Electric and Hybrid Vehicle

Electric powertrain - sizing

The components of electric and hybrid vehicles

(Battery, Fuel cell, converters, electric motor, induction charging and energy recovery)

El-Hassane AGLZIM – MCF 63

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Institut Supérieur de l'Automobile et Transport

Département de Recherche en Ingénierie des Véhicules pour l'Environnement

49, rue Mademoiselle Bourgeois

58027 NEVERS

Who I am ?

Dr. El-Hassane AGLZIM

Associate Professor

ISAT de Nevers
Laboratoire DRIVE

Topics of research

Fuel cell
Hybrid systems
Data acquisition
Electrical engineering

Contents

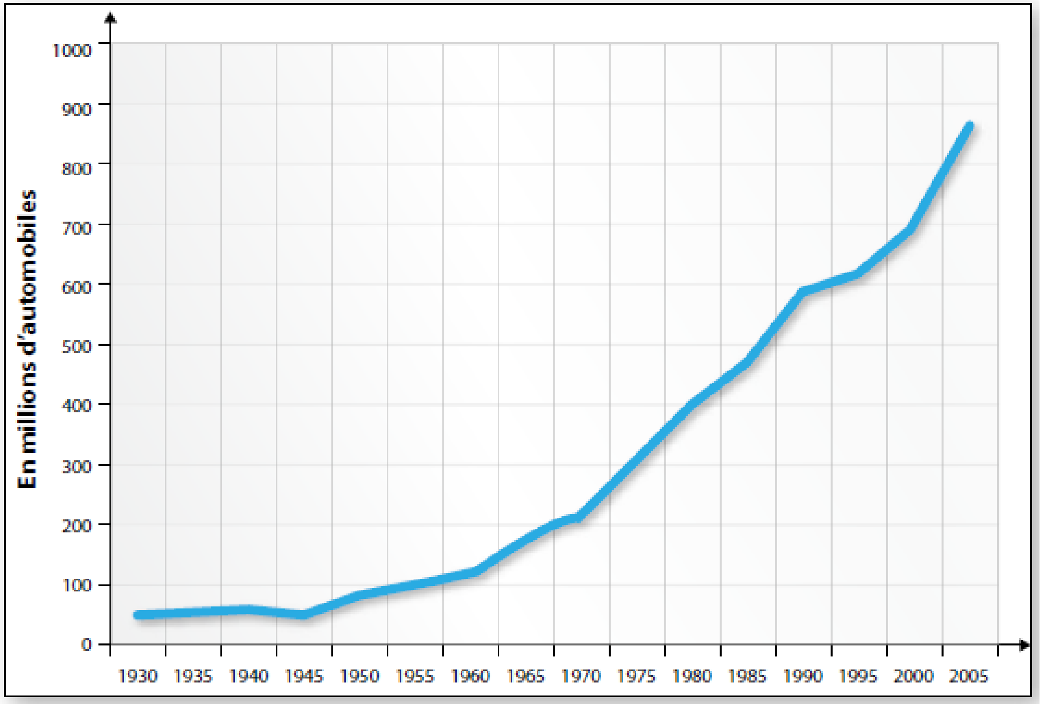
History

Why electric cars begin to democratize nowadays?

- *Context more favorable to the development and deployment of the engine.*

- *Oil was at that time an abundant and affordable energy.*

- *The low rolling vehicle fleet, despite its significant emissions do not pose a danger to humans and the environment.*

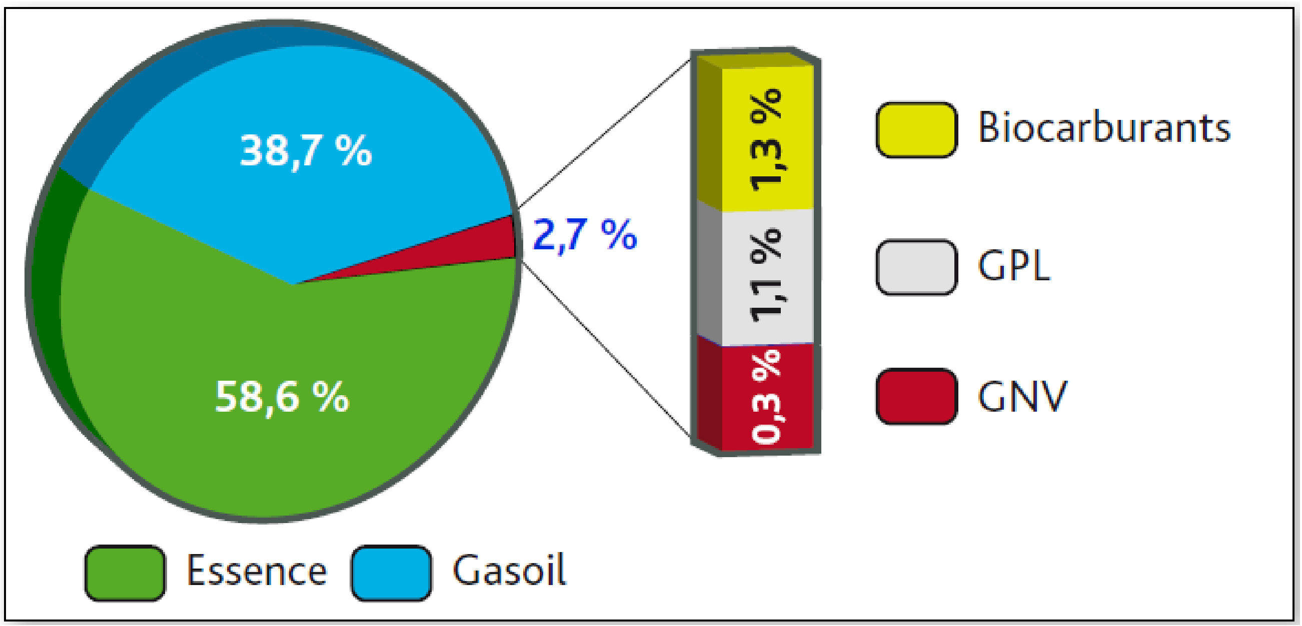


<u>Evolution of the global car fleet from 1930 to 2005</u>

History

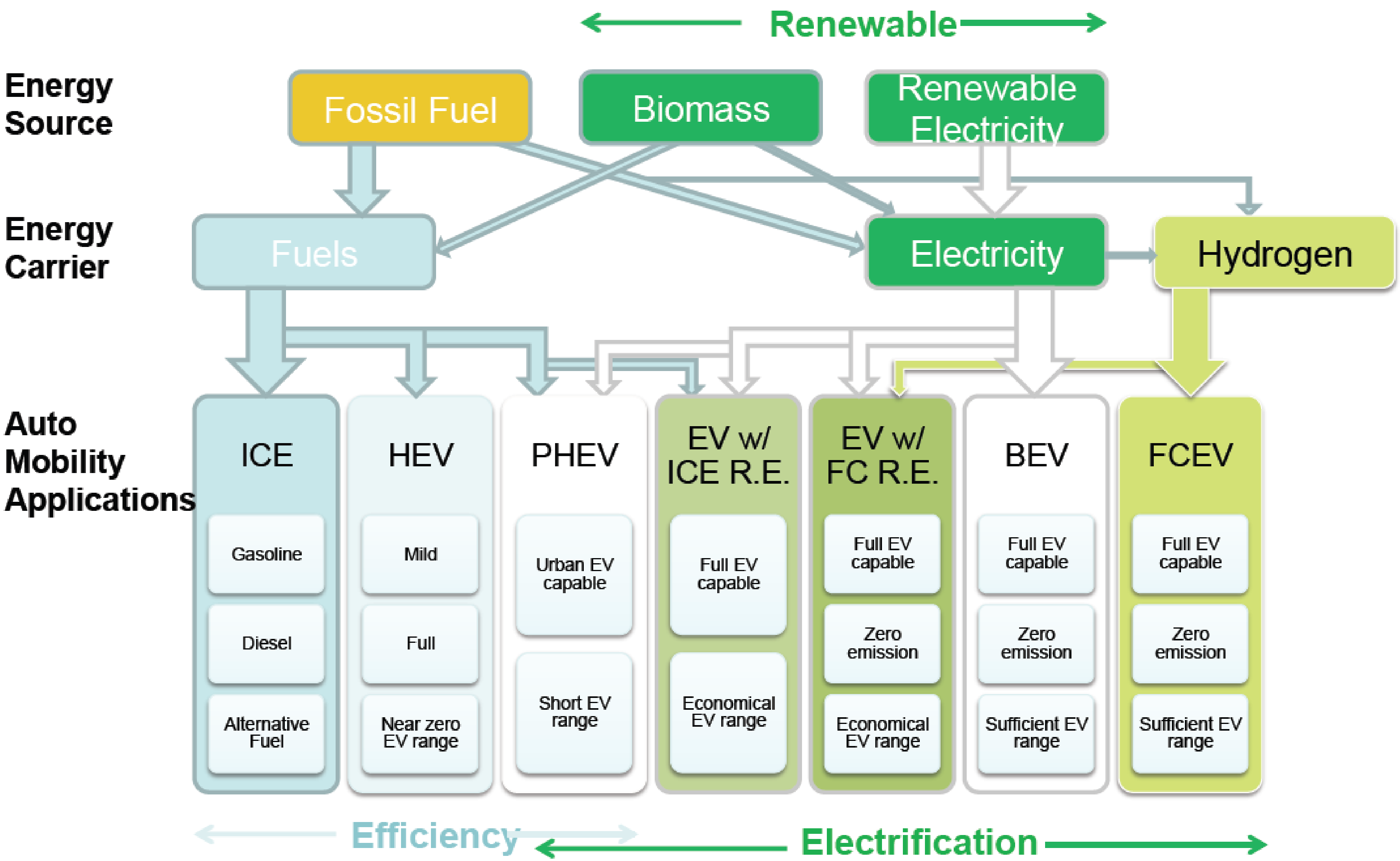
Since its origins, the automotive sector is totally dependent on oil production.

To date, the research of diversified sources of energy have reduced this dependence as shown by the diagram below:



Distribution of fuel in the world

Introduction



Hybrid vehicle / electric

Hybrid vehicle

- *Engine*
- *Electric motor*

Electric vehicle

- *Electric motor*
- *Batteries, converter, …*

Hybrid vehicle / electric

Electric vehicle :

- *It looks like a thermal vehicle*
- *Nevertheless differs from the latter by its specific chassis,*
- *The chassis includes a HT battery (High Tension, the volume and mass are large about 300 kg). This allows for a weight distribution favoring the dynamic stability of the vehicle.*

Hybrid vehicle :

- *According to the Oxford dictionary, the term hybrid is derived from the Latin "hybrida" which can be translated as "composed of two elements of different natures"*
- *In automobile, this term means that vehicles are equipped with two types of engine, use two types of energy and supports two energy storage.*

Hybrid vehicle / electric

<u>In all types of electric or hybrid vehicles, we find some or more of the following elements:</u>

HV Batterie : *The high voltage battery is the storage device of the recovered energy, kinetic or potential stored in an electrical form.*

Electric motor : *The motor converts electrical energy into mechanical energy during the phases of traction and conversely the mechanical energy into electrical energy during braking phases (regeneration).*

Converter : *The inverter is the power output calculator. It receives parameters from multiple sensors like accelerator pedals and brake and control the engine.*

Hybrid vehicle / electric

In all types of electric or hybrid vehicles, we find some or more of the following elements:

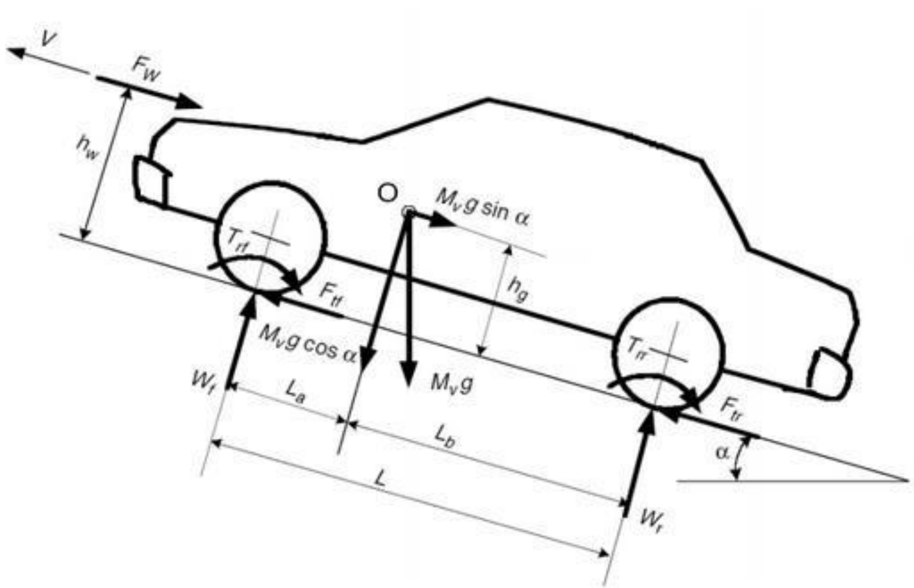
12V batterie : *Hybrid vehicles systems require power provided by a 12 V battery,*

