of solar irradiance received during the summer months will be:

500 W/m^2 for 1 m^2

722.9 W/m^2 for 1.4458 m^2

$$722.9\text{ W/m}^2 \times 2\text{ hours} = 1445.8\text{ Wh/m}^2 \text{ or } 1.4458\text{kWh/m}^2$$

Thus, from above, we can see that if 0.7229 kWh/m^2 is equal to one Peak Sun Hour (PSH), then 1.4458 kWh/m^2 is equal to 1.4458 peak sun hours, or 1.4458 PSH.

$$E = 1.4458 * 0.339 * 1.4458 * 0.75 = 531.4\text{ Wh} = 0.5314\text{ kWh}$$

II.13.4.2. Calculation of time charging:

Here are efficiency ranges of the main types of rechargeable batteries:

- ✓ Lead-acid batteries: ZWhE = 80 - 85%
- ✓ Lithium-ion batteries: ZWhE = 90 - 95%
- ✓ Ni2Cd=Ni2MH: ZWhE = 70 - 85%

Formula:

$$\text{charge time} = \frac{(\text{battery capacity} \times \text{depth of discharge})}{(\text{charge current} \times \text{charge efficiency})} \quad (\text{II.7})$$

- Characteristic of battery lithium [89]

Battery model	<u>Lithium Iron Phosphate (LiFePO4</u> – LFP)
Battery current (Ah)	150 Ah
Battery voltage (V)	12 V
Power (W)	1800 W
Nominal voltage (V)	12.8 V
Depth of discharging DOD (%)	60%

- Calculate of charging time:

$$T_{\text{charging}} = \frac{1800 \times 0.6}{339 \times 0.95} = 1.117 \text{ h} = 3 \text{ h } 21 \text{ min}$$

II.13.5. Results

Efficiency (%)	33.9%	
Area (m ²)	1.4458	
Voc (V)	1.966	
Jsc (A/m ²)	207.6	
Fill factor (%)	83%	
Power (W)	339	
Charging time (lithium)	3h 21min	
Season	Summer	Winter
Solar irradiation (W/m ²)	1445.8	722.5
Time (hour)	6 h	2 h
Peak sun hours (PSH)	8.6748	1.4458
Energy (kWh)	3.188	0.5314

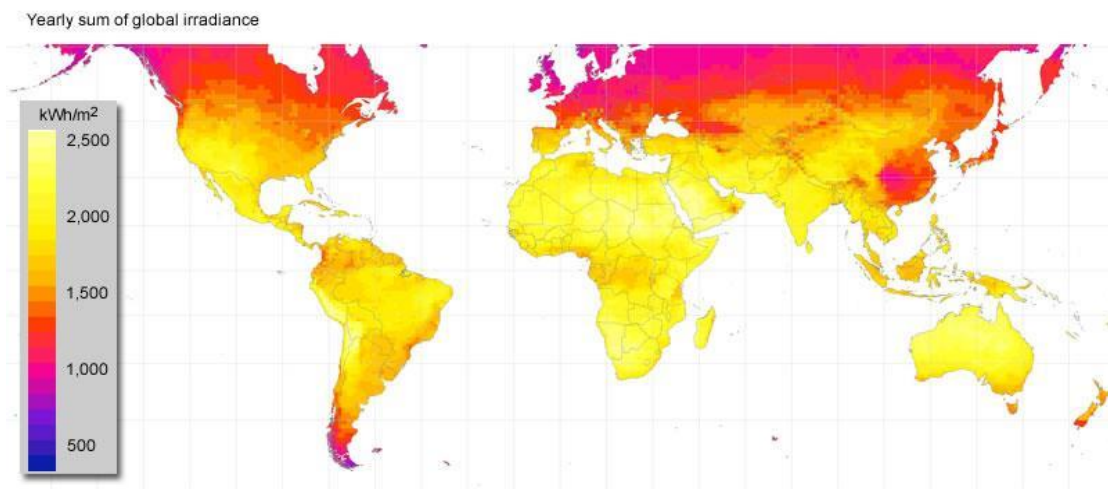


Figure II. 40 : World Map Annual global irradiance [90]

II.13.6. Advantage and inconvenience

Advantage:	inconvenience:
<ul style="list-style-type: none"> ● Low cost and ease of manufacturing: Perovskites hold the promise of being a low-cost technology with great ease of manufacture and decreased capital expenditure. 	<ul style="list-style-type: none"> ● Degradation issue of methyl ammonium lead iodide Perovskite need to be studied.
<ul style="list-style-type: none"> ● Efficiency: perovskite-based solar cells are showing an impressive rise in efficiency over in the last decade (recent studies have even passed 30%), and hopefully will allow for high-performance, low-cost PVs. 	<ul style="list-style-type: none"> ● Main issues in perovskite solar cells are film quality and thickness.
<ul style="list-style-type: none"> ● Low weight: (when produced on plastics, compared to glass-based silicon PVs) 	<ul style="list-style-type: none"> ● The perovskite material will break down quickly due to exposure of heat, moisture, snow etc.
<ul style="list-style-type: none"> ● Flexible form factors: since perovskite materials can be solution-processable, they can be printed or painted over flexible surfaces and enable solar windows, entire rooftops and more. 	<ul style="list-style-type: none"> ● The material is toxic in nature.
<ul style="list-style-type: none"> ● Recyclability: most perovskite panels are highly recyclable, some reaching a 100% recyclability rate. 	

II.14. Conclusion

The EV has improved considerably this decade, and this trend will continue. Autonomy, recharging, and on-board intelligence are subjects to follow closely in order to keep in mind the evolution of this type of vehicle. With this cutting-edge information by 2036 we can easily replace the conventional vehicle

An aerial photograph of a road with a central strip of green grass growing between two lanes of asphalt. The grass is a vibrant green, contrasting with the dark grey asphalt. The road is straight and runs vertically through the center of the frame. The text 'Chapter III: Environmental impacts' is overlaid in white serif font on the bottom left, with a vertical line to its left.

Chapter III:
Environmental impacts

III.1. Introduction

The environmental impact of electric vehicles compared to gasoline vehicles is positive for these four criteria: impacts on human health, impacts on ecosystems, GHG emissions and depletion of fossil resources. This data takes into account the production of vehicle parts, including the battery, transport to the user, vehicle use and end of life, we tried in this chapter mentioned this essentials factors so we can evolute the impacts of EVs

III.2. World battery market

Electric vehicles (EVs) are becoming more common throughout the U.S. CHINA, EUROPE with **millions now** cruising on roadways alongside their gas-powered counterparts. As more companies join EV giants like Tesla, competition for the burgeoning EV market share is likely to intensify. For many domestic and foreign automotive manufacturers, there's more at stake in pursuing alternative fuels than just breaking technological ground.

After long being confined to a very small commercial niche attracting only technophile consumers, the electric car has now entered the era of mass consumption and is emerging more and more clearly as the new standard for individual mobility in the medium to short term (10 years or even much less in some countries, notably Scandinavia). While just 17,000 EVs were on the road worldwide in 2010, sales exceeded 2.1 million in 2019, up 40% on 2018, taking the global fleet to 7.2 million units. Nearly half (47%) of the EVs on the road are in China, while with 1.7 and 1.5 million EVs on the road at 1 January 2020, Europe² and the United States account for 25% and 20% respectively of the global EV fleet. [91]

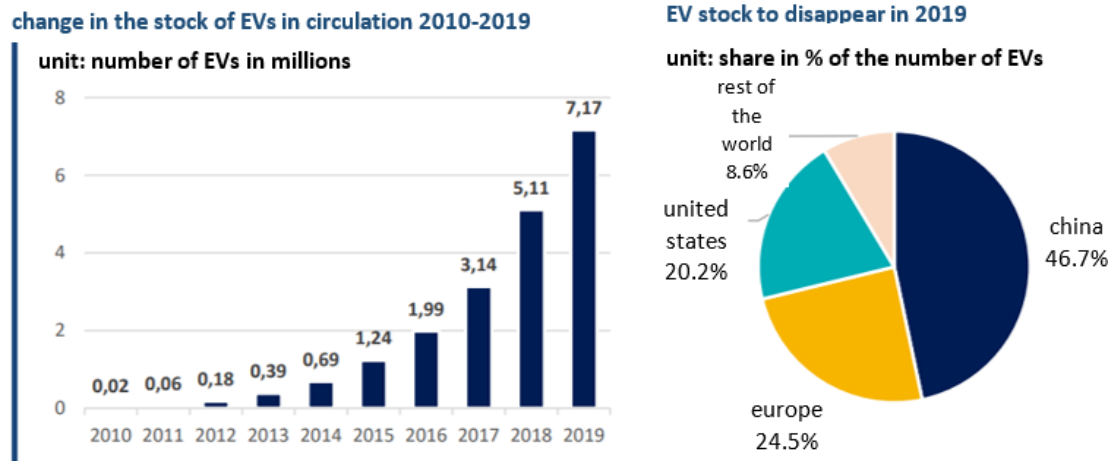


Figure III. 1 : Change in the stock of EVs in circulation 2010-2019

Admittedly, these sales only corresponded to a market share of 2.6% worldwide in 2019 (i.e., around 1% of the global car fleet). But it is rising very rapidly (almost doubling compared with 2017) and is much higher in certain markets considered to be pioneers, particularly China (4.9%) and Europe (3.5%). What's more, the economic crisis linked to the COVID-19 pandemic seems, contrary to all expectations, to be accelerating the process of electrifying the car fleet, particularly in Europe.

The overall market share of EVs should therefore be well over 3% in 2020, driven by exceptional growth in sales in Europe, particularly in the final months of the year. While car sales (all engine types combined) collapsed around the world in the first few months of 2020 as a result of the health crisis, EV sales held up well overall. In Europe, they even increased by 113% over the first 11 months of 2020 compared with the same period in 2019, while the car market as a whole shrank by more than 25%. [91]

We are truly witnessing a paradigm shift in consumption in Europe. In 2020, the EV market share reached 12% in Germany (compared with 3% in 2019), 10% in France and the UK (2.8% in 2019 in both countries), 30% in Sweden (11.5% in 2019) and even 73% in Norway (56% in 2019 and less than 1% in 2011). In November 2020 alone, the market share of EVs rose to 20% in Germany, 16% in the UK, 15% in France, 39% in Sweden and 80% in Norway, where sales of combustion engine cars (diesel and petrol) have virtually ceased, accounting for just 10% of the market. While China largely dominated the EV market until 2019 (during which half of global EV sales took

place in China, compared with a quarter in Europe and 16% in the United States), Europe is expected to account for around 40% of EV sales this year, on a par with China.[91] [92]

In addition to the 7.2 million EVs, there were some 377,000 electric light commercial vehicles (LCVs) on the road worldwide in 2019 (compared with 310,000 in 2018), two-thirds of them in China and the remaining third in Europe. Market share is still negligible, both in China (2.2% in 2019) and in Europe (just over 1%) and, unlike EVs, is struggling to take off in the absence of incentive policies.

Other modes of transport also contribute, albeit to a much lesser extent, to the demand for batteries (in particular electric two- and three-wheelers and micro mobility devices such as scooters and electric bicycles), or could do so in the future (buses, commercial vehicles and heavy goods vehicles, boats and aircraft).

Significant technological progress has already been made in the electrification of two- and three-wheelers, enabling some 350 million electric motorbikes and scooters to be used around the world today, a quarter of them in China, where many cities have banned combustion-powered two- and three-wheelers.

The market for electric buses is still relatively small, except in China, where almost all the world's electric bus fleet is concentrated (half a million units by the end of 2019).

While demand for electric buses is likely to grow in the future, not least because many cities in Europe, Asia (Calcutta, Bombay, etc.) and America (Mexico City, Santiago de Chile, etc.) want to combat air pollution by converting their bus fleets to electric, the technological choices are more open in this segment, where clean hydrogen and bioNGV offer undeniable advantages for decarbonisation.



Figure III. 2 : Electric bus [93]

Similarly, decarbonising road freight transport will not necessarily involve electrification. Today, only a few thousand electric trucks are on the road worldwide. Admittedly, manufacturers are tending to increase the range with new models (some of which are from new entrants to the market, such as the Americans Tesla and Nikola), but the technological choices remain more open for heavy goods vehicles than for passenger cars. While some manufacturers are focusing on electric vehicles as a priority (notably Daimler, Renault and Volvo, which have begun production of electric trucks in 2019), hydrogen, biofuels, carbon-neutral green gases and even LNG are now serious alternatives for heavy goods vehicles, thanks to their advantages (range, recharging speed, etc.). [92][94]

Finally, for ships and aircraft, the use of electricity is still a very distant possibility. Although the electrification of maritime transport is progressing, it is currently limited to ferries and other short-haul vessels. In the short term, purely electric ships should only be economically competitive with other low-carbon powertrains (hydrogen, biofuels, etc.) over short distances (up to 200 km). In aviation, small electric turboprop aircraft do exist, and there have been several demonstrations of small battery-electric aircraft flying very short distances (the first flight of an all-

electric commercial passenger aircraft took place in December 2019 in Canada, lasting 15 minutes). However, even with a rapid increase in the energy density of batteries, it seems unlikely that battery-powered aircraft will be able to cover distances of more than 1,000 km for several decades. Hybrid electric aircraft could nevertheless emerge in the next generation of aircraft, making it possible, for example, to reduce fuel consumption and emissions by electrifying ground operations (taxiing, etc.). [94]

“Nearly one in five cars sold in 2023 was electric, Electric car sales neared 14 million in 2023, 95% of which were in China, Europe and the United States “

Almost 14 million new electric cars were registered globally in 2023, bringing their total number on the roads to 40 million, closely tracking the sales forecast from the 2023 edition of the Global EV Outlook

Electric car sales in 2023 were 3.5 million higher than in 2022, a 35% year-on-year increase. This is more than six times higher than in 2018, just 5 years earlier. In 2023, there were over 250 000 new registrations per week, which is more than the annual total in 2013, ten years earlier. Electric cars accounted for around 18% of all cars sold in 2023, up from 14% in 2022 and only 2% 5 years earlier, in 2018. These trends indicate that growth remains robust as electric car markets mature. Battery electric cars accounted for 70% of the electric car stock in 2023.

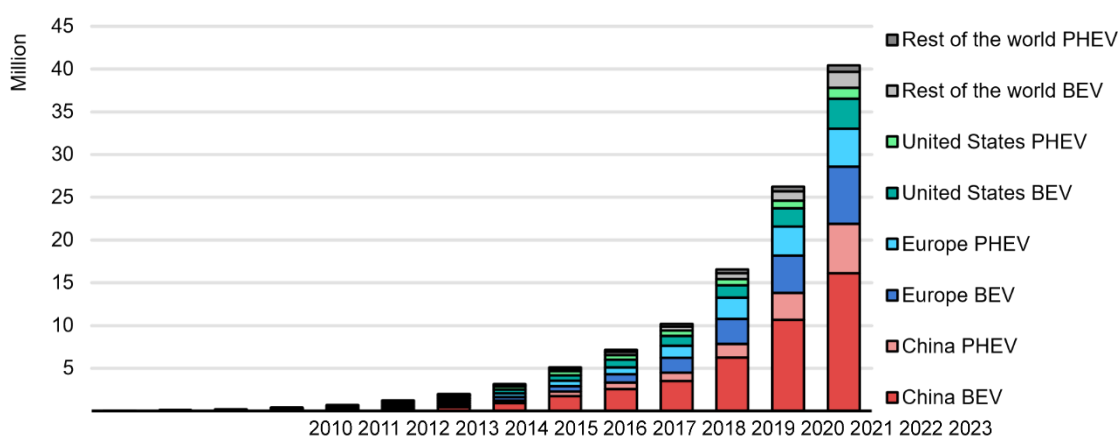


Figure III. 3 : Global electric car stock trends, 2010-2023 [95]

While sales of electric cars are increasing globally, they remain significantly concentrated in just a few major markets. In 2023, just under 60% of new electric car registrations were in the People’s Republic of China (hereafter “China”), just under 25% in Europe, and 10% in the United States – corresponding to nearly 95% of global

electric car sales combined. In these countries, electric cars account for a large share of local car markets: more than one in three new car registrations in China was electric in 2023, over one in five in Europe, and one in ten in the United States. However, sales remain limited elsewhere, even in countries with developed car markets such as Japan and India. As a result of sales concentration, the global electric car stock is also increasingly concentrated. Nevertheless, China, Europe and the United States also represent around two thirds of total car sales and stocks, meaning that the EV transition in these markets has major repercussions in terms of global trends

Throughout Africa, Eurasia and the Middle East, electric cars are still rare, accounting for less than 1% of total car sales. However, as Chinese carmakers look for opportunities abroad, new models – including those produced domestically – could boost EV sales. For example, in Uzbekistan, BYD set up a joint venture with UzAuto Motors in 2023 to produce 50 000 electric cars annually, and Chery International established a partnership with ADM Jizzakh. This partnership has already led to a steep increase in electric car sales in Uzbekistan, reaching around 10 000 in 2023. In the Middle East, Jordan boasts the highest electric car sales share, at more than 45%, supported by much lower import duties relative to ICE cars, followed by the United Arab Emirates, with 13%.

Electric vehicles are currently more expensive to buy than combustion vehicles. However, the price of batteries has fallen sharply over the last decade due to economies of scale and higher energy densities. This makes electric vehicles more attractive. However, the decline in prices has slowed in recent years. The point of cost parity, where an average electric vehicle will cost the same as an average combustion vehicle, will be reached around 2026. Vehicles in the compact and city car categories are likely to reach the price parity point later.

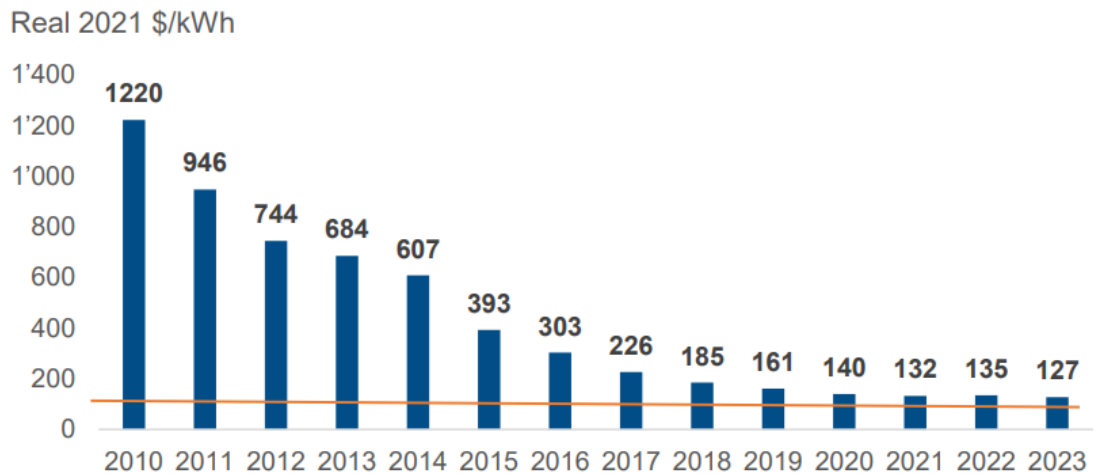


Figure III. 4 : Price of battery each year

battery cell prices have fallen to around \$100/kWh (**Figure III. 4**) For a complete battery, this value rises to around \$132/kWh. Due to the considerable rise in energy and raw material prices, cell prices rise again in April 2022 to \$135-175/kWh.