DC/DC converter : *The DC / DC converter recharge the 12V battery using the HT battery (High Tension).*

Charger : *The charger adapt the energy supplied by the electricity distribution network (220-380V ~) to recharge the battery HT. This element is specific to Plug in HEVs.*

Modelisation of a vehicle

A vehicle can be modelized



v	= vehicle speed [m/s]
a	= vehicle acceleration [m/s^2]
ρ	= density of the air (≈1.2 kg/m^3)
s	= surface (frontal area) of vehicle [m^2]
C_x	= drag coefficient
m_v	= mass of vehicle + load [kg]
g	= gravity acceleration [9.81 m/s^2}
μ	= friction coefficient [≈0.01]
α	= slop [rad]

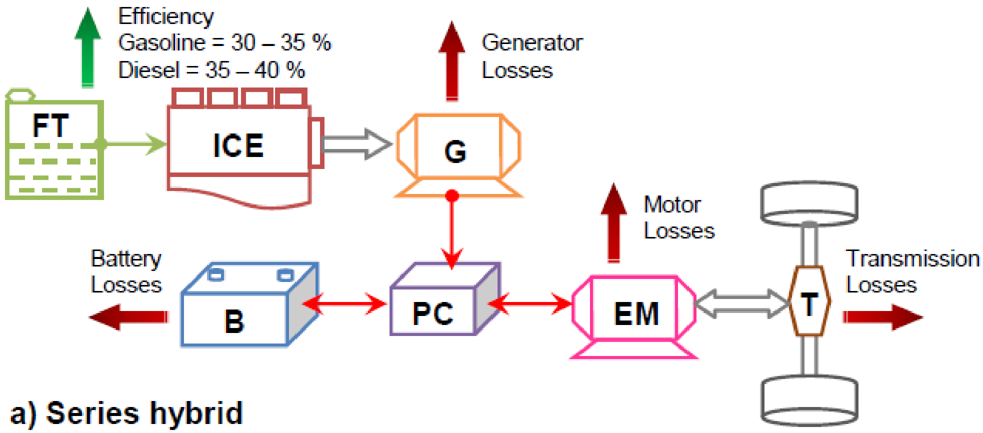
From this force F [N], we can calculate the power, P [W] : **P = F.V**

$$F = F_{Aerodynamic} + F_{rolling} + F_{Acceration} + F_{Climbing}$$
$$= (0{,}5.\rho.s.C_x.V^2) + (m_v.g.\mu) + (m_v.a) + m_v.g.\sin\alpha$$

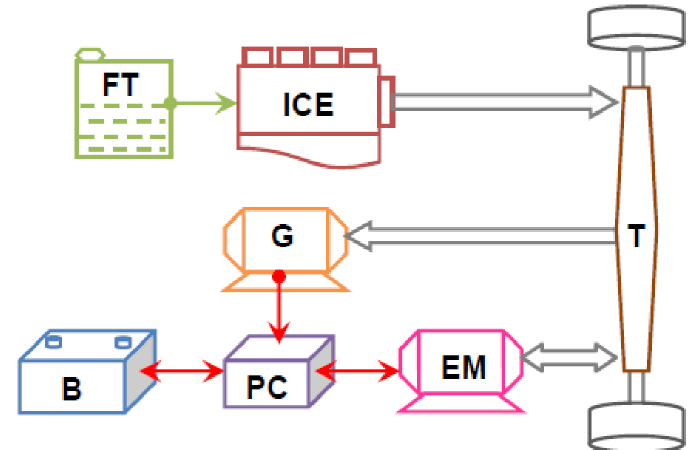
Modelisation of a vehicle

Model	m[kg]	D[m]	A[m²]	Cd
Mini Scooter	185	0.42	0.6	0.75
Aprilia Tuono 1000R	255	0.6218	0.913	0.75
Microcar (M.Go)	350	0.532	2.34	0.33
C1	865	0.5571	2.03	0.337
Mini One	1135	0.6085	1.97	0.33
Noao	1100	0.58	1.3	0.4
Prius(2000-2003)	1254.2	0.5831	2.01	0.29
Prius(2010-)	1317	0.6345	2.17	0.25
Tesla Roaster(2008)	1335	0.5989	1.8	0.35
Tesla S	1735	0.7031	2.38	0.22
Fisker Karma	2404	0.73	2.4	0.313
Exagon Furtive eGT	1600	0.6725	2.153	0.29

Architectures



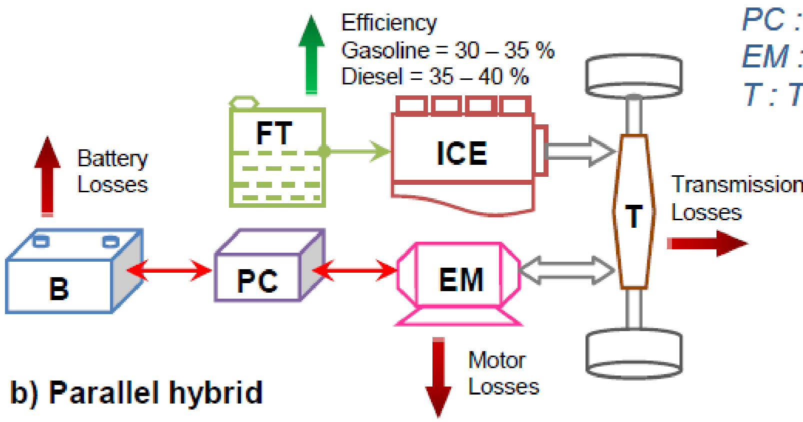
a) Series hybrid



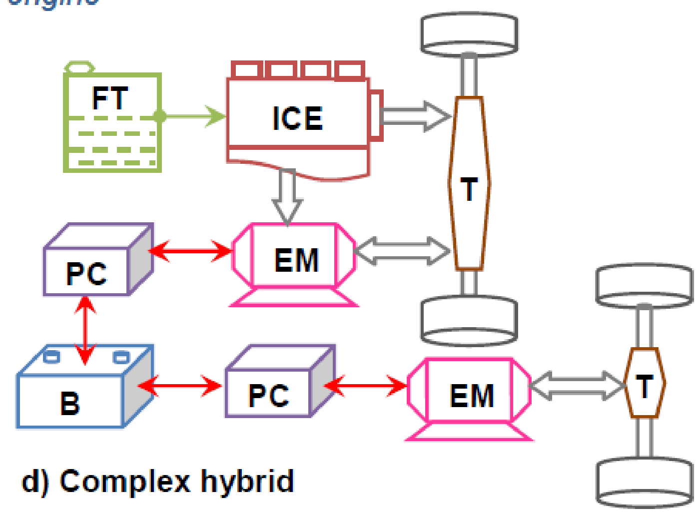
c) Series-parallel hybrid

Hydraulic link
Electrical link
Mechanical link

FT : Fuel tank
ICE : Internal combustion engine
G : Generator
B : Battery
PC : Power converter
EM : Electric motor
T : Transmission



b) Parallel hybrid



d) Complex hybrid

Architectures

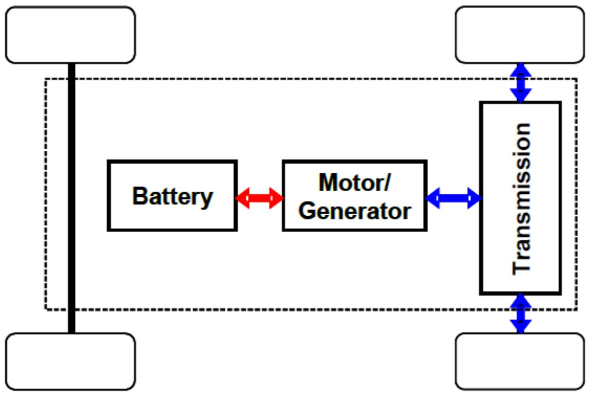


Figure 1: Schematic of a battery electric vehicle (BEV) powertrain

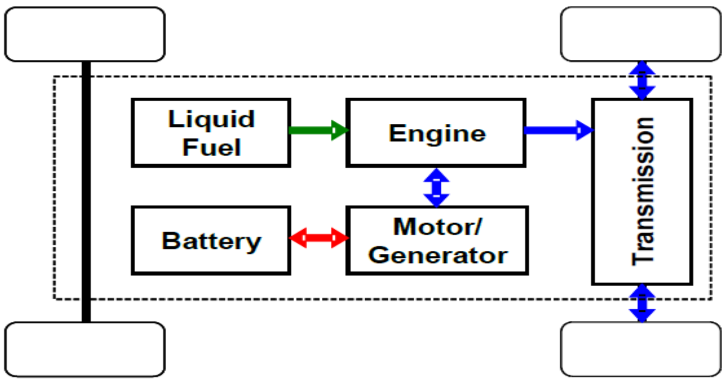


Figure 2: Schematic of a Mild Hybrid powertrain

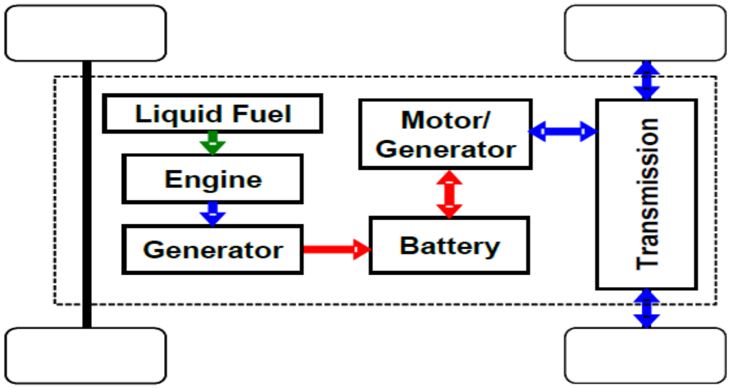


Figure 3: Schematic of a Series Hybrid powertrain

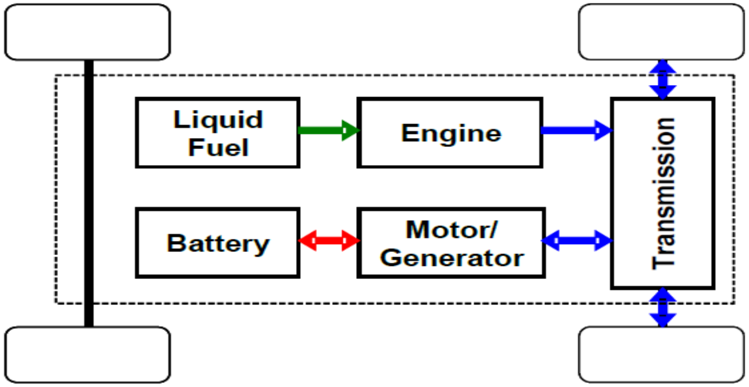
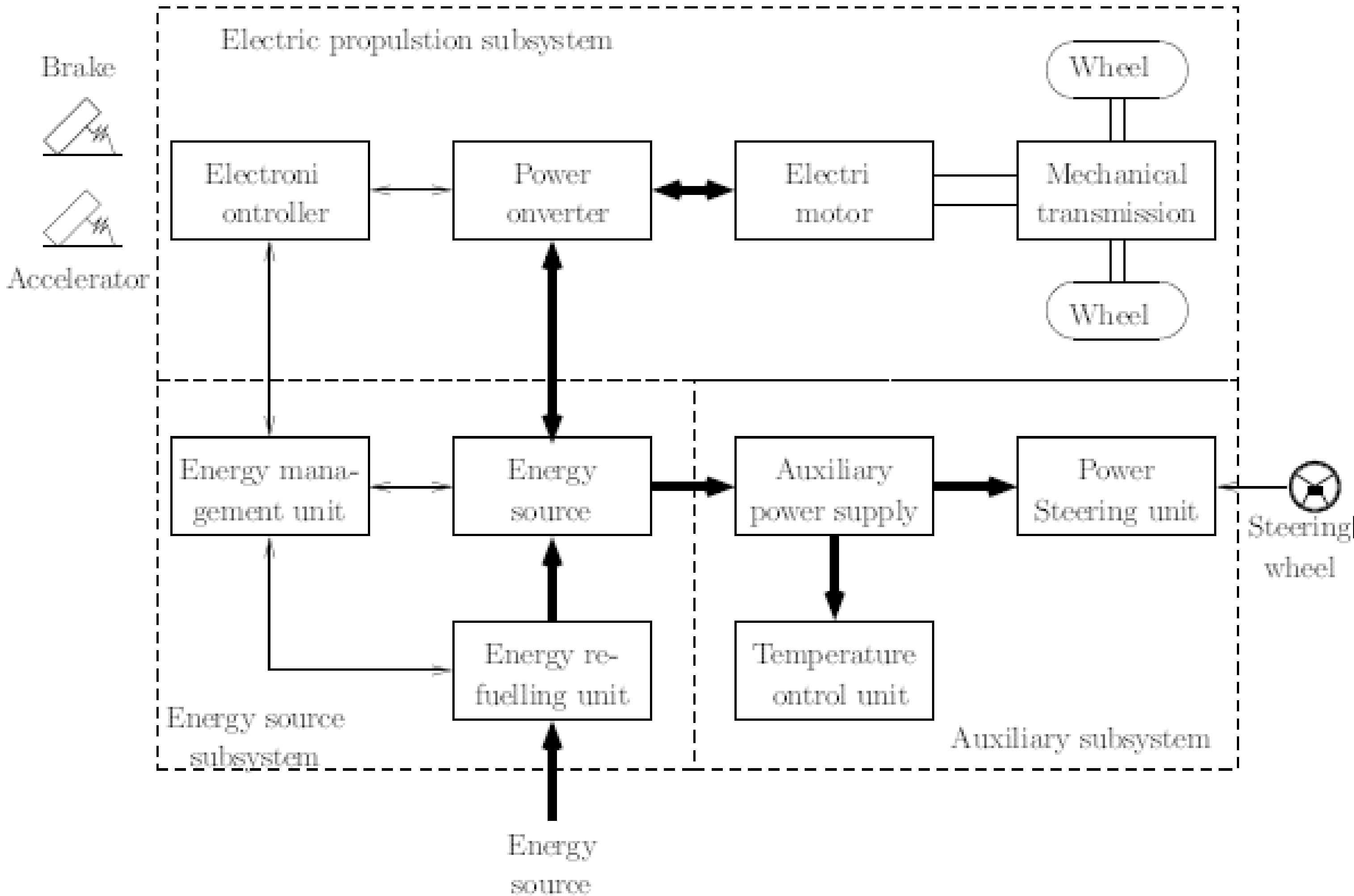