This is the first time since 2010 that this price has risen, leading to a rise in battery prices of around 2% in 2022/2023

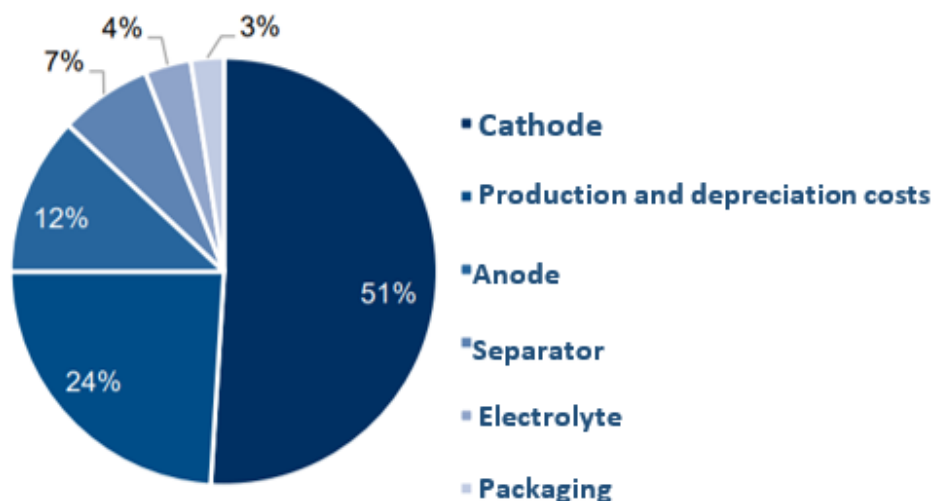


Figure III. 5 : Percentage of each material prices

III.3. Best 10 EV Battery Suppliers in 2024

As of 2023, the following names stood out as leading suppliers in the EV battery sector, marking their prominence within the industry:

- **CATL**
- **LG Energy Solutions**
- **PANASONIC**
- **Samsung SDI**
- **SK Innovation**
- **BYD**
- **Gotion High-Tech**
- **Northvolt**
- **DENSO**
- **Bosch**

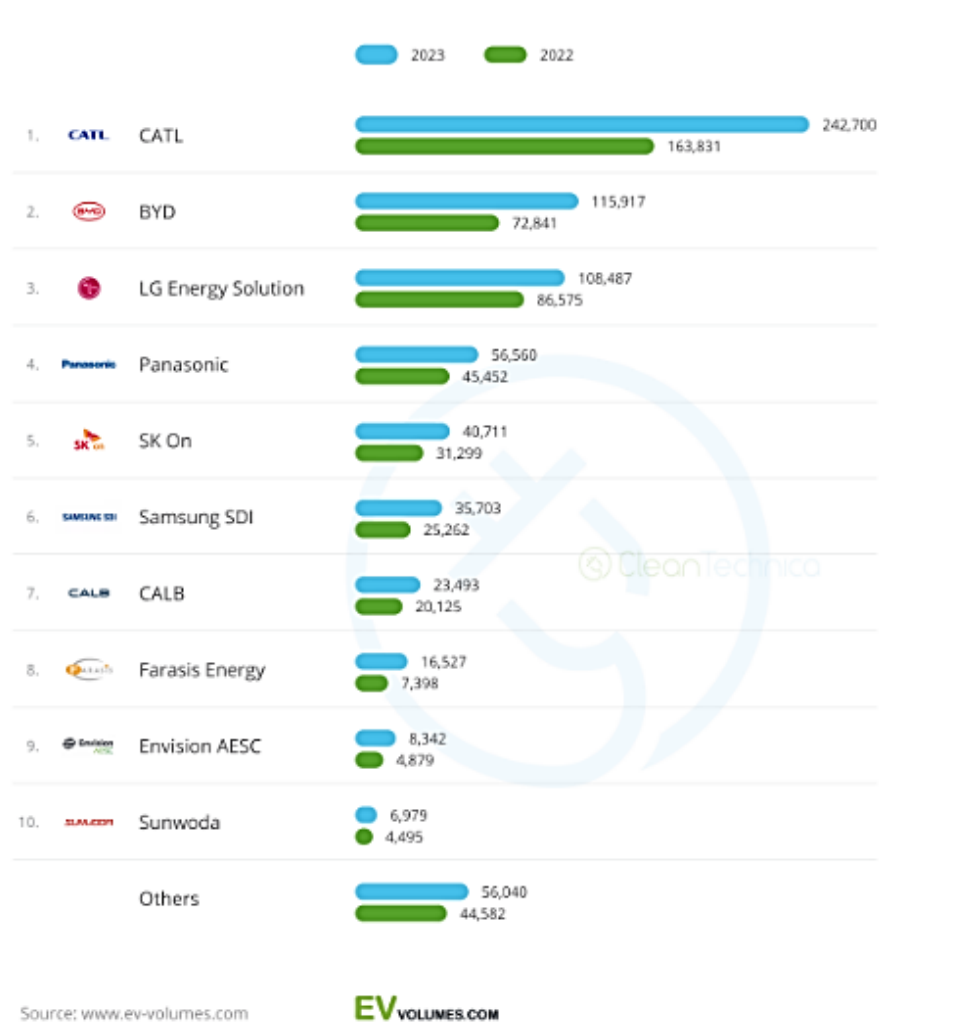


Figure III. 6 : Capacity of batteries manufactured in 2022 - 2023 (MWh) [96]

CATL continues to lead the charge, and it has increased its share from 32% to 34% due to a slightly over-average growth rate. That's thanks to the continued success of the Made-in-China Tesla Model Y, SAIC's MG4/Mulan, Li Auto's success, as well as a long list of clients. With the recently introduced Qilin battery and promising new Shenxing batteries, expect the battery maker to consolidate its share and remain in the lead through 2024, and even for years after that.

Fast growing BYD (+59% YoY) is the new silver medalist, with the Chinese everything battery maker jumping from 14% in 2022 to 16% in the same period of 2023 thanks to the rise and rise of the namesake brand. But the growth is also due to the new 3rd party supply deals it now has. It supplies the Made-in-Germany Tesla Model Y, Toyota bZ3, Changan UNI-V, Venucia V-Online, as well several Haval and FAW models. And with other brands lining up to get their batteries in 2024 (Kia, KG Mobility, etc.), expect the Shenzhen make to continue increasing its share throughout the year.

This was done at the cost of LG, which lost share in 2023, going from 17% in 2022 to 15% by the end of 2023. This was due to the lack of new orders, GM's troubled ramp-up of its new EVs, the end of life of some important volume models (Renault Zoe...), and also the fact that volume from some clients, like Mercedes or Ford, is being diverted to the competition.

III.4. Battery materials

The strong demand for batteries for electric vehicles is leading to a considerable increase in demand for the metals needed to manufacture them (**Figure III. 7, Figure III. 8, Figure III. 9**)

Between the beginning of 2021 to 2022 and 2023, lithium prices increased more than sevenfold, while cobalt and nickel prices doubled



Figure III. 7 : Value of cobalt on the commodities market from 2017 to 2023, in USD per ton (Trading economics, 2023a).

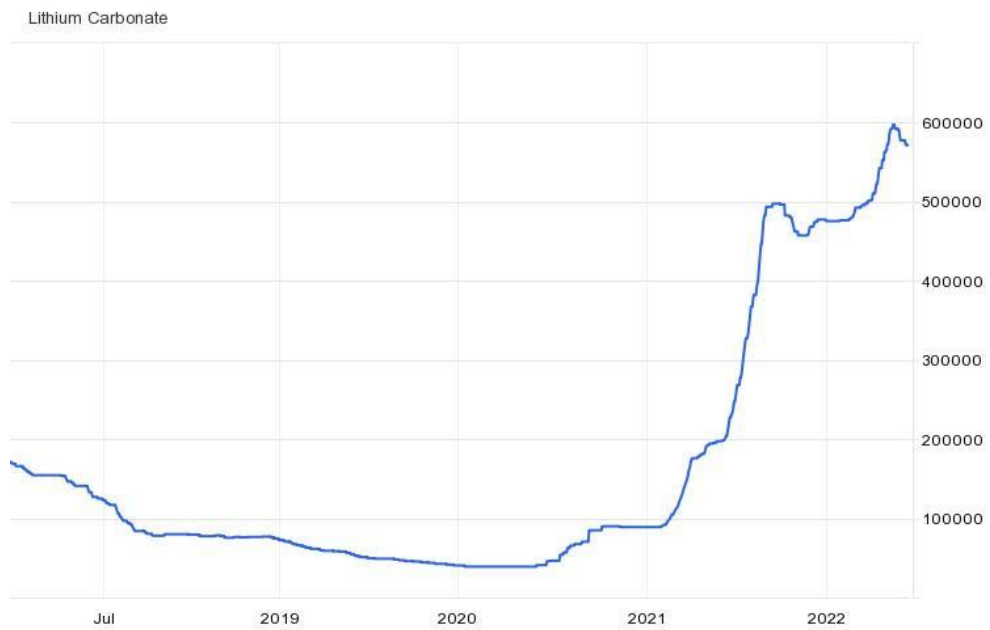


Figure III. 8 : Value of lithium carbonate on the commodities market from 2017 to 2023, in CNY per ton (Trading economics, 2023b)

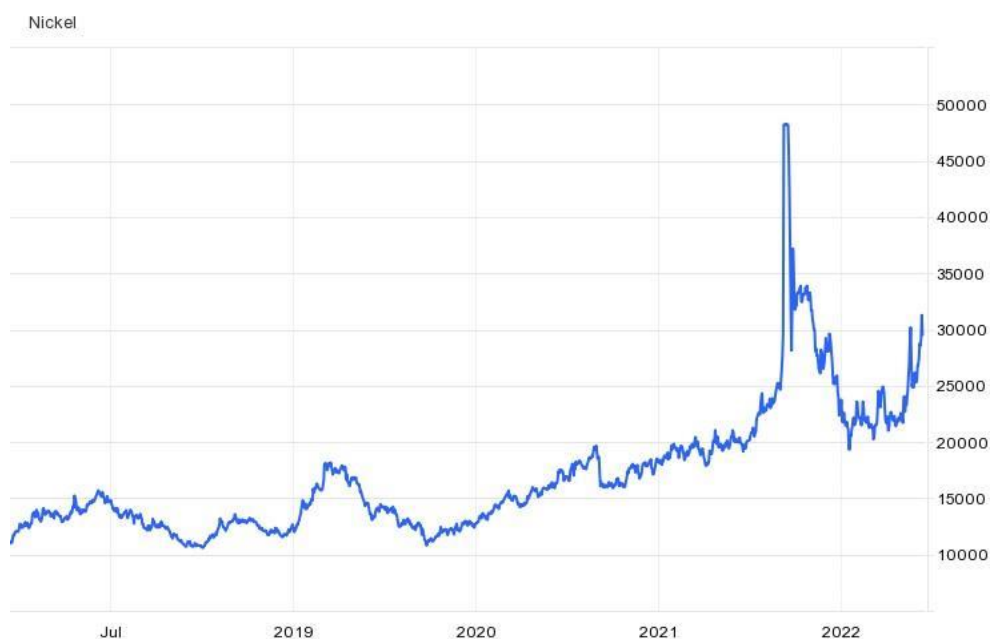


Figure III. 9 : Value of nickel on the commodities market from 2017 to 2023, in USD per ton (Trading economics, 2023c).

Several factors explain why battery prices have remained partly uncoupled from the rise in raw material prices.

Rising prices have encouraged manufacturers to change battery types. Many carmakers have opted for cheaper cathode chemistries that are less dependent on the price of raw materials, such as LFP. They have also concentrated on nickel-rich types of battery, such as NMC811, which has considerably reduced the use of cobalt.

So, despite temporary fluctuations, the downward trend in battery prices should continue in the long term. (Figure III. 10) shows the projections for the types of batteries used in passenger cars up to 2030. The share of LFP batteries is expected to rise sharply, to 35% of the market in the "Base" scenario and 60% in the "Constrained" scenario. As far as NMC batteries are concerned, it is mainly the more nickel-rich variants that are expected to gain ground. Other types of battery, such as sodium, LNMO, LNO and NMCA, are likely to play a secondary role.

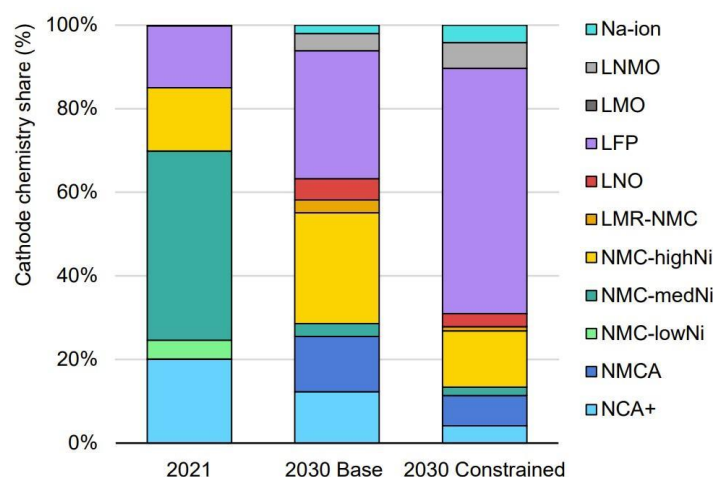


Figure III. 10 : Projections of battery types used in passenger cars in 2021 and 2030

III.5. Extraction of primary materials

The main raw materials used for NMC cells are cobalt, lithium, nickel, copper, graphite and manganese. LFP batteries, on the other hand, contain no nickel, manganese or cobalt. Steel and/or aluminum are also used for the battery as a whole, as a conductive support for the cathode and for packaging, rare earths are not used in batteries, but are necessary for the production of certain electric motors.

Global reserves of cobalt, lithium, nickel, copper, graphite and manganese are considered sufficient for the future electrification of the vehicle fleet. As far as cobalt is concerned, the situation is likely to improve with the development of low-cobalt, nickel-rich batteries. Lithium reserves should be sufficient, while uncertainties remain as regards nickel. However, temporary shortages, supply problems and short-term price spikes cannot be ruled out for some raw materials. This could happen if the development of new mines fails to meet demand or if exports from producing countries are compromised, for example. For lithium, copper, cobalt and nickel, sophisticated recycling processes on an industrial scale will be increasingly relevant in the future. [97]

- **Cobalt**

In 2021, global cobalt production reached its highest level at 170,000 tons, up from 144,000 tons in 2019. The driving force behind this increase has been the worldwide growth in electric mobility. More than 70% of the world's cobalt ore comes from the Democratic Republic of Congo, mainly as a by-product of copper and nickel mining, with production of 120,000 tons in 2021, of which 12% to 30% is extracted in small-scale artisanal mines using very simple mechanical methods. The rest is extracted industrially the other main producers are Russia with 7,600 tons, Canada with 4,300 tons, Cuba with 3,900 tons and Australia with 5,600 tons. Cobalt is almost always mined in combination with other metals such as copper, nickel, platinum group metals and zinc. Most of the ore is processed into cobalt metal in China. Cobalt is used in particularly hard superalloys used in the manufacture of cutting tools, catalysts, pigments and magnetic alloys used in electric motors and li-ion batteries. [98][99]

Around 34% of the world's cobalt was used in the production of batteries for electric vehicles (Cobalt Institute, 2023). By 2026, global demand for li-ion batteries for electric vehicles is expected to at least double cobalt requirements (Buchholz, 2023). Projections by Fraunhofer ISI predict global cobalt demand, taking into account cathode materials with reduced cobalt content, of 150,000 to 250,000 tons by 2050. Bloomberg's projections for global demand are at the lower end of this range, at around 100,000 tons in 2030. This would represent a total demand of 6 to 9 million tons of cobalt - as a primary material - between now and. Global cobalt reserves have been estimated at 7.6 million tons in 2021. Onshore resources amount to 25 million tons and a further 120 million tons of cobalt reserves could be found in manganese nodules at the bottom of the Atlantic, Indian and Pacific Oceans (VDI/VDE, 2023). However, technological innovations are still needed to exploit these resources profitably. In addition, reservations have been expressed about this technology, particularly for environmental reasons. [99]

More than 90% of cobalt can be recovered from collected. The EU is currently dependent on cobalt imports. However, Finland has both cobalt

reserves and refining capacity. Finland's share of world cobalt extraction is currently only around 0.8% (VDI/VDE, 2023).

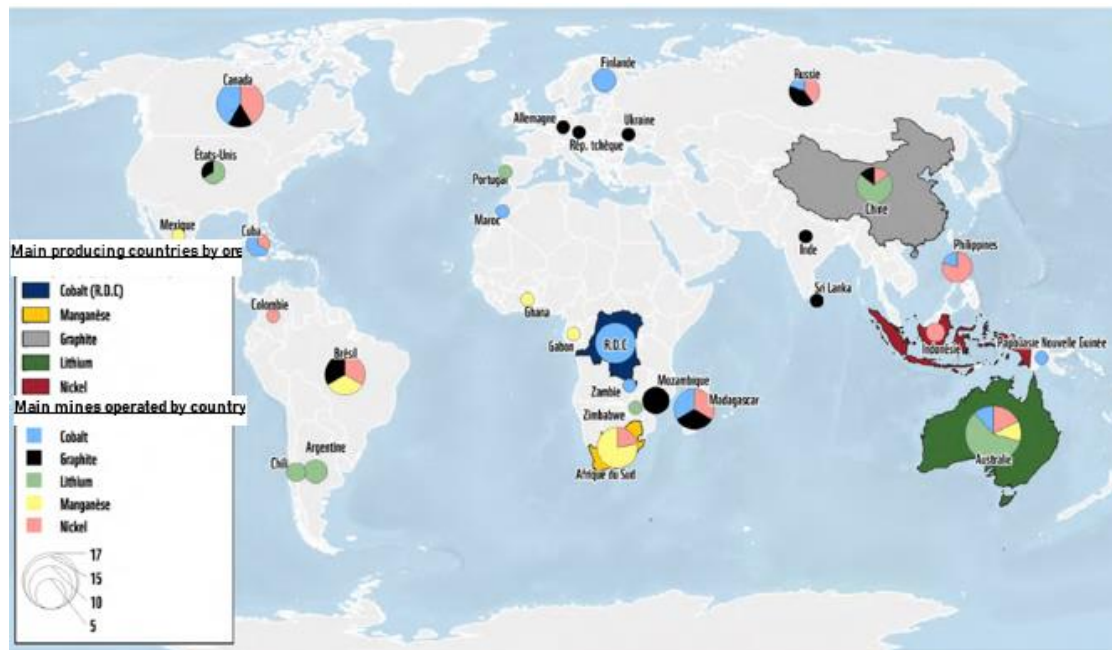


Figure III. 11 : Production of strategic minerals for the manufacture of electric cars [100]

- **Lithium**

Annual world production in 2021 was 104,800 tons of lithium. Of this total, 55,000 tons were mined in Australia, 26,000 tons in Chile, 14,000 tons in China, 6,200 tons in Argentina and 3,600 tons in three other countries. By 2026, global demand for lithium is expected to triple due to the boom in electric mobility in 2021, around 75% of global lithium production was used for batteries, of which almost two-thirds were used for electromobility (Statista, 2023c), 14% was used for the production of ceramics and glass, and the rest was split between various other applications (Statista, 2023a).

Global lithium requirements are expected to reach 1 to 1.3 million tons by 2050. If we add up the requirements up to 2050, this would represent 14 to 20 million tons of lithium (Fraunhofer ISI, 2023). The world's known lithium reserves are currently estimated at around 21 million tons, which is 256 times the amount extracted in 2020. As far as current global resources are concerned, data and estimates differ widely. According to data from the U.S. Geological Survey

(USGS), the world's lithium resources currently stand at around 89 million tons. [101][102]

- **Nickel**

The main nickel-producing country is Indonesia with 771,000 tons in 2021, followed by the Philippines with 334,000 tons, Russia with 283,000 tons, New Caledonia with 200,000 tons, Canada and Australia with nearly 170,000 tons each and China with 120,000 tons). World production will be around 3.7 million tons in 2024. [102]

The development of high-performance batteries with a low cobalt content and a high nickel content is certain to change estimates of nickel requirements and reserves in the years ahead. For the time being, it is difficult to assess the extent of this change, so temporary shortages or price rises in the short to medium term cannot be ruled out. Projections by the Fraunhofer ISI Institute for the year 2050 predict a global demand for nickel of between 4 and 6 million tons per year. However, this range could be slightly lower due to the possible development of batteries with reduced nickel content or an increase in the use of LFP batteries. Cumulative nickel requirements are estimated at between 70 and 110 million tons up to 2050. Current global reserves are estimated at 95 million tons and resources at 130 million tons. Most of the nickel required can be recycled from used batteries. The security of nickel supply can be ensured as long as end-of-life batteries are collected and recycled in a sufficiently efficient manner. [102]

- **Copper**

Chile is the world's largest copper producer, with around 5.6 million tons to be mined by 2021, followed by Peru with 2.2 million tons, Congo and China with 1.8 million tons each, and the United States with 1.2 million tons, to name but a few. China is currently the leading country in copper refining, processing around 10 million tons of copper a year, well ahead of Chile with around 2.2 million tons. [101][102]

World copper reserves stand at around 880 million tons, Undiscovered resources are estimated at around 3.5 billion tons. Based on current reserves, copper availability should be assured for around 40 years if demand remains

stable. If we add to this the world's resources (i.e., known deposits) of copper, it is possible to rule out a future shortage. However, demand for copper could double by 2040 due to the development of additional electricity grids

According to certain projections, the copper recovery rate from the recycling of lithium-ion batteries will be around 99% by 2025. Currently, this rate is around 45% in Europe. However, the battery recycling sector is constantly developing with this.