Figure 4: Schematic of a parallel hybrid powertrain

Architectures



Batteries

Generalities

A vehicle, whether electric or hybrid, needs to store the electric energy produced by transforming the kinetic and potential energies during the recovery phases.

- *The electric vehicle is characterized by the fact that in addition to the propulsion power, it should store the required energy to ensure acceptable performance and autonomy. Storage requirements are not the same. High storage capacity is needed: charge and discharge cycles are slow. This type of vehicle uses battery of energy.*

- *For a hybrid vehicle, a small amount of storage is sufficient. Simply store the kinetic and potential energies until their use in the next acceleration. This type of vehicle uses battery of power.*

Generalities

Storage of electrical energy inside a vehicle is currently the main major problem. This storage is characterized by two main parameters

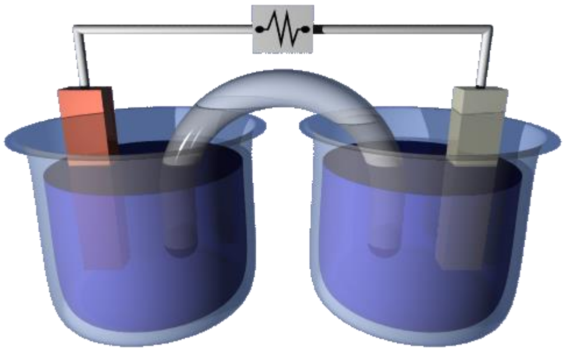
- *Usable power (P = I.U) kW (kilowatt). It is the product of the battery voltage by the maximum it can charge. Usable power must be at least equal to the peak power of the electric motor to allow its supply throughout its operating range.*

- *The energy stored in kW / h (kilowatt / hour). This energy can be compared to the volume of a fuel tank of an internal combustion engine vehicle. It is the energy stored which will determine the autonomy of an electric vehicle and recovery opportunities for a hybrid vehicle.*

Generalities

There are two ways of storing electricity used in the automotive industry:

- *Electrochemical: Use of electric charges released during chemical reactions of an electrochemical couple, are the batteries.*

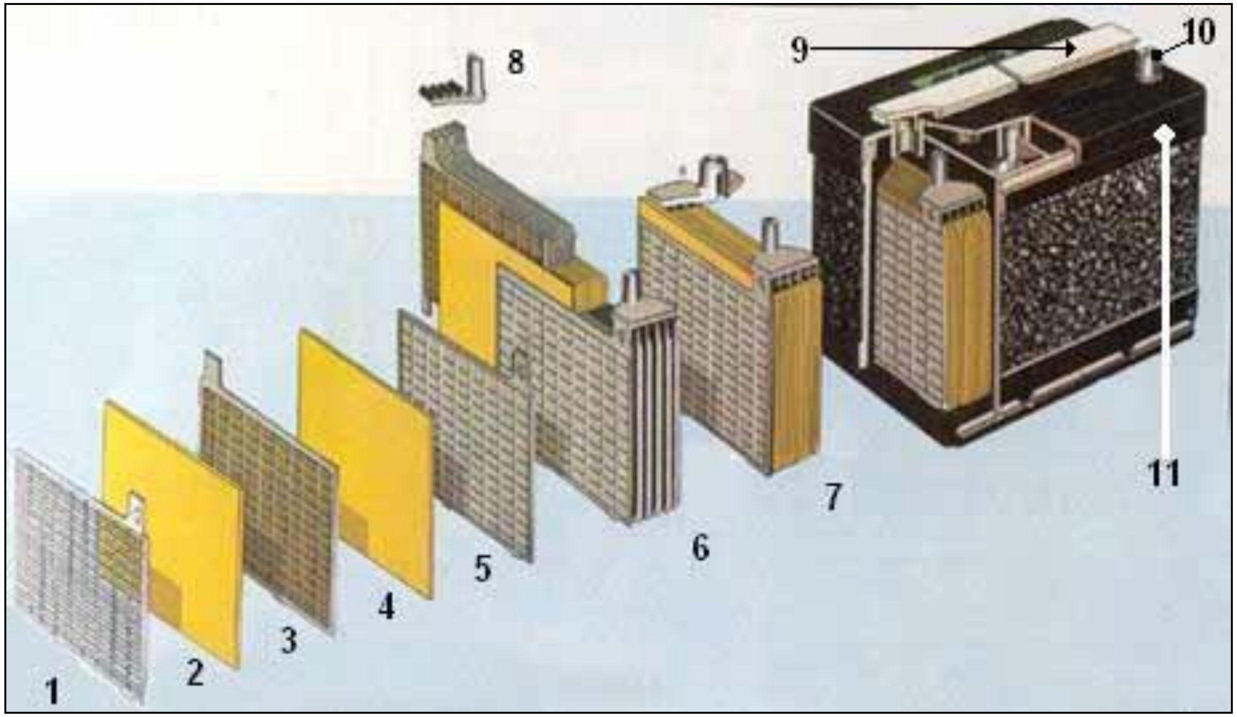


- *Electrostatic capacitors by using very high values that are supercapacitors.*

Lead acid battery

The oldest of Accumulators, discovered by Gaston Plante in 1859, is still used today for electric traction.

Its cell voltage is 2.1 V and the energy density of 30 to 50 Wh / kg.



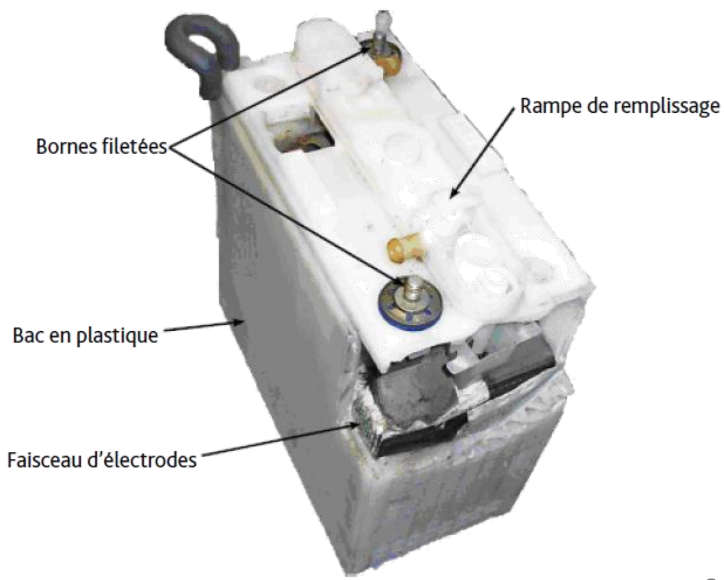
1. Plaque négative
2. Séparateur
3. Plaque positive
4. Séparateur
5. Plaque négative
6. Assemblage des éléments 1 à 5
7. Élément assemblé
8. Pont de connexion
9. Bouchon
10. Borne
11. Bac

Cadmium Nickel (Ni-Cd)

Result of the work of Waldemar Jungner of Sweden in 1899, these batteries are much lighter and have a lifetime longer than lead acid batteries but they are expensive.

These batteries equipped the electric vehicles produced in the 1990s by PSA, Renault as well as buses.
The high toxicity of cadmium is at the origin of the Directive 2002/95/EC to minimize the use of it and use alternative materials.

Voltage is 1.2 V and the energy density of 45 to 80 Wh / kg (high memory effect).



Nickel Métal hydrure (Ni-Mh)

Batteries nickel / metal hydride emerged in the early 1990s. With the same voltage to Ni-Cd batteries but with a higher capacity, they have quickly replaced to power small appliances. Because these batteries do not use cadmium, the pollution of the environment is significantly less.

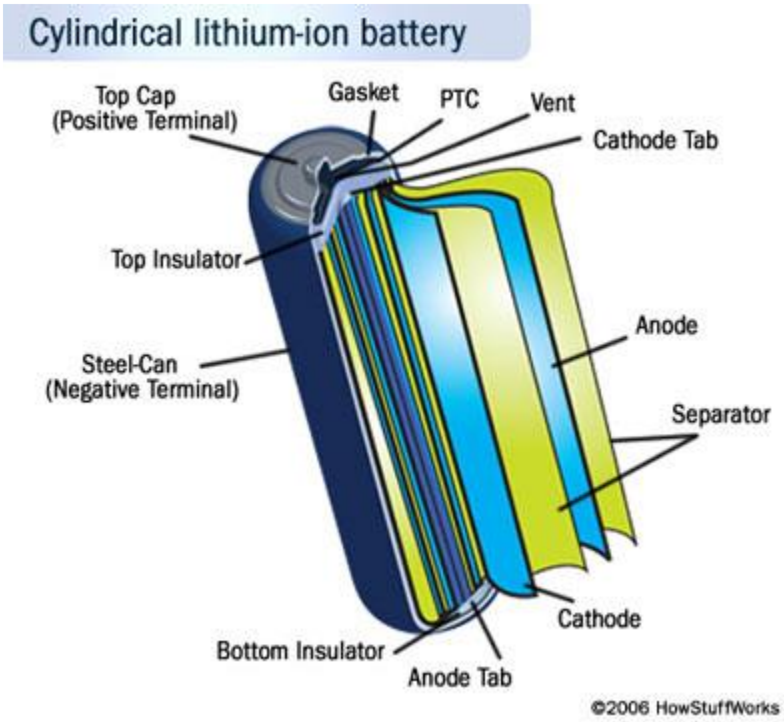
Taking the basics of Ni-Cd batteries, batteries nickel / metal hydride batteries are lighter and more powerful but also more expensive because their manufacture requires metals and rare earths such as lanthanum. The voltage is 1.2V and energy density of 60 to 90 Wh / kg (low memory effect).

Toyota Prius batteries

Lithium ion (Li-ion)

Its main advantages are a high energy density (two to five times more than Ni-MH for example) as well as the lack of memory effect. Self-discharge is relatively low compared to other batteries. However, the cost remains high.

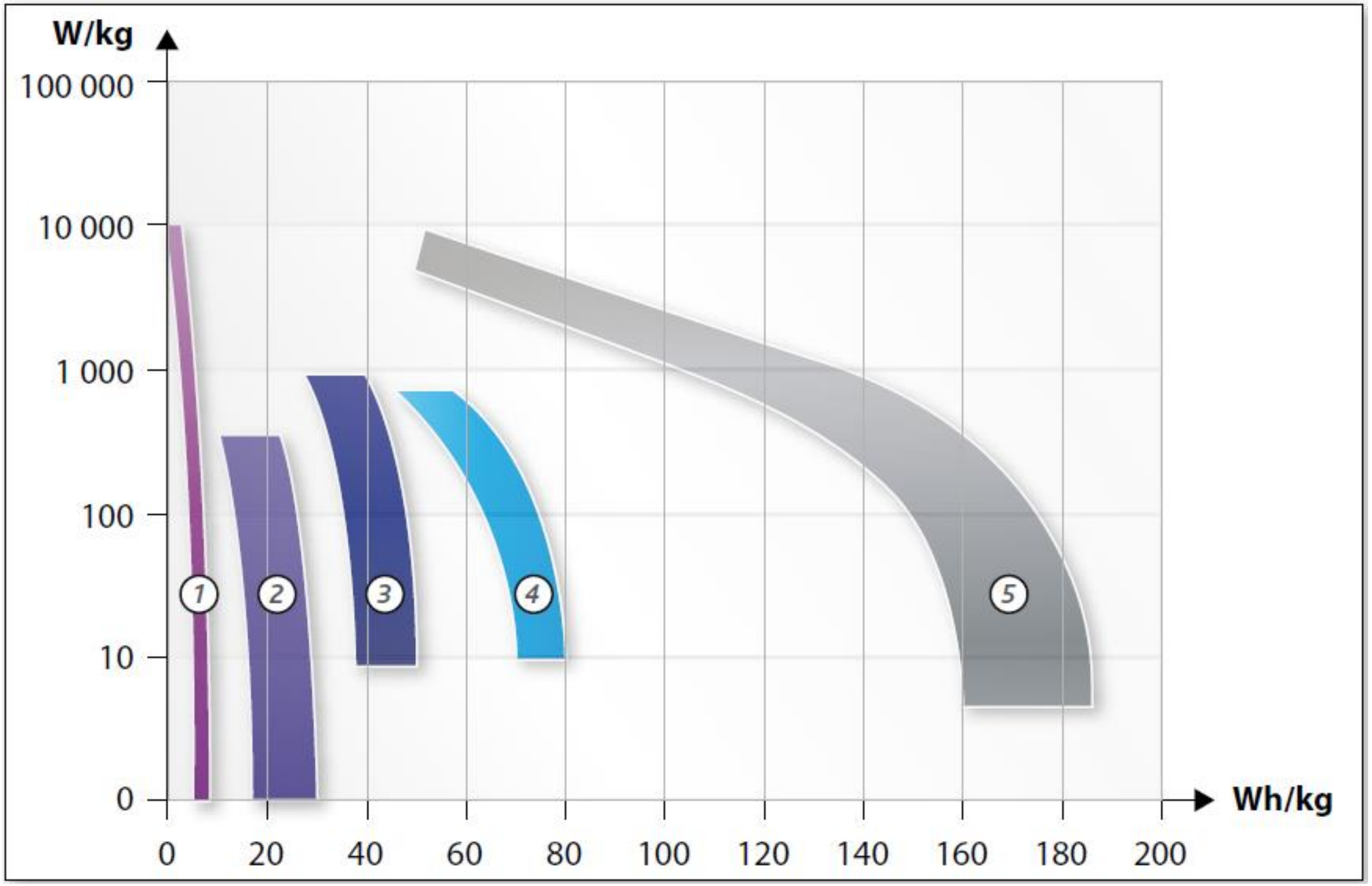
Its nominal voltage is 3.6 V and maximum operating range from 2.5 V to 4.2 V.



Some characteristics of batteries

Véhicule	Type	Capacité (Ah)	Tension (V)	Énergie (kWh)	Technologie	Poids (kg)
Mercedes S400H	Hybride	6.5	120	0.78	Li-Ion	28
BMW série 7	Hybride	6.5	120	0.78	Li-Ion	28
HONDA IMA	Hybride	6.0	144	0.86	Ni-Mh	30
TOYOTA PRIUS	Hybride	6.5	201.6	1.31	Ni-Mh	39
LEXUS RX400H	Hybride	6.5	288	1.87	Ni-Mh	60
PEUGEOT 106	Électrique	100	120	12	Cd_Ni	256
PEUGEOT Partner	Électrique	100	162	16.2	Cd-Ni	345
THINK	Électrique	72	300	22	Li-Ion	245
THINK	Électrique	75	300	23	ZEBRA	260
FAM	Électrique	200	72	14.4	Ni-Mh	290
SMART	Électrique			16.5	Li-Ion	
KANGOO ZE	Électrique		240-408		Li-Ion	260

Batteries used in automotive



1 Supercapacité (accumulateur électrostatique)
2 Batterie plomb (Pb)
3 Batterie Cadmium Nickel (Cd-Ni)
4 Batterie Nickel Métal hydrure (Ni-Mh)
5 Lithium-Ion (Li-Ion)

Electrical characteristics

Electrical specifications: EMF

- *EMF is the open circuit voltage with no electric current. It depends on the materials constituting the electrodes. The table below shows the values used for a car.*

Type de batterie	F.E.M (Volt)
Plomb	2.1
Cadmium Nickel	1.2
Nickel Métal Hydrure	1.2
Lithium Ion	3.6
Zébra	2.6

Electrical characteristics

<u>State of Charge</u>: ***SOC***

It is always essential to know the state of charge of the battery SOC (State Of Charge), which corresponds to the level of fuel for a combustion engine vehicle, because in addition to displaying the charge level on the dashboard, it determines strategies for the battery management sytsme (BMS) and engine management.

For most batteries, three parameters are enough to determine:

Voltage
Current
Temperature

Charge of the batteries

Battery Charging: Equalisation of the charges

It is impossible to make all batteries identical. During use, it appears the different levels of load between the various batteries, which can lead to their destruction.

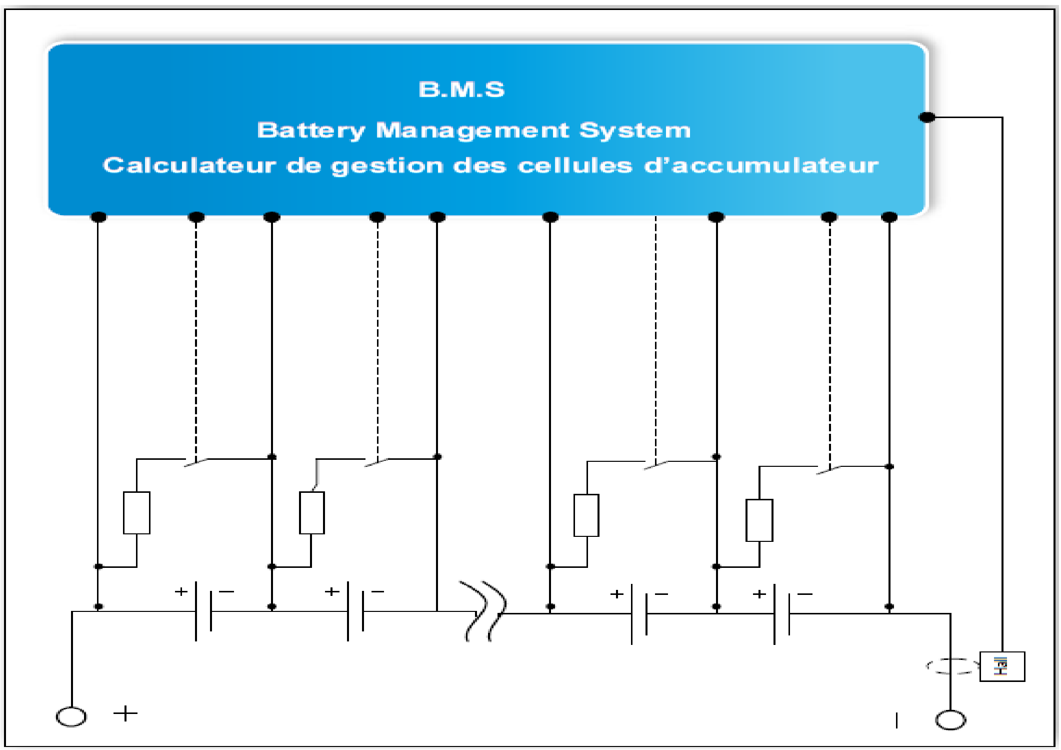
There are two methods of equalizing charges:

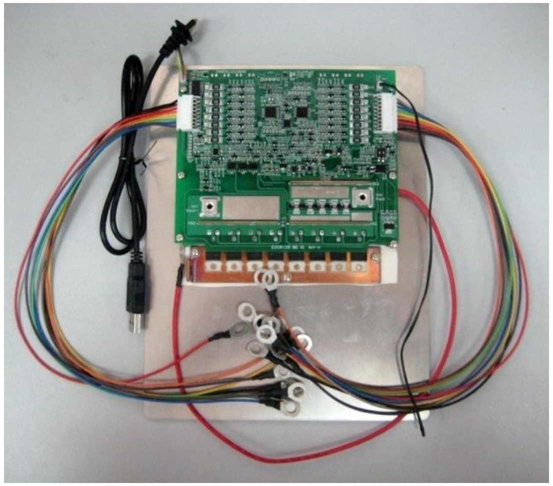
- *Overload equalization (if the technology permits)*
- *Electronic Monitoring (Battery Management System)*

Charge of the batteries

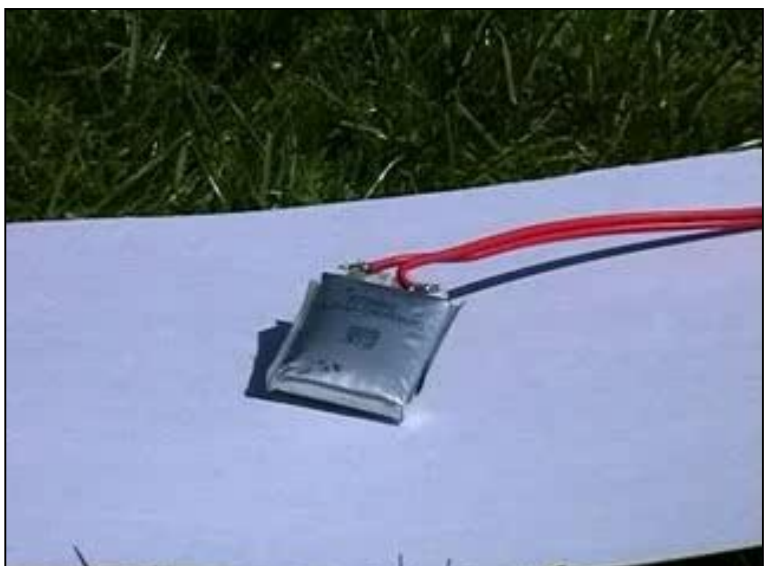
Battery Charging: Equalisation of the charges : BMS

The BMS (Battery Management System) connects at the terminals of the cells, the most heavily loaded, resistors to discharge them.





Safety rules (explosion, burns)



Safety rules

- *Never drill a battery*
- *Never short circuit a battery*
- *Be careful when filling (burns due to acid)*
- *Never add water into concentrated acid, it instantly produces a violent reaction leading to projections of concentrated acid with water vapor.*
- *Beware of electric shock (high voltage battery)*

During charging of a battery, a release of hydrogen occurs.
This gas is highly flammable

- *It is necessary to ventilate the room where the load is done.*
- *It is forbidden to smoke near a battery charging.*
- *Do not unplug the charger cables before turning off the charger*

Embedded protection systems

The battery provides the traction voltage and intensity, potentially dangerous and require various safety systems. These systems include:

- *The isolation*
- *Battery cut-off relay*
- *Interlock system HT*

Galvanic isolation

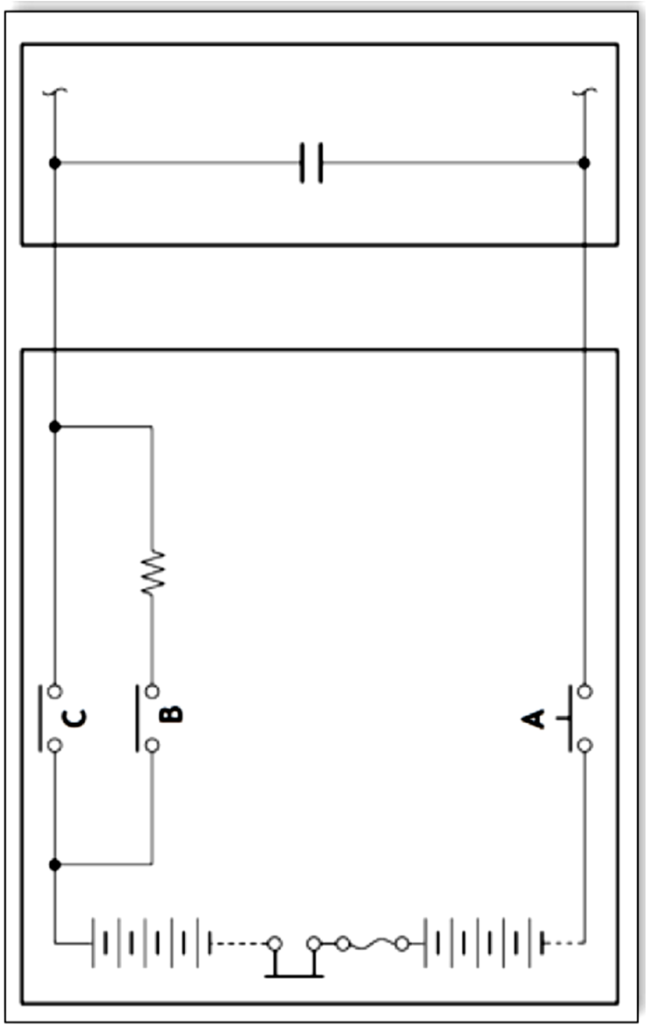
Its principle is to completely isolate the High Voltage circuit from the vehicle body. This monitoring of the galvanic isolation is usually performed by the BMS.
An insulation defect can result in automatic disconnection of the High voltage battery by the BMS, which eliminates any risk of HT short-circuit by the mass of the vehicle.