- **Graphite**

In 2021, by far the largest producer of graphite was China with 820,000 tons, followed by Brazil with 68,000 tons and Mozambique and Russia with almost 30,000 tons each. Around 7% of global production was used in the production of lithium-ion batteries, it is expected to rise to 30% by 2025. Graphite is extracted from open-cast or underground mines, then crushed and enriched using a relatively simple industrial process. As well as being used for battery anodes, graphite is also used as an anode in electrolysis cells. It is also used in the production of refractory materials, pencils and lubricants. Graphite can be extracted in ore form (natural graphite) or produced synthetically. [103]

- **Manganese**

Manganese is mainly extracted in the form of ore from industrial open-pit or underground mines. In 2021, global production was around 20,000 tons. Of this total, 7,400 tons came from South Africa, 3,600 tons from Gabon, 3,300 tons from Australia, 1,300 tons from China and 640 tons from Ghana. Global reserves are estimated at around 1.5 million tons, or 75 times 2021 production. Manganese resources are currently considered to be virtually unlimited worldwide. By 2025, the potential recovery rate of manganese from the recycling of lithium-ion batteries should be around 30%. By 2030, this recovery rate should reach 70%. [104]

III.6. Outlook and trends in global

the production of batteries for electric vehicles was responsible for almost half of global demand for lithium. Global demand for lithium is set to quadruple between now and 2030, with the proportion used in the production of batteries for electric vehicles rising from 70% at present to almost 80%, depending on the scenario considered (IEA, 2022). Given that the most common type of battery for electric vehicles contains a lot of nickel, demand for nickel should continue to rise sharply between now and 2030, despite the growth in the market share of LFP batteries. For cobalt, the trend is the opposite, as manufacturers increasingly reduce the cobalt content of the batteries they produce. However, rising global demand for batteries is expected to continue to increase global demand for cobalt over the decade.

The supply of metals for batteries should be sufficient to meet demand in the International Energy Agency's STEPS scenario, if the announced production capacity is implemented as planned. However, the more ambitious A S and NZE15 scenarios require greater investment in our production and recycling capacity (**Figure III. 12**). In the long term, recycling will make a significant contribution to supply. Until 2030, however, recycling is expected to make only small contributions (< 1% of total forecast demand for lithium and nickel, and around 2% for cobalt)

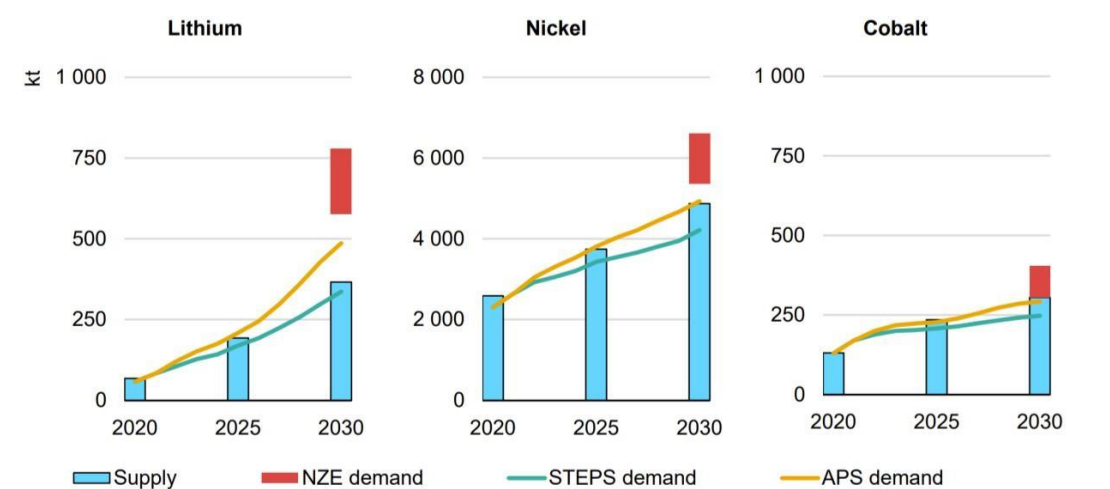


Figure III. 12 : Total demand and supply for lithium, nickel, cobalt 2020-2030 [105]

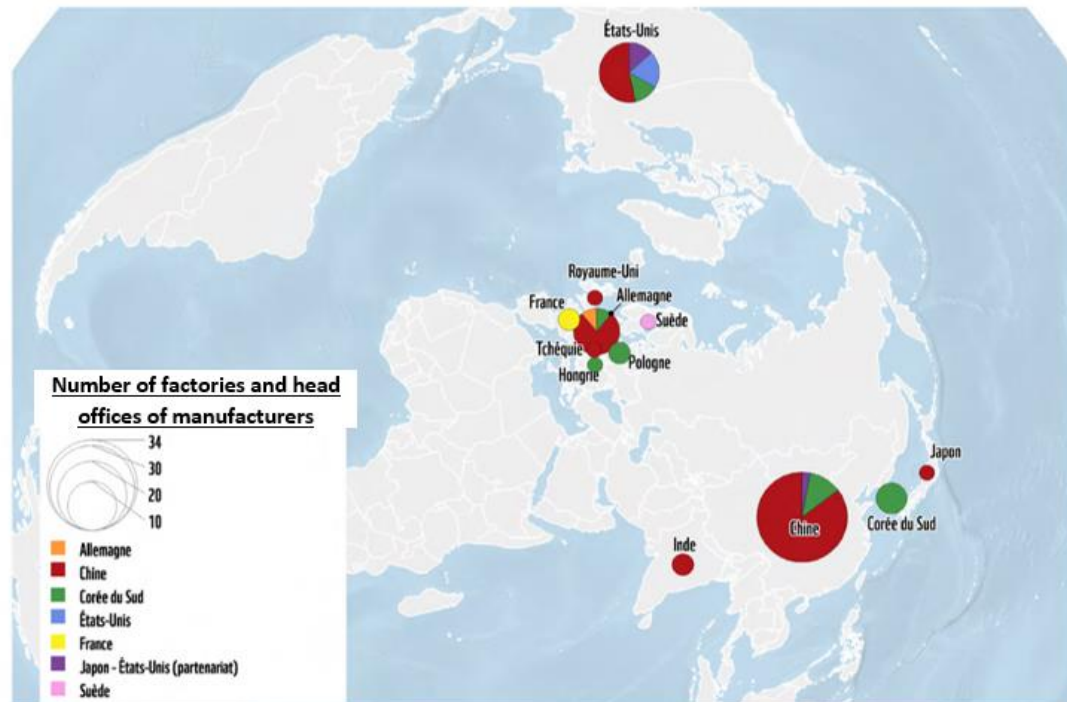


Figure III. 13 : Battery production plants worldwide [100]

III.7. Social and environmental impacts of raw materials extraction

The extraction of raw materials - regardless of the type of vehicle engine used - involves certain environmental and social risks. The European Commission defines sustainable batteries as follows: Sustainable batteries must be produced with the lowest possible environmental impact and using materials obtained in full compliance with social and environmental standards. Batteries must have a long life, be safe and be able to be repaired, re-used and re-purposed. [102]

Raw materials for battery production are usually extracted in countries where poverty is widespread and environmental and social standards are low. Local occupational health and safety standards are often inadequate, and there is a lack of appropriate monitoring and regulatory mechanisms. Future growth in battery production is expected to significantly increase global demand for raw materials, which should lead to increased mining. The environmental and social impacts of raw materials extraction have been widely documented (Conde,

2017). The Transition Minerals Tracker, affiliated to the Business and Human Rights Resource Centre (BHRRC, 2022), records human rights violations committed by the mining industry. Since 2010, 495 complaints have been registered against 103 companies producing lithium, cobalt, copper, manganese and nickel for low-carbon technologies, which also include electric mobility. [102]

The Environmental Justice Atlas documents hundreds of conflicts in raw materials extraction projects, resulting in environmental and social impacts (EJAtlas, 2022). In this sector, human rights violations and other negative impacts include restricted access to water, pollution of water, soil and air, and threats to health and safety, [99][101][102]

III.8. Causes of supply problems

Temporary supply difficulties throughout the supply chain are always possible and can arise for a variety of reasons. It is not possible to give a general answer to the question of current and future shortages, and these may only affect certain companies, raw materials or components.

Many players are involved in the entire lithium-ion battery manufacturing process. Delays in delivery to the end customer can therefore occur, as can bottlenecks between carmakers and their cell or battery suppliers. For some raw materials, temporary shortages, supply problems or short-term price rises cannot be ruled out, due in particular to limited supply on the market and geopolitical instabilities. This could happen, for example, when new extraction sites come on stream, if raw materials cannot be extracted in time to meet demand or if exports from producing countries cannot be guaranteed there is still uncertainty about the future availability of raw materials for nickel, so temporary shortages or delivery problems cannot be ruled out [106]

III.9. Consequences of the wars

Shortages of semi-conductors and raw materials, as well as the global COVID pandemic, have had a major impact on production in recent years, leading to delays in vehicle deliveries. The war in Ukraine, which began in the spring of 2022, has further exacerbated delivery difficulties in the automotive market. For example, parts supplied by Ukrainian factories, such as cable harnesses, have been missing.

The lithium, cobalt and graphite supply chains are less affected by these supply disruptions. However, the situation is worrying for nickel: Russia is the world's third largest producer, with around 9% of the world's nickel mined and around 6% of the world's nickel produced. [106][107]

. The situation is even more critical when you consider that Russia produces around 20% of the world's class 1 nickel, with a nickel content of at least 99.8%, which is needed for batteries. [107]

III.10. Environment challenges

While the climate crisis has many factors that play a role in the exacerbation of the environment, some warrant more attention than others. Here are some of the biggest environmental problems of our lifetime, from deforestation and biodiversity loss to food waste and fast fashion.

- **Global Warming from Fossil Fuels**

2023 was the hottest year on record, with global average temperatures at 1.46C above pre-industrial levels and 0.13C higher than the eleven-month average for 2016, currently the warmest calendar year on record. The year was marked by six record-breaking months and two record-breaking seasons

- **Air pollution**

According to a 2023 study, air pollution in South Asia – one of the most polluted areas in the world – cuts life expectancy by about 5 years. The study blames a series of factors, including a lack of adequate infrastructure and funding for the high levels of pollution in some countries. Most countries in Asia and

Africa, which together contribute about 92.7% of life years lost globally due to air pollution, lack key air quality standards needed to adequate policies. Moreover, just 6.8% and 3.7% of governments in the two continents, respectively, provide their citizens with fully open-air quality data.