Embedded protection systems

Cutoff relay battery:

The High voltage supplied by the battery, should not, as a safety measure, be constantly present on the circuits of the vehicle. It is therefore necessary to connect the battery when the vehicle is switched on and disconnect it when the vehicle is switched off.

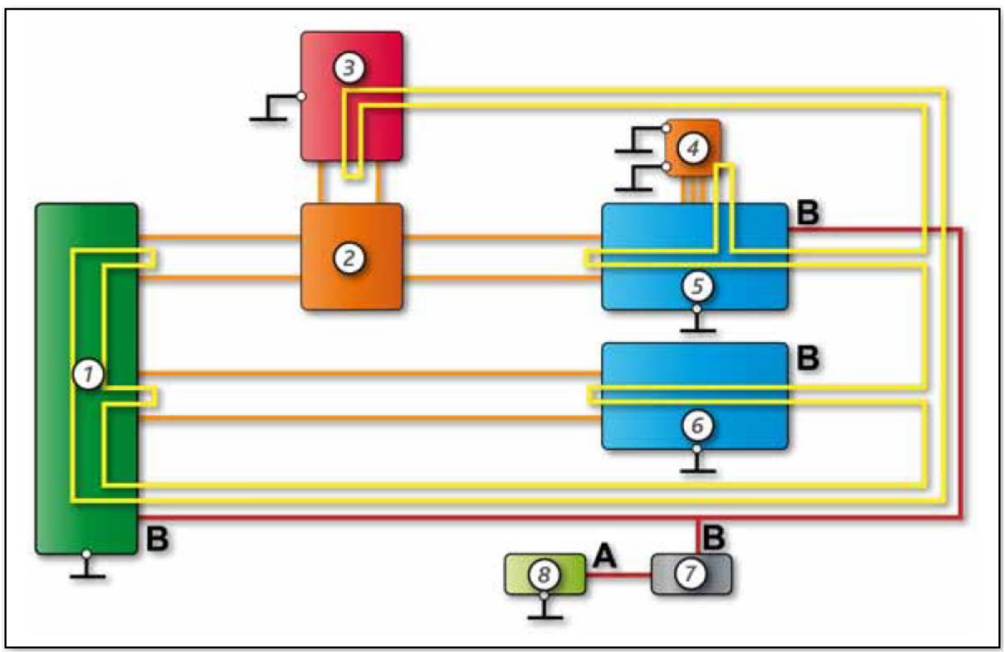
This function is performed by a group of relays controlled in a specific order by the BMS. Indeed, the cut off of a high voltage battery is tricky. The minimum voltage maintenance of an electric arc in air is only 25V, it is imperative that the current circulating in the wires is zero to not initiate an arc.



Embedded protection systems

Interlock system HT :

BMS continually monitors the correct connection of all HT connectors. When a disconnection occurs, the BMS opens the HT battery relay, cutting off the power supplied to the connector pins and ensure the safety of the worker.

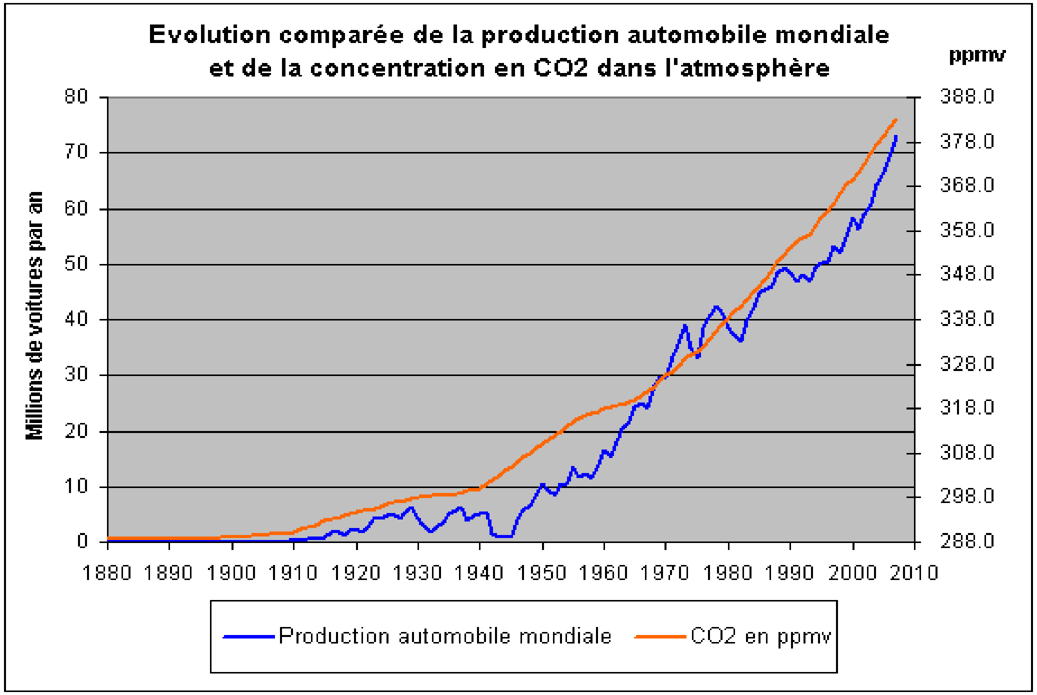


1 Calculateur système de gestion de batterie (BMS)
2 Unité de distribution de puissance (PDU)
3 Compresseur frigorifique électrique
4 Moteur électrique
5 Calculateur électronique de puissance
6 Calculateur convertisseur DC/DC
7 Élément de coupure pyrotechnique
8 Batterie 12 V
A Borne 30
B Borne 30c
Circuit rouge : câble 12 V
Circuit jaune : câble signal interlock
Circuit orange : câble haute tension

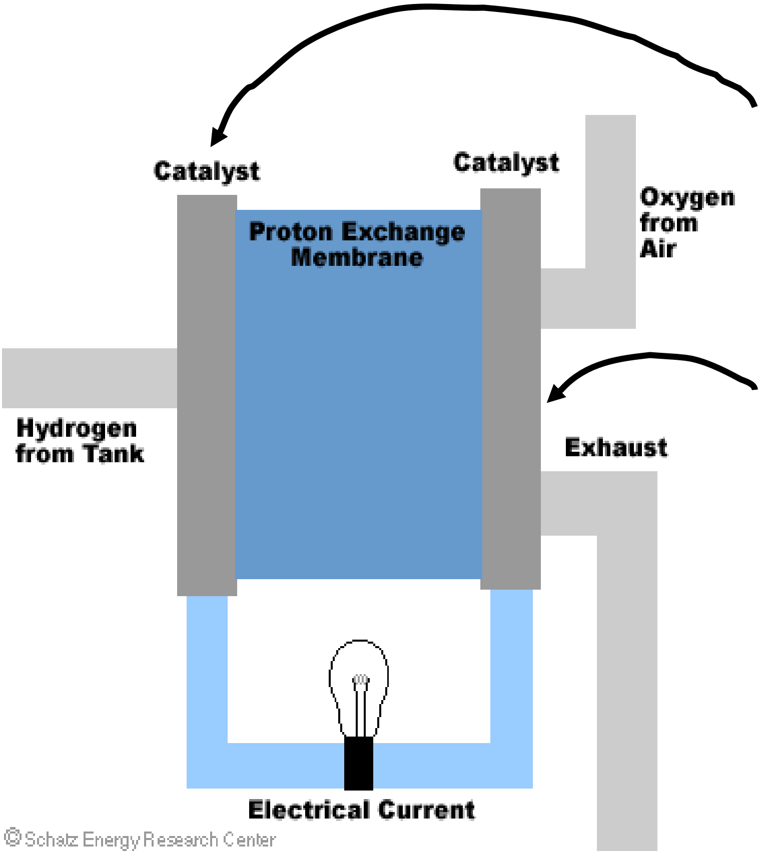
Fuel cells

Introduction

- *Urgent need for environmental protection.*
- *Need a clean and abundant energy.*
- *Use of oxygen and hydrogen to produce electricity.*
- *The Fuel Cell is a good and essential vector for the production of energy in the future.*
- *Power range suitable tens of mW to several MW.*