- **Cobalt Mining**

Cobalt is quickly becoming the defining example of the mineral conundrum at the heart of the renewable energy transition. As a key component of battery materials that power electric vehicles (EVs), cobalt is facing a sustained surge in demand as decarbonisation efforts progress. The world's largest cobalt supplier is the Democratic Republic of Congo (DRC), where it is estimated that up to a fifth of the production is produced through artisanal miners.

- **Soil Degradation**

Organic matter is a crucial component of soil as it allows it to absorb carbon from the atmosphere. Plants absorb CO₂ from the air naturally and effectively through photosynthesis and part of this carbon is stored in the soil as soil organic carbon (SOC). Healthy soil has a minimum of 3-6% organic matter. However, almost everywhere in the world, the content is much lower than that.

III.11. Environmental Challenges of EVs

- ✓ A deficiency in socio-economic assessment
- ✓ A lack of integrated modeling approaches and macro-level evaluation
- ✓ Inadequate consideration of end-of-life management and circular economy applications
- ✓ An insufficient representation of the developing world
- ✓ An inadequate representation of emerging technology

III.12. Environmental impact of production

Estimates of energy consumption for battery cell production vary considerably from one study to another. This is because the plants considered are of different sizes and do not all operate at full capacity. Modern giga factories operating at full load are at the lower end of the scale in terms of energy

consumption in the literature. In addition, the different industrial processes used and the types of batteries produced also explain the variation in energy consumption between facilities. For example, energy consumption decreases if water is used instead of NMP as the solvent for drying the electrodes. The global warming potential for two popular cell chemistries and the main drivers for these values:

- NMC811 = 76.7 kg CO₂ eq. per kWh
- LFP = 77.9 kg CO₂ eq. per kWh

III.13. Sources of energy used to produce batteries

The energy sources used to produce batteries and the upstream processes have a strong influence on their environmental impact. Greenhouse gas emissions per kWh of battery produced are 3 to 9% lower if they are produced using a European electricity mix (43% fossil-fuel based) compared with a Chinese electricity mix (73% fossil-fuel based). [108]

According to another study, battery production using the Swedish electricity mix, which is almost entirely carbon-free, emits 55% fewer greenhouse gases than production using the South Korean mix, with almost all of the environmental impact attributable to upstream processes. [108]

Emissions of fine particles come largely from the manufacture of materials, i.e., extraction and metallurgical processes.

III.14. Influence of battery type

The type of batteries produced also has an influence on the environmental impact of lithium-ion battery production, although to a lesser extent. Greenhouse gas emissions (in kg CO₂eq/kWh) during the production of NMC111, NMC811 and NCA battery modules differ by a maximum of 10% when they are produced in a similar way. [108][109]

All types of battery are generally produced using similar processes. The main difference lies in the active material used for the cathode. The determining factor is the proportion of nickel and cobalt in the cathode's active material.

However, there is a greater difference in impact between LFP cells and NMC or NCA cells, because their cathodes are made from very different materials. [108]

The main difference between NMC and NCA cathodes lies in the use of manganese for NMC cathodes, or aluminum for NCA cathodes. In general, aluminum production has a higher environmental impact than manganese in most impact categories, which is why NCA batteries are marginally less efficient than NMC batteries. [109]

The main difference between NMC622 and NMC111 batteries is that NMC622 batteries have a lower cobalt content and a higher nickel content.

III.15. battery size

From an environmental point of view, the battery must be as small as possible to minimize the impact of its production. A higher mass also means higher energy consumption. On the other hand, a larger battery has advantages in winter, such as greater range or slower ageing despite lower temperatures. The optimum battery size therefore depends on individual needs and is a compromise between maximum range, cost and environmental impact. [109]

The distance travelled each day is the main criterion when choosing a vehicle. In principle, a full 100% charge cycle every two days ensures that the battery can be used for at least 12 years. If you drive an average of 40 km a day, the battery is optimally used, with a real range of 80 km. But as vehicles are not generally used in the same way every day, average use is not the only relevant criterion.

III.16. Recycling

III.16.1. Producing batteries from recycled materials

The medium-term aim is to arrive at a circular economy for batteries by developing closed loop recycling. The European Commission is currently working on drafting a regulation that will incrementally impose the use of recycled materials in the composition of electric vehicle batteries.

Threshold levels for recycled materials will concern all batteries sold into the European market, irrespective of their place of manufacture. Starting in 2025, it will be



Figure III. 15 : Stages in recycling electric vehicle batteries

The main stages are described below:

- **Collection and making safe.**

Before any recycling can take place, batteries have to be removed from the vehicle where they were installed. They then have to be fully electrically discharged and made safe so that they can be handled securely at every step of the process. These stages are of great importance as it is possible to damage the batteries. They contain highly inflammable materials and chemicals that are harmful to humans and the environment. [112]

- **Dismantling.**

The protective plastic or aluminum casing, electronic components, wires, connectors and the cooling system are all removed to locate the separate modules that comprise the battery. This part of the process is accomplished manually by trained operators. Next, the aluminum protection around the modules is removed to uncover the battery cells. [112]

- **Mechanical recycling.**

The battery cells are then ground up to separate the elements with less value from those that are more valuable. Cell grinding takes place under high humidity to avoid all risk of fire or explosion. The ground materials are then mechanically separated to obtain three primary materials: paper and plastics; aluminum, copper and steel; and “black mass”, a powder containing mostly a mixture of carbon, nickel, lithium and cobalt. [112]

- **Chemical recycling.**

The black mass is then processed chemically to separate and purify the materials it contains. Two main technologies are used to achieve purification: hydrometallurgy and pyrometallurgy. Although pyrometallurgy is simpler to use, it requires large amounts of energy and does not deliver high levels of purification. This means that it

often needs to be followed by a hydrometallurgical process that allows materials to be extracted selectively. Veolia applies a hydrometallurgy process directly to purify lithium, nickel and cobalt and separate them from the black mass. [112]

- **Production of precursors**

If the by-products produced by hydrometallurgy units are sufficiently pure, they can be used in the production of precursors and materials for anodes and cathodes. This closes the recycling loop as it means recycled lithium, nickel and cobalt can be used in the production of new batteries. [112]

The job-creation potential of battery recycling activities

Developing battery recycling activities is also about promoting new skills and encouraging an ecological shift that creates employment. There are several estimates of the job-creation potential of battery recycling. According to a recent study into how to achieve a well-balanced transition in the French automobile industry, conducted by the Foundation Nicolas Hulot (June 2021), battery recycling will create 9,000 jobs in 2030-2035 an earlier study by the Centre for European Policy. [113]

III.17. Conclusion

In 2024, the results of the electric car are even more positive. They continue to improve. Indeed; more and more new electric vehicles are manufactured from end-of-life vehicle batteries. In fact, recycling electric batteries has so many benefits that car manufacturers now offer electric motorists the chance to recover their batteries free of charge.

All these innovations are trying to make a less carbonized battery so that prove that the electric car is not totally innocent and requires a responsible behavior toward the environment.

General conclusion

In recent years, global warming has been occurring ecological debates, and road vehicles with their emissions carbon dioxide CO₂, are put forward as one of the major causes of this phenomenon. Thus, recently, new alternative structures to conventional vehicles, which combine the advantages of thermal and electric propulsion, are put in place, these new vehicles.

This time we focused under the instructions of the supervisor on batteries and the most important alternatives like lithium, sodium and renewable materials, in terms of materials, price and environmental impact. Electric cars are innovative due to their environmental benefits, energy efficiency, and advancements in technology. They produce fewer emissions, promote renewable energy use, and feature cutting-edge technologies such as regenerative braking, advanced driver-assistance systems, and smart connectivity. These innovations contribute to a cleaner, more sustainable future for e-mobility. These solutions offer more advantages like:

- Establishing laws requiring all POS and car manufacturers to sell, produce and market electric vehicles in parallel with cars with internal combustion engines
- Set up facilities for people and users using electric cars.
- Environmental awareness
- Supporting research and development in university and technical laboratories and spreading the search of EVs.
- Protecting human and workers' rights and combating child labor in the third world countries
- Develop and support recycling batteries and the transition towards renewable energy sources must run away

Therefore, the electric car is considered the best in the technological arena, both in terms of development and environmental impact, in the hope of generalizing marketing, especially in third world countries.

References

1. Dossier : L'histoire de la voiture électrique ..Marché mobilité, Transition énergétique, 18 janvier 2022, <https://www.mobilitytechgreen.com/blog/2014/07/24/dossier-lhistoire-de-la-voiture-electrique/>
2. Les moteurs de véhicules électriques,2024,<https://www.ave-re-france.org/les-moteurs-de-vehicules-electriques/>
3. Gérard Stevens. Les voitures électriques ont-elles une transmission ?<https://www.way.com/fr/blog/do-electric-cars-have-a-transmission/>
4. <https://www.trumonytechs.com/fr/materiaux-dinterface-thermique-batterie/>
5. <https://www.volkswagen-group.com/en/press-releases/in-brief-key-components-for-a-new-era-the-battery-system-17010>
6. <https://www.batterydesign.net/volkswagen-meb-battery-pack-id-family/>
7. https://www.epa.gov/sites/default/files/2018-03/documents/spanenberger_epa_webinar_-_3-22-18_-_argonne.pdf
8. Procédé de fabrication de plaque pour accumulateur au plomb-acide , Inventor Rongrong ChenShay Harrison Wellington Y. Kwok , Date of publication and mention of the grant of the patent: 09.02.2011 Bulletin 2011/06
9. Piles NiCd Nickel Cadmium, <http://fr.bateriapoder.com/>
10. <https://www.usinenouvelle.com/article/la-snam-recyclera-les-batteries-de-toyota-motor-europe.N162892>
11. Sophie Bécherelm Les inventeurs de la batterie au lithium-ion décrochent le prix Nobel de chimie, Boris Hallier, Publié le mercredi 9 octobre 2019
12. Projet d'usine de production de batteries de Douvrin/Billy-Berclau_ Dossier de concertation, Février 2021, <https://www.concertation-acc-batteries.fr/download/files/documentation/Projet-ACC-dossier-de-concertation.pdf#page=16>
13. <https://www.radiofrance.fr/franceinter/les-inventeurs-de-la-batterie-au-lithium-ion-decrochent-le-prix-nobel-de-chimie-4465893>
14. Ngoc Anh, Tran. (2021). Thesis 14122020. 10.13140/RG.2.2.33090.09921.
15. FABRICATION DE BATTERIE LITHIUM,
16. <https://www.lipobattery.us/lithium-polymer-battery-specification/>
<https://www.buschvacuum.com/global/fr/applications/lithium-battery-manufacturing/>

17. Matan, Author at Electricity-Magnetism|2024.
<https://www.electricity-magnetism.org/fr/author/matan/page/41/>
18. Principe de fonctionnement et constituants d'une batterie Les vélos à assistance électrique
Jean-Loup PRENSIER – Cédric LUSSEAU
19. Traitement des batteries lithium fer phosphate en fin de vie par hydrométallurgie Auteur : Landouré, Seydou Mamadou Promoteur(s) : Gaydardzhiev, Stoyan Faculté : Faculté des Sciences appliquées Diplôme : Master en ingénieur civil des mines et géologue, à finalité spécialisée en ressources minérales et recyclage Année académique : 2022-2023
https://matheo.uliege.be/bitstream/2268.2/16741/7/TFE%20Seydou_M_Landour%C3%A9.pdf
20. <https://www.avere-france.org/les-batteries-de-vehicules-electriques/>
21. CEA, « Accumulateurs, piles et batteries : des performances en constante amélioration » in L'énergie dans tous ses états [consulté le 3 novembre 2020],
<https://www.cea.fr/multimedia/Documents/publications/clefs-cea/archives/fr/encadrea.pdf>
22. Source : [European Technology and Innovation Platform on Batteries – Batteries Europe](#), « Strategic Research Agenda for batteries », 4 décembre 2020, page 14
23. Evolution of li-ion battery price 1995-2019 page internet actualisé le 30 juin 2020
24. <https://medium.com/@bintorosoft/the-future-of-energy-storage-how-solid-state-batteries-are-revolutionizing-power-fea9bb9a598d>
25. Clément BONNET, Gondia SOKHNA SECK, Emmanuel HACHE, Marine SIMOËN, Samuel CARCANAGUE, « Copper at the crossroads: assessing the interactions of the low carbon energy transition with a non-ferrous and structural metal », IFPEN/IRIS, juillet 2019, <https://www.iris-france.org/notes/copper-at-the-crossroads-assessing-the-interactions-of-the-low-carbon-energy-transition-with-a-non-ferrous-and-structurous-metal-2/>
26. Source : [IEA](#), « Global EV Outlook 2020, Entering the decade of electric drive? », juin 2020
27. Coffin, D., & Horowitz, J., « The supply chain for electric vehicle batteries ». *J. Int'l Com. & Econ.*, 1, 2018,
<https://heinonline.org/HOL/LandingPage?handle=hein.journals/jice2018&div=9&id=&page=>
28. <https://www.jungheinrich-profishop.fr/fr/guide-pro/batterie-lithium-air/>

29. Alain GELDRON, « L'épuisement des métaux et minéraux : faut-il s'inquiéter ? », ADEME, juin 2017
<https://www.ademe.fr/sites/default/files/assets/documents/epuisement-metaux-minerauxfiche-technique.pdf>
30. Han, L., Lehmann, M. L., Zhu, J., Liu, T., Zhou, Z., Tang, X., ... Saito, T. (2020). *Recent Developments and Challenges in Hybrid Solid Electrolytes for Lithium-Ion Batteries. Frontiers in Energy Research*, 8. doi:10.3389/fenrg.2020.00202
31. Source : [IEA](#), « Global EV Outlook 2020, Entering the decade of electric drive? », juin 2020
32. Amélie LOREC, Aude GANIER et Fabrice MATHÉ (infographie) et Florence FUSALBA, « Une batterie d'autonomie », Hors-série « Préparer demain... et l'après demain », Les défis du CEA, CEA-Liten, octobre 2015 [consulté le 10 novembre 2020] <https://www.cea.fr/multimedia/Documents/publications/les-defis-du-cea/Les-defis-du-CEA70ans.pdf>
33. CEA, « Accumulateurs, piles et batteries : des performances en constante amélioration » in L'énergie dans tous ses états [consulté le 3 novembre 2020], <https://www.cea.fr/multimedia/Documents/publications/clefs-cea/archives/fr/encadrea.pdf>
34. <https://nadionenergy.com/sodium-ion-battery-technology/>
35. Clément BONNET, Gondia SOKHNA SECK, Emmanuel HACHE, Marine SIMOËN, Samuel
36. CARCANAGUE, « Copper at the crossroads: assessing the interactions of the low carbon energy transition with a non-ferrous and structural metal », IFPEN/IRIS, juillet 2019 <https://www.iris-france.org/notes/copper-at-the-crossroads-assessing-the-interactions-of-thelow-carbon-energy-transition-with-a-non-ferrous-and-structurous-metal-2/>
37. THE MOST SOLD LITHIUM BATTERIES IN ITALY, FLASH BATTERY produces lithium batteries for industrial machines and electric vehicles
<https://www.flashbattery.tech/fr/batteries-etat-solide-comment-fonctionnent-elles/>
38. Batterie lithium-air: l'avenir de la technologie des batteries?, 13 Déc. 2023, Connaissances sur les batteries au lithium, Guide matériaux <https://www.jungheinrich-profishop.fr/fr/guide-pro/batterie-lithium-air/>
39. Recent Developments and Challenges in Hybrid Solid Electrolytes for Lithium-Ion Batteries, Lu Han^{1*} Michelle L. Lehmann^{1,2} Jiadeng Zhu¹ Tianyi Liu³ Zhengping Zhou¹

- Xiaomin Tang¹ Chien-Te Heish^{4,5} Alexei P. Sokolov^{1,6} Pengfei Cao¹ Xi Chelsea Chen¹ Tomonori Saito^{1,2*} *Front. Energy Res.*, 02 September 2020, Sec. Electrochemical Energy Storage Volume 8 – 2020, <https://www.frontiersin.org/articles/10.3389/fenrg.2020.00202/full>
40. Chen, C., Lee, CS. & Tang, Y. Fundamental Understanding and Optimization Strategies for Dual-Ion Batteries: A Review. *Nano-Micro Lett.* **15**, 121 (2023). <https://doi.org/10.1007/s40820-023-01086-6>
41. <https://www.unamur.be/recherche/actus/images-actus/NaDIBbattery.jpg/view>
42. Meilleur fournisseur de batteries au lithium et au phosphate de fer en Chine – LYTH, Qu'est-ce qu'une batterie sodium-ion ? mars 1, 2023, <https://www.lythbattery.com/what-is-a-sodium-ion-battery/?lang=fr>
43. JULIEN ARSENAULT, Batteries Les plus et les moins. Mis à jour le 2 déc. 2023, <https://www.lapresse.ca/affaires/economie/2023-12-02/batteries/les-plus-et-les-moins.php#:~:text=Batterie%20sodium%20Dion&text=Avantages%20%3A%20une%20abondance%20de%20sodium.aux%20balbutiements%20de%20sa%20commercialisation>
44. J. Li, J. Fleetwood, W.B. Hawley, W. Kays, From materials to cell: state-of-the-art and prospective technologies for lithium-ion battery electrode processing. *Chem. Rev.* 122(1), 903–956 (2022). <https://doi.org/10.1021/acs.chemrev.1c00565>
45. Sumbulla, Innis. (2022). Analysis of Prevailing Battery Innovations and Concept Technologies. 10.13140/RG.2.2.17752.83201.
46. M.N. Obrovac, V.L. Chevrier, Alloy negative electrodes for Li-ion batteries. *Chem. Rev.* 114(23), 11444–11502 (2014). <https://doi.org/10.1021/cr500207g>
47. <https://trustmyscience.com/batterie-sodium-base-algues-supporte-1000-cycles-charge/>
48. Wang, Jing & Xu, Zhen & Zhang, Qicheng & Song, Xin & Lu, Xuekun & Zhang, Zhenyu & Onyianta, Amaka & Wang, Mengnan & Titirici, Magda & Eichhorn, Stephen. (2022). Stable Sodium Metal Batteries in Carbonate Electrolytes Achieved by Bifunctional, Sustainable Separators with Tailored Alignment. *Advanced Materials.* 34. 10.1002/adma.202206367.
49. F. Ming, H. Liang, G. Huang, Z. Bayhan, H.N. Alshareef, MXenes for rechargeable batteries beyond the lithium-ion. *Adv. Mater.* 33(1), 2004039 (2021). <https://doi.org/10.1002/adma.202004039>
50. Y. Lyu, X. Wu, K. Wang, Z. Feng, T. Cheng et al., An overview on the advances of LiCoO₂ cathodes for lithiumion batteries. *Adv. Energy Mater.* 11(2), 2000982 (2021). <https://doi.org/10.1002/aenm.202000982>

51. <https://www.leblogauto.com/electrique/bmw-va-tester-la-batterie-avancee-de-one-92273>
52. Storing Energy, with Special Reference to Renewable Energy Sources, Book • Second Edition • 2022, <https://www.sciencedirect.com/book/9780128245101/storing-energy>
53. <https://evtechinsider.com/2023/12/05/gemini-battery-powers-bmw-ix-608-miles-on-a-single-charge/>
54. [A Novel TiSe₂-Graphite Dual Ion Battery: Fast Na-Ion Insertion and Excellent Stability | Runtian Zheng, Haoxiang Yu, Xikun Zhang, Yang Ding, Maoting Xia, Kangzhe Cao, Jie Shu*, Alexendru Vlad, Bao-Lian Su * | Angewandte Chemie International Edition - Volume 60, Issue 34, Pages 18430-18437 | DOI: 10.1002/anie.202105439, <https://terranostra.unamur.be/nouvelles/upnews.2021-08-27.5254264499/view>](#)
55. <https://one.ai/range>
56. <https://insideevs.fr/news/699207/batterie-doubler-autonomie-voiture-electrique/>
57. https://www.seminet.co.kr/ti/micro_content.html?category=article&no=10542
58. ne batterie au sodium à base d'algues capable de supporter 1000 cycles de charge, Fleur Brosseau · 12 octobre 2022, <https://trustmyscience.com/batterie-sodium-base-algues-supporte-1000-cycles-charge/>
59. Christian D, Batterie électrique : avec Gemini, ONE va-t-il enfin faire baisser le prix des véhicules ?, Publié le 13 septembre 2022 à 13:10 . <https://www.generation-nt.com/actualites/one-gemini-batterie-electrique-cellule-double-chimie-2004960>
60. <https://www.ti.com/document-viewer/lit/html/SSZT204>
61. Joshi, Adit. (2018). Hardware-in-the-Loop (HIL) Implementation and Validation of SAE Level 2 Automated Vehicle with Subsystem Fault Tolerant Fallback Performance for Takeover Scenarios. 1. 13-32. 10.4271/12-01-01-0002.
62. Gemini Dual-Chemistry Battery Powers BMW iX 608 Miles, <https://one.ai/dual-chemistry-gemini-battery-powers-bmw-ix-608-miles-on-a-single-charge>
63. <https://www.nissan-global.com/EN/INNOVATION/TECHNOLOGY/ARCHIVE/WCS/>
64. Elghanam, Eiman & Hassan, Mohamed & Osman, Ahmed. (2021). Design of a High Power, LCC-Compensated, Dynamic, Wireless Electric Vehicle Charging System with Improved Misalignment Tolerance. Energies. 14. 885. 10.3390/en14040885.
65. [*Wired vs. Wireless Communications in EV Battery Management.*](#)
- Watch the webinar, [Battery Management Systems Seminar – Intelligent Battery Junction Box for Voltage and Current Synchronization.](#)