Operating principle



- ***Anode reaction:***

$$2H_2 \rightarrow 4H^+ + 4e^-$$

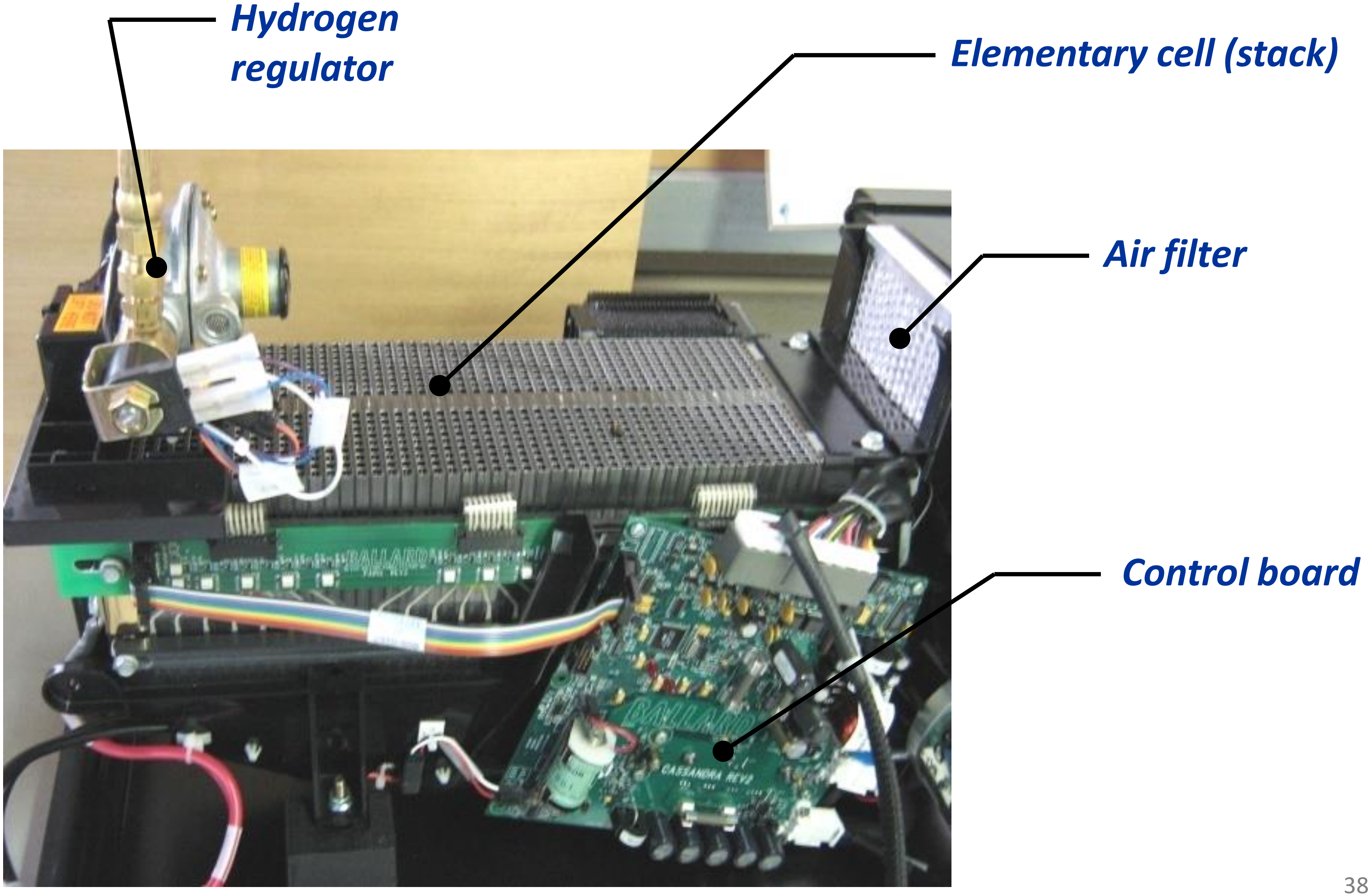
- ***Cathode reaction :***

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

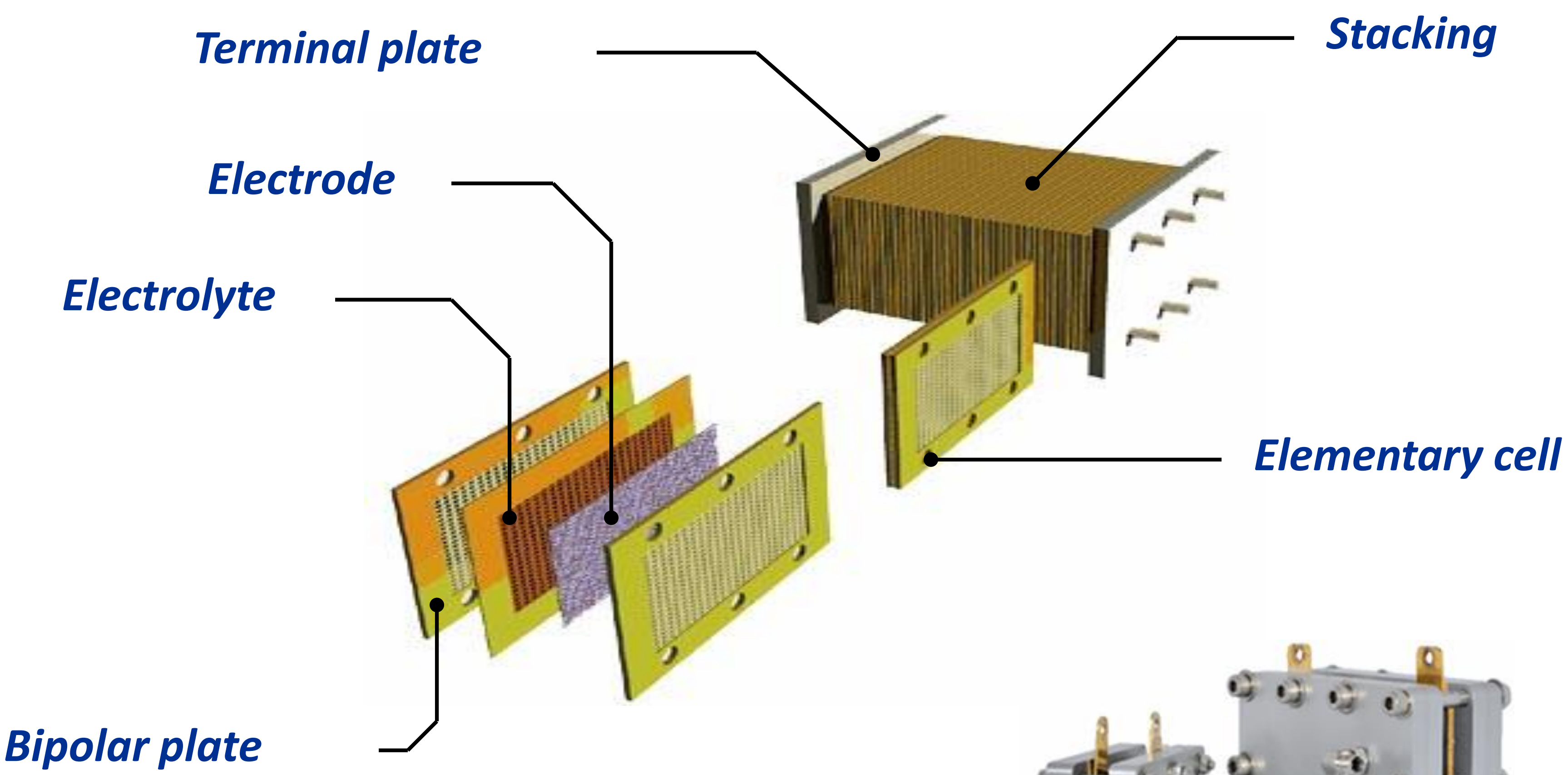
- ***Global reaction:***

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + Heat + electricity$$

Nexa fuel cell 1.2kW (Ballard)



Constitution



Fields of application

- ***Portable***

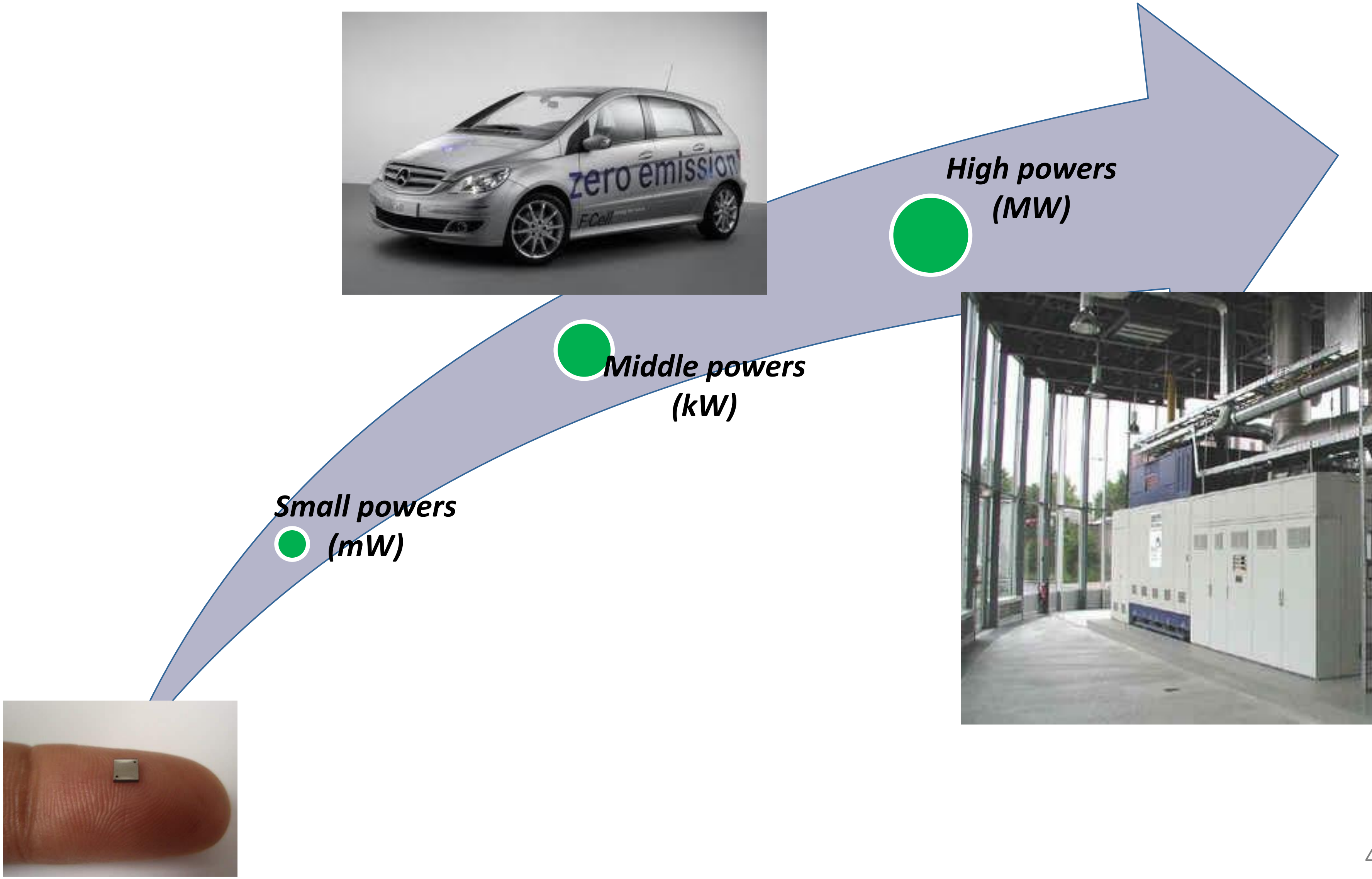
Fields of application

- ***Stationary***

Fields of application

Transportation

Range of powers



Type of fuel cells

Type of fuel cells	***Acronym***	***Electrolyte***	***Operating temperature***	***Application***
Proton exchange membrane	*PEFC or PEMFC*	*Membrane polymère solide*	*80°C*	*Transport Stationnaire Portable*
Alcaline	*AFC*	*Hydroxyde de potassium*	*60°C – 200°C*	*Transport*
Phosphoric acid	*PAFC*	*Acide phosphorique*	*200°C*	*Stationnaire*
Molten carbonate fuel cell	*MCFC*	*Carbonate de métaux alcalins*	*600°C – 700°C*	*Stationnaire*

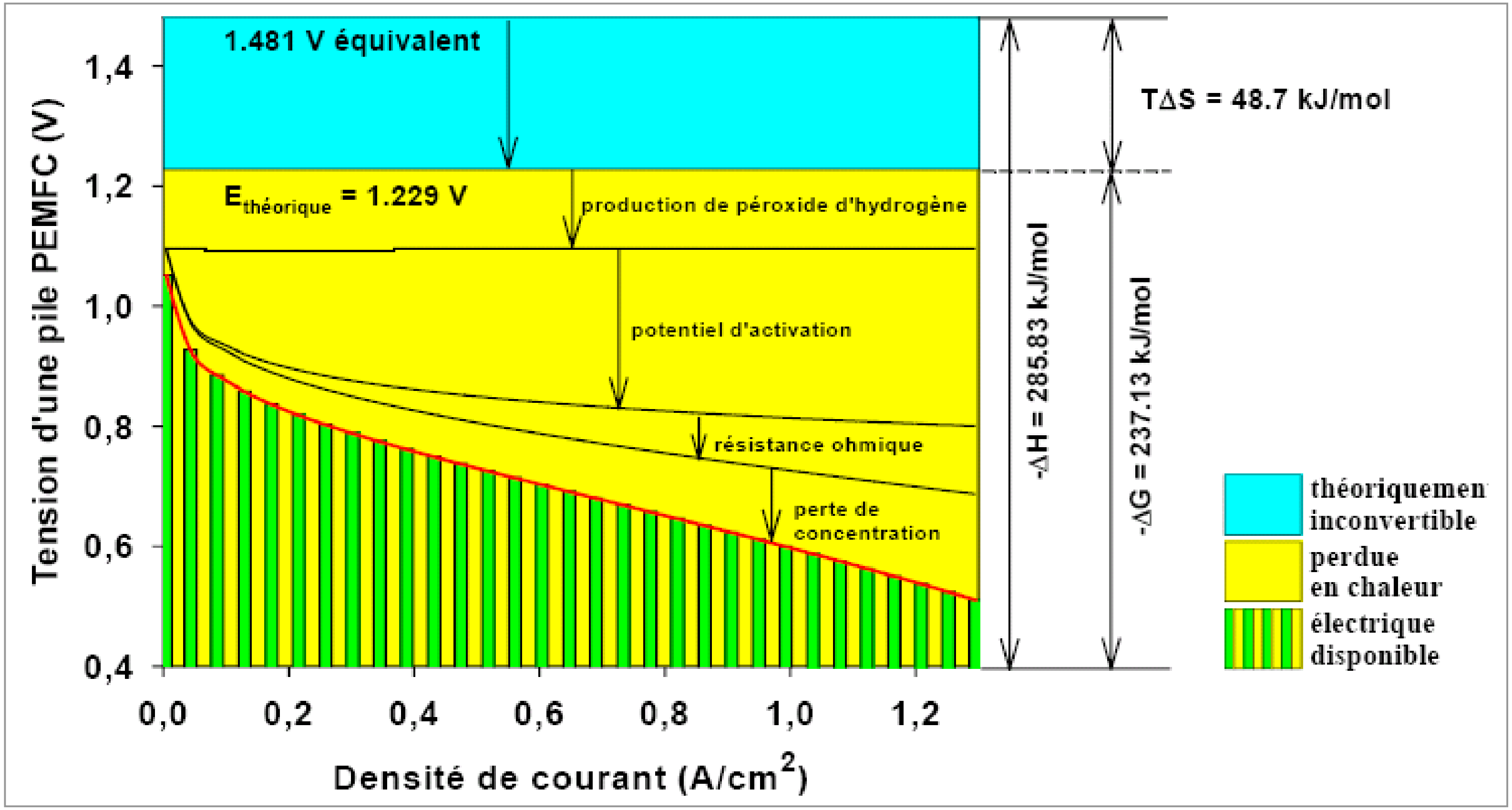
Different types of fuel cells (1/2)

Type of fuel cells

Type of fuel cells	*Acronym*	*Electrolyte*	*Operating temperature*	*Application*
Solid oxyde	*SOFC* *IT-SOFC*	*Céramique*	*800°C – 1000°C* *550°C*	*Stationnaire* *Transport*
Direct methanol	*DMFC*	*Membrane polymère*	*80°C*	*Portable* *Stationnaire* *Transport*
Reversible	*RFC*	*Membrane polymère*	*80°C*	*Transport* *Stationnaire*
Zinc-air	*ZAFC*	*Liquide alcalin*	*Ambient temperature*	*Portable* *Transport*

Different types of fuel cells (2/2)

Electrical characteristics



Polarisation curve

Electrical characteristics

- *Electrochemical activation losses (loss of energy due to the activation of the electrochemical reaction).*

- *Electrical ohmic losses due to the internal resistance (membrane).*

- *Fluid: mass transport losses due to a drop in the partial pressure of the reactants.*

Advantages

Presented as a solution for the future against pollution

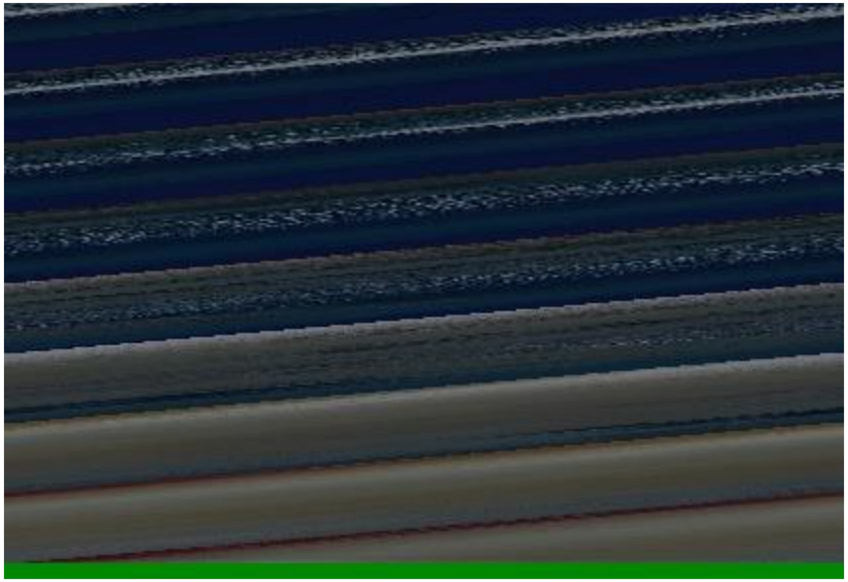
- *High efficiency,*
- *Low noise,*
- *Low pollutant emission,*
- *Built in a modular fashion,*
- *Diverse operating temperature,*
- *Diverse operating power,*
- *Abundant fuel used on Earth,*

Disadvantages

Some problems remain to be solved

- *The cost*
- *Weight,*
- *Volume,*
- *Life,*
- *Thermal management,*
- *Management of water (moisture)*
- *Generation fuel*
- *Succession of cycles start / stop*

Safety rules (explosion, burns)



Hydrogen

The simplest chemical element
The lightest atom existing
The most abundant element in the Universe

Destruction of the dirigible Hindenburg in 1937

Safety rules (explosion, burns)

Hydrogen

The simplest chemical element
The lightest atom existing
The most abundant element in the Universe

Extremely flammable gas

Propriétés	Unités	Hydrogène	Propane
Domaine d'inflammabilité dans l'air	*% vol*	4 - 75	2,1 – 9,5
Energie minimale d'inflammation	*mJ*	0,02	0,26
Température d'auto-inflammation	*°K*	858	760
Vitesse de combustion dans l'air (à P_{atm} et T_{amb})	*cm/s*	265-325	30-40
Energie d'explosion	*g TNT/g produit* *kg TNT/cm^3 gaz (à PE)*	24 2,02	10 20,3

Safety rules

- *Never bypass a fuel cell*
- *Never disassemble the components of a fuel cell*
- *Never block the air filter of a fuel cell*
- *Be careful with the control card*
- *Be careful to the cells (graphite)*
- *Presence of an open circuit voltage operation (no load)*

This gas is highly flammable

- *It is therefore necessary to ventilate the room where the tests is performed*

Normes : *http://www.norme-standard.com/tag/pile-a-combustible*

Converter

Introduction

The circuit board of an electric or hybrid vehicle is identical to that of a thermal vehicle and must be powered by a 12V battery.

This function is then entrusted to a DC / DC converter, which draws electrical energy into the high-voltage battery and transforms it to charge the 12 V battery, while ensuring electrical isolation between the two batteries (galvanic isolation).

<u>Electrical energy is available:</u>

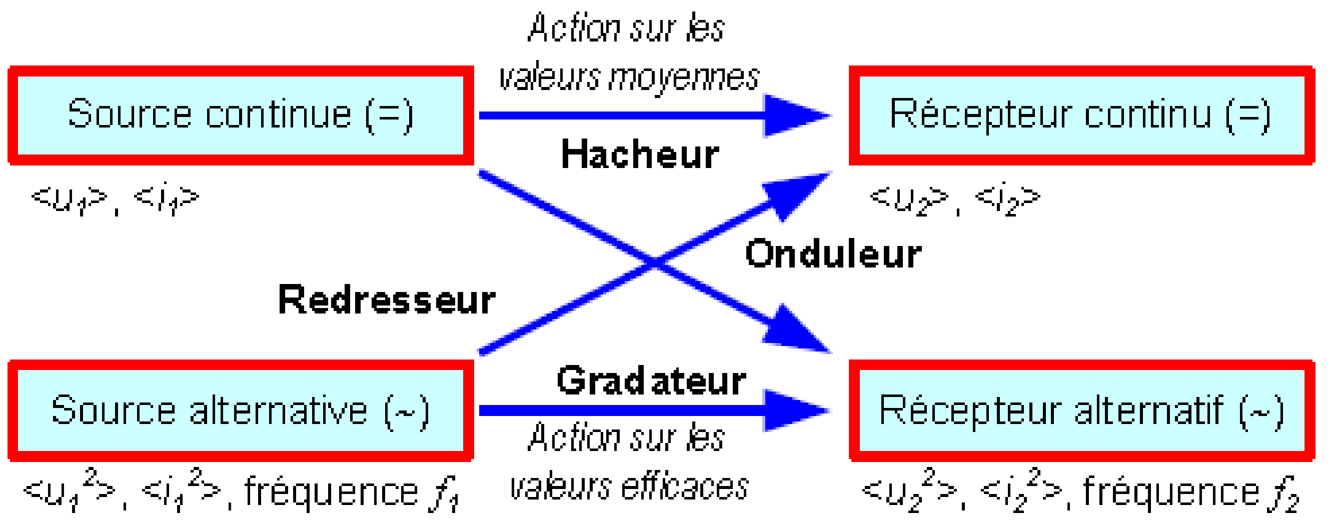
- *in alternative form for industrial distribution network or an alternator,*
- *in continuous form by accumulator batteries or DC generators.*

For the load, according to its nature, it requires energy in alternative or continuous form.

Type of converters

We thus define four classes of converters directly transforming electrical energy :

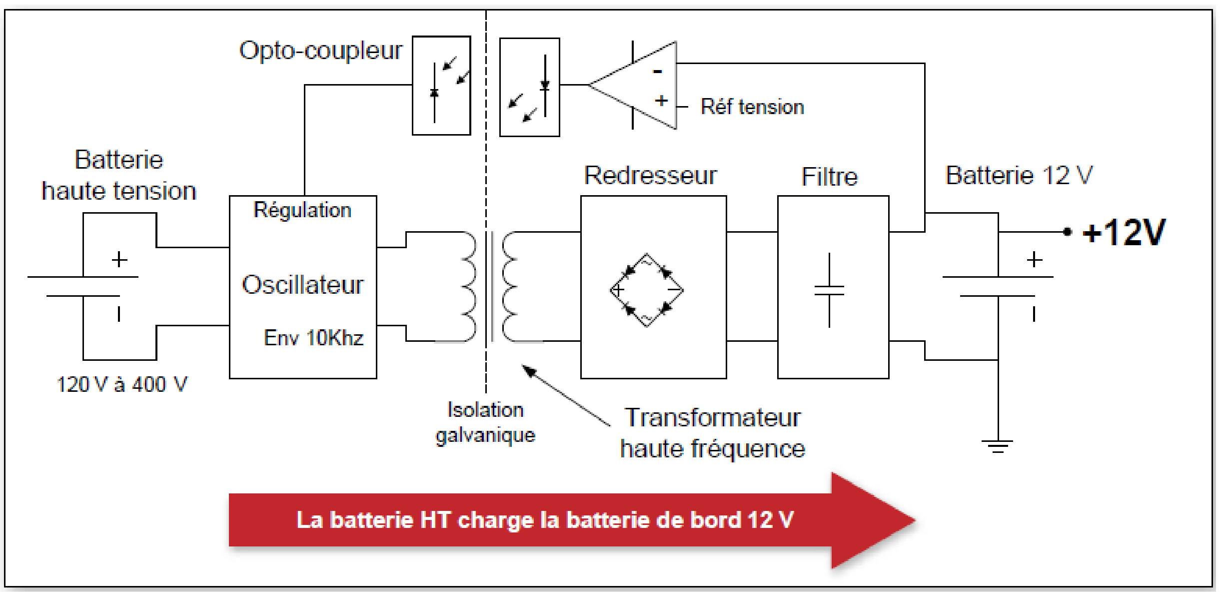
- *alternative → continued* ***(AC/DC)*** ***Rectifier***
- *continued → continued* ***(DC/DC)*** ***Chopper***
- *continued → alternative* ***(DC/AC)*** ***Inverter***
- *alternative → alternative* ***(AC/AC)*** ***Cycloconverter***



Unidirectional converter

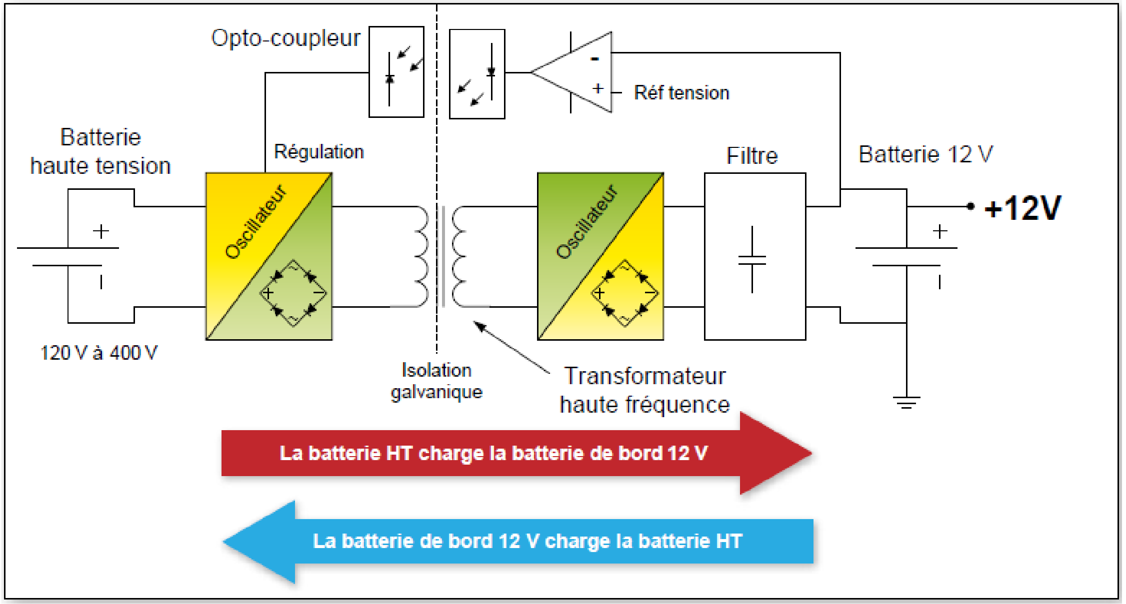
When it comes to energy conversion, the notion of conversion is important. It qualifies the reversibility of the converter.

A converter is reversible when the energy can pass in a bidirectional way. The notions of input and output are upset: both change according to the direction of energy transfer. A non-reversible converter transfers energy from a source to a user load. Energy can not flow in the other direction.