-
66. Texas Instruments: *Functional Safety Considerations in Battery Management for Vehicle Electrification*.
- the technical article, [How to design an intelligent battery junction box for advanced EV battery management systems](#)
67. <https://www.takomabattery.com/electric-vehicle-wireless-charging/>
68. Zhang, R.; Zhang, S.; Qian, Z.; Xiao, M.; Wu, J.; Ge, J.; Lu, S. Collaborative Interactive Wireless Charging in a Cyclic Mobispace. In Proceedings of the 2018 IEEE/ACM 26th International Symposium on Quality of Service (IWQoS), Banff, AB, Canada, 4–6 June 2018; pp. 1–10.
69. <https://chargedevs.com/newswire/kaust-team-assesses-deployment-of-dynamic-wireless-charging-in-cities/> Shen, X.; Fantacci, R.; Chen, S. Internet of Vehicles *Proc. IEEE* 2020, 108, 242–245. [CrossRef]
70. Bayram, I.S.; Papapanagiotou, I. A survey on communication technologies and requirements for internet of electric vehicles. *EURASIP J. Wirel. Commun. Netw.* 2014, 223, 1–8. [CrossRef] Gil, A.; Sauras-Perez, P.; Taiber, J. Communication requirements for dynamic wireless power transfer for battery electric vehicles. In Proceedings of the 2014 IEEE International Electric Vehicle Conference (IEVC), Florence, Italy, 17–19 December 2014; pp. 1–7.
71. Mou, X., Zhao, R., & Gladwin, D.T. (2018). Vehicle to Vehicle Charging (V2V) Bases on Wireless Power Transfer Technology. *IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society*, 4862-4867.
72. Smiai, O.; Bellotti, F.; De Gloria, A.; Berta, R.; Amditis, A.; Damousis, Y.; Winder, A. Information and communication technology research opportunities in dynamic charging for electric vehicle. In Proceedings of the 2015 Euromicro Conference on Digital System Design, Madeira, Portugal, 26–28 August 2015; pp. 297–
73. everything You Need to Know About Wireless EV Charging, 2024 EV Charging Summit Blog, <https://evchargingsummit.com/blog/everything-you-need-to-know-about-wireless-ev-charging/>
74. Elghanam, Eiman & Ahmed, Ibtihal & Hassan, Mohamed & Osman, Ahmed. (2021). Authentication and Billing for Dynamic Wireless EV Charging in an Internet of Electric Vehicles. *Future Internet*. 13. 257. 10.3390/fi13100257.
75. Design of a High Power, LCC-Compensated, Dynamic, Wireless Electric Vehicle Charging System with Improved Misalignment Tolerance by Eiman ElGhanam, Mohamed

Hassan Ahmed Osman Department of Electrical Engineering, American University of Sharjah, P.O. Box 26666 Sharjah, UAE

76. Case Study | Electric Vehicle Rental Services: Project in Okinawa, Japan, Claire Weiller and Andy Neely, Cambridge Service Alliance

77. <https://energypost.eu/tandem-solar-cells-perovskite-silicon-can-reach-40-energy-conversion-rates/>

78. <https://www.intechopen.com/chapters/78864>

79. Kajal, P., Ghosh, K., & Powar, S. (2017). Manufacturing Techniques of Perovskite Solar Cells. *Energy, Environment, and Sustainability*, 341–364. doi:10.1007/978-981-10-7206-2_16

80. Kajal, P., Ghosh, K., Powar, S. (2018). Manufacturing Techniques of Perovskite Solar Cells. In: Tyagi, H., Agarwal, A., Chakraborty, P., Powar, S. (eds) *Applications of Solar Energy. Energy, Environment, and Sustainability*. Springer, Singapore. https://doi.org/10.1007/978-981-10-7206-2_16

81. Afre, Rakesh A., and Diego Pugliese. 2024. "Perovskite Solar Cells: A Review of the Latest Advances in Materials, Fabrication Techniques, and Stability Enhancement Strategies" *Micromachines* 15, no. 2: 192. <https://doi.org/10.3390/mi15020192>

82. Li, Z., Klein, T. R., Kim, D. H., Yang, M., Berry, J. J., van Hest, M. F. A. M., & Zhu, K. (2018). *Scalable fabrication of perovskite solar cells. Nature Reviews Materials*, 3(4), 18017. doi:10.1038/natrevmats.2018.17

83. Tripathi, S. L., & Padmanaban, S. (Eds.). (2020). *Green Energy*. doi:10.1002/9781119760801

84. Green MA, Dunlop ED, Yoshita M, et al. Solar cell efficiency tables (Version 63). *Prog Photovolt Res Appl*. 2024; 32(1): 3-13. doi:[10.1002/pip.3750](https://doi.org/10.1002/pip.3750)

85. <https://www.nrel.gov/pv/cell-efficiency.html>

86. F M Markos and J Sentian 2016 *J. Phys.: Conf. Ser.* 710 012032

87. <https://www.alternative-energy-tutorials.com/solar-power/solar-irradiance.html>

88. <https://www.alternative-energy-tutorials.com/solar-power/solar-irradiance.html>

89. https://www.powertechsystems.eu/wpcontent/uploads/specs/PowerBrick_PRO+_12V_150Ah_Lithium-Ion_battery.pdf

90. Абасс, Ахмед Зкеар Абасс & Pavlyuchenko, D.A. (2019). Turning Iraq into a country of energy exporter through the exploitation of solar energy and vast desert land. E3S Web of Conferences. 114. 05009. 10.1051/e3sconf/201911405009.
91. AAA. (2019). AAA Electric Vehicle Range Testing. American Automobile Association.
- Aalund, R., Diao, W., Kong, L., & Pecht, M. (2021). Understanding the Non-Collision Related Battery Safety Risks in Electric Vehicles a Case Study in Electric Vehicle Recalls and the LG Chem Battery (S. 6). IEEE.
92. Abdel-Shafy, H. I., & Mansour, M. S. M. (2016). A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. Water Research & Pollution Control Department, National Research Center, Tahreer Street (El-Behous St.), Dokki, Cairo, Egypt.
93. <https://www.nagpurtrends.com/articles/nagpur-to-have-about-150-ebuses-now-k9riGv>
94. Accurec. (2022). Lithium – Accurec Recycling GmbH. <https://accurec.de/lithium>
95. <https://medium.com/@martinblackd23d/a-mini-analysis-on-ev-trends-6a048d4cacf0>
96. <https://cleantechnica.com/2024/01/19/top-10-battery-producers-in-the-world-2023-provisional-data/>
97. Adeola, A. O., Akingboye, A. S., Ore, O. T., Oluawjana, O. A., & Adewole, A. H. (2021). Crude oil exploration in Africa: Socio-economic implications, environmental impacts, and mitigation strategies. Department of Chemical Sciences, Adekunle Ajasin University, 001 Akungba-Akoko.
98. BATREC. (2022). Batterie-Recycling. Batrec Industrie. <https://batrec.ch/de/batterie-recycling/>
99. Battery University. (2019). BU-1003a: Battery Aging in an Electric Vehicle (EV). <https://batteryuniversity.com/article/bu-1003a-battery-aging-in-an-electric-vehicle-ev>
100. <https://www.enerdata.net/publications/executive-briefing/global-battery-market-outlook.html>
101. Bayram, S. (2021). Impacts of Electric Vehicle Charging under Cold Weather on Power Networks. Department of Electronic and Electrical Engineering University of Strathclyde
102. Global X. (2022). How China Is Transforming the Global Lithium Industry. Global X. <https://www.globalxetfs.com/how-china-is-transforming-the-global-lithium-industry/>
103. Golder Associates. (2007). Environmental Impact Assessment Tenke Fungurume Project—Volume A: ESIA Introduction and Project Description. Tenke Fungurume Mining.

104. Greenpeace. (2020). Ranking the World's Sulfur Dioxide (SO₂) Hotspots: 2019-2020 [Report]. Delhi: Center for Research on Energy and Clean Air & Greenpeace India.
105. <https://fintel.io/doc/sec-chilean-cobalt-corp-1727255-10k-2023-march-24-19440-3142>
106. statista. (2022c). Projected global battery demand from 2020 to 2030, by application.
107. Halleux, V. (2022). New EU regulatory framework for batteries: Setting sustainability requirements | Think Tank | European Parliament. European Parliament. [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2021\)689337](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)689337)
108. Shahan, Z. (2022, Oktober 20). World Needs To Mine 25× More Lithium By 2050. CleanTechnica. <https://cleantechnica.com/2022/10/20/world-needs-to-mine-25x-more-lithium-by-2050/>
109. SOMO. (2020). The battery paradox: How the electric vehicle boom is draining communities and the planet (S. 65). Centre for Research on Multinational Corporations.
110. <https://www.statista.com/statistics/268787/lithium-usage-in-the-world-market/#:~:text=In%202021%2C%20batteries%20were%20by,made%20up%20another%2014%20percent.>
111. European Commission, Study on the EU's list of Critical Raw Materials - Final Report (2020)
112. statista. (2022b). Major countries in worldwide graphite mine production in 2021. <https://www.statista.com/statistics/267366/world-graphite-production/>
113. Groux, O. (2018). In-house Recycling von Li-Ionenbatterien: Alternativen zu etablierten Recyclingoptionen unter Beachtung rechtlicher und sicherheitstechnischer Auflagen— Bachelorarbeit [Bachelorarbeit]. Zürcher Hochschule für Angewandte Wissenschaften Life Sciences und Facility Management Institut für Umwelt und Natürliche Ressourcen. Statista. <https://www.statista.com/statistics/1103218/global-battery-demand-forecast/>