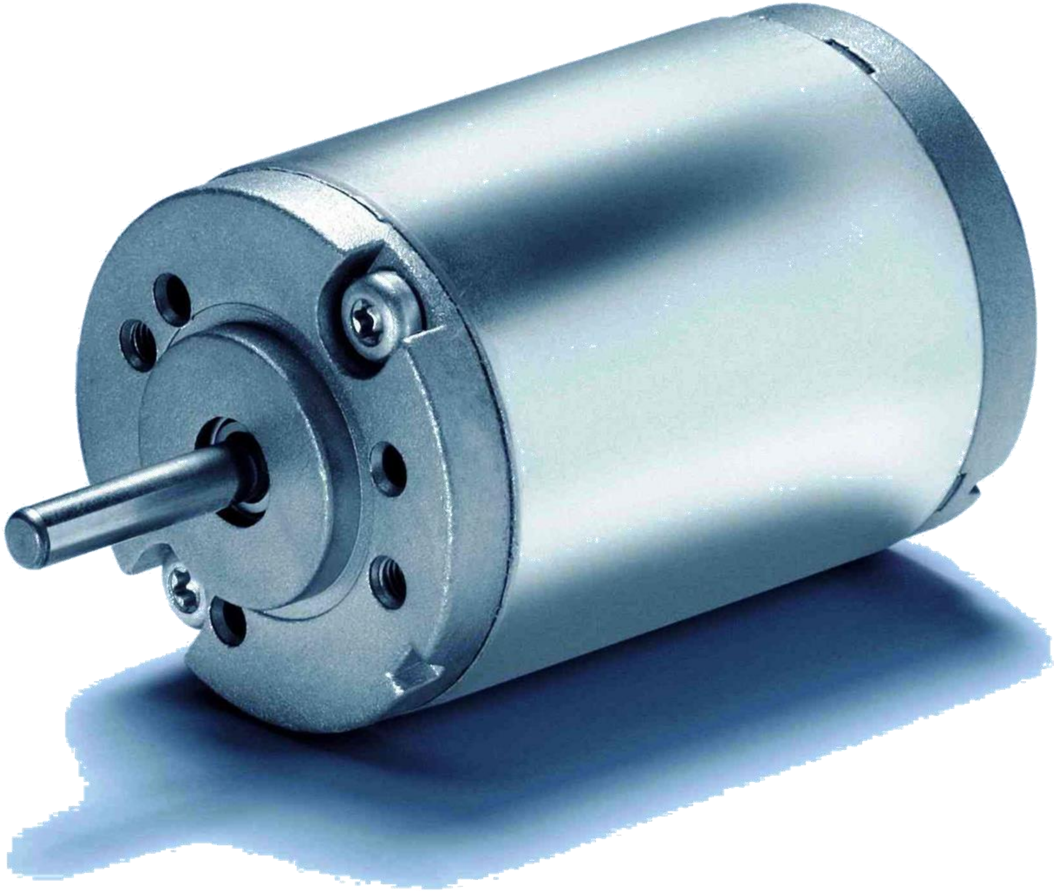


Bidirectional converter

For all hybrid vehicles, the energy required to start the engine is provided by the high voltage battery. During a complete discharge of the latter, it is impossible to start the engine.
This is why we also meet bidirectional converters that allow a partial recharge of the high voltage battery from the 12V battery. This requires connecting a charger, which can supply about 80A to the 12V battery and put the ignition (Mercedes S400H, BMW 7 series).



Electric motor



Introduction

Very used for more than a century, the electric motor is flexible, silent, does not pollute and adapts to all the situations.

Specifically, the electric traction motor must meet the following criteria:

It must be able to turn and brake in both directions of rotation,

- *It must have a large torque at low speed,*
- *It must have a good performance.*

For these reasons, the manufacturers guide, depending on the type of vehicle manufactured, their choices on:

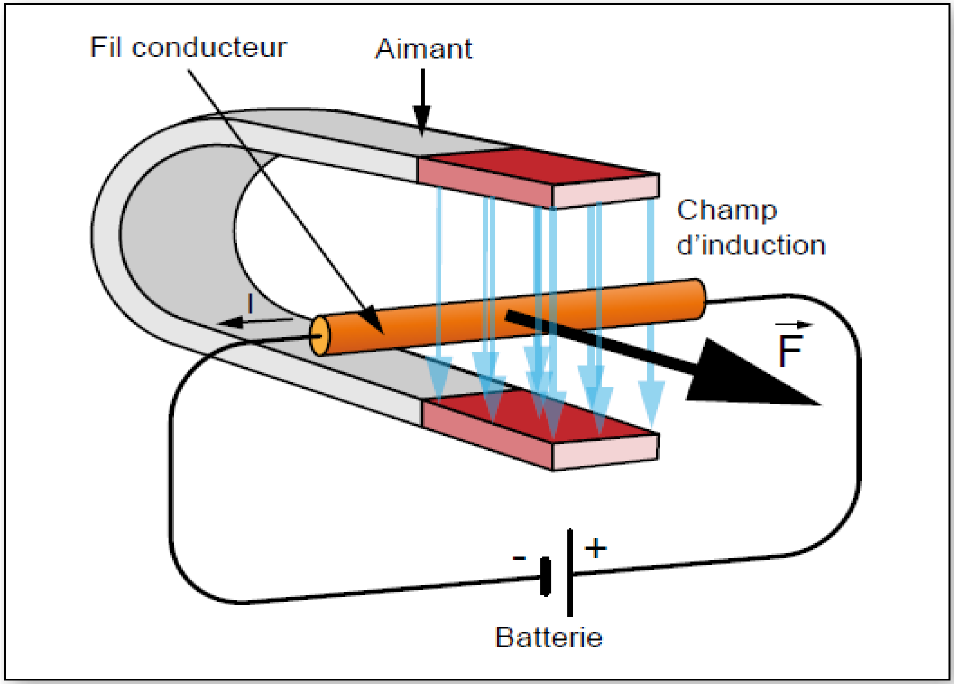
- *DC motor,*
- *Synchronous AC motor*

Principle of operation

When a conductor, traversed by a current, is placed in an induction field, it is subjected to a force perpendicular to the conductor and to the induction field F (Laplace's law).

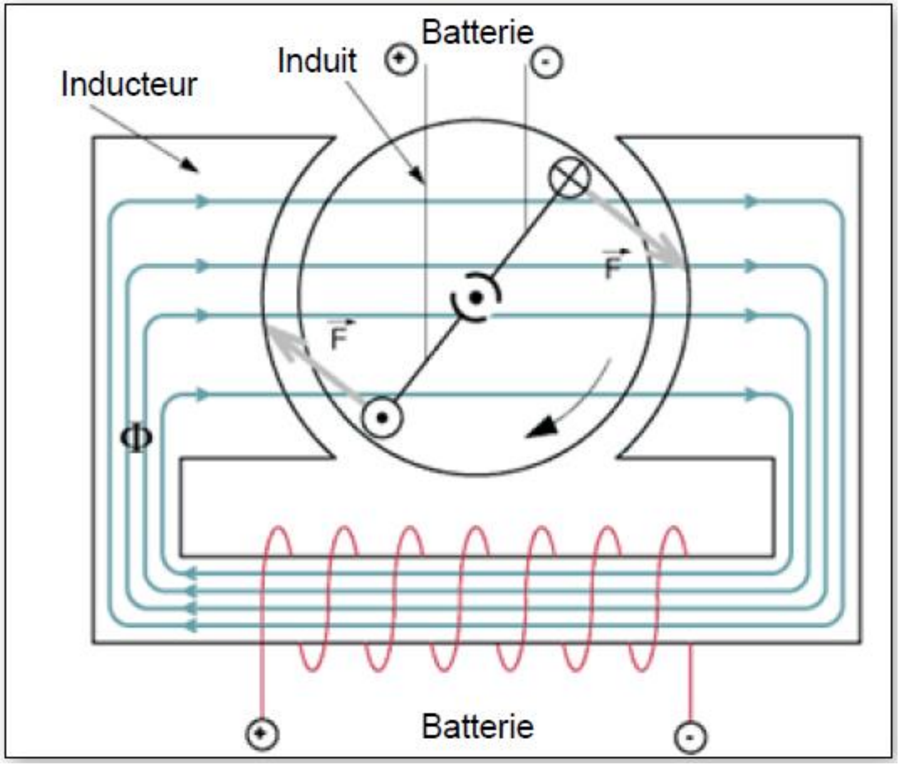
The direction of this force depends on the direction of the current and that of the field. This is the electromagnetic force.

- *The conductive wire is pushed towards the outside of the magnet,*
- *If the polarity of the battery is reversed, the wire is drawn towards the inside of the magnet.*



DC Electric Motor

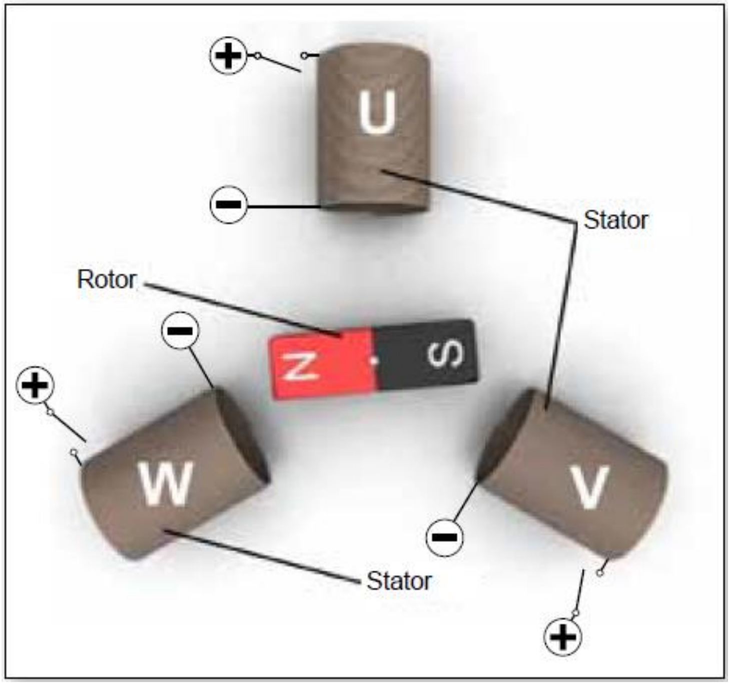
A conductive wire placed on the periphery of the armature is called the active strand. The way of arranging the active strands on the armature will make it possible to create tangential forces which will constitute the driving torque.



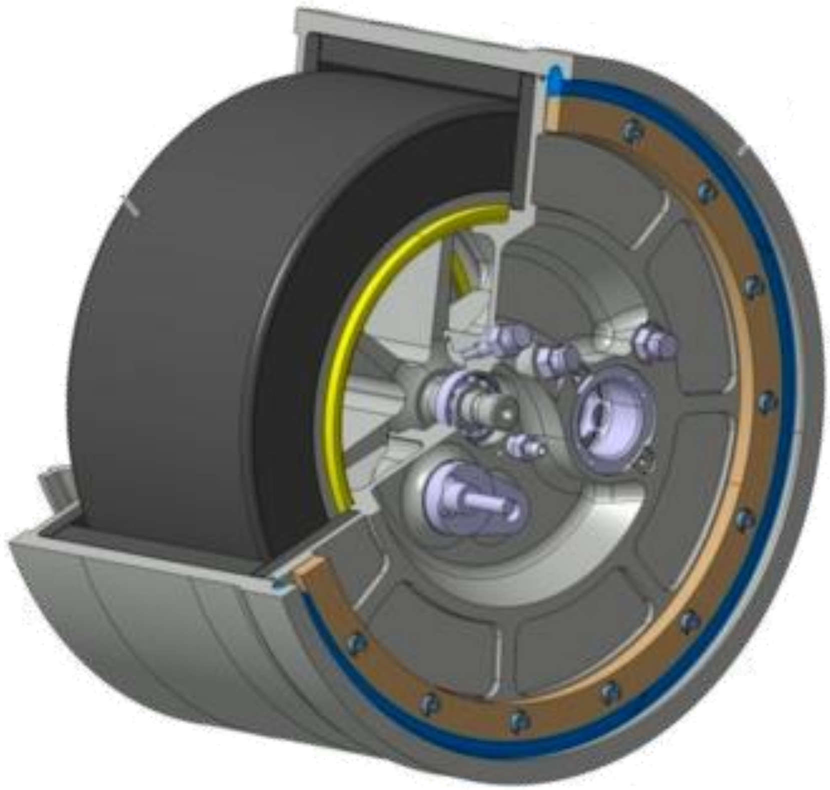
Synchronous AC motor

The three-phase synchronous motor offers the best torque and the best performance among all electric motors. This type of engine is maintenance-free, resulting in lower cost of ownership than DC motors.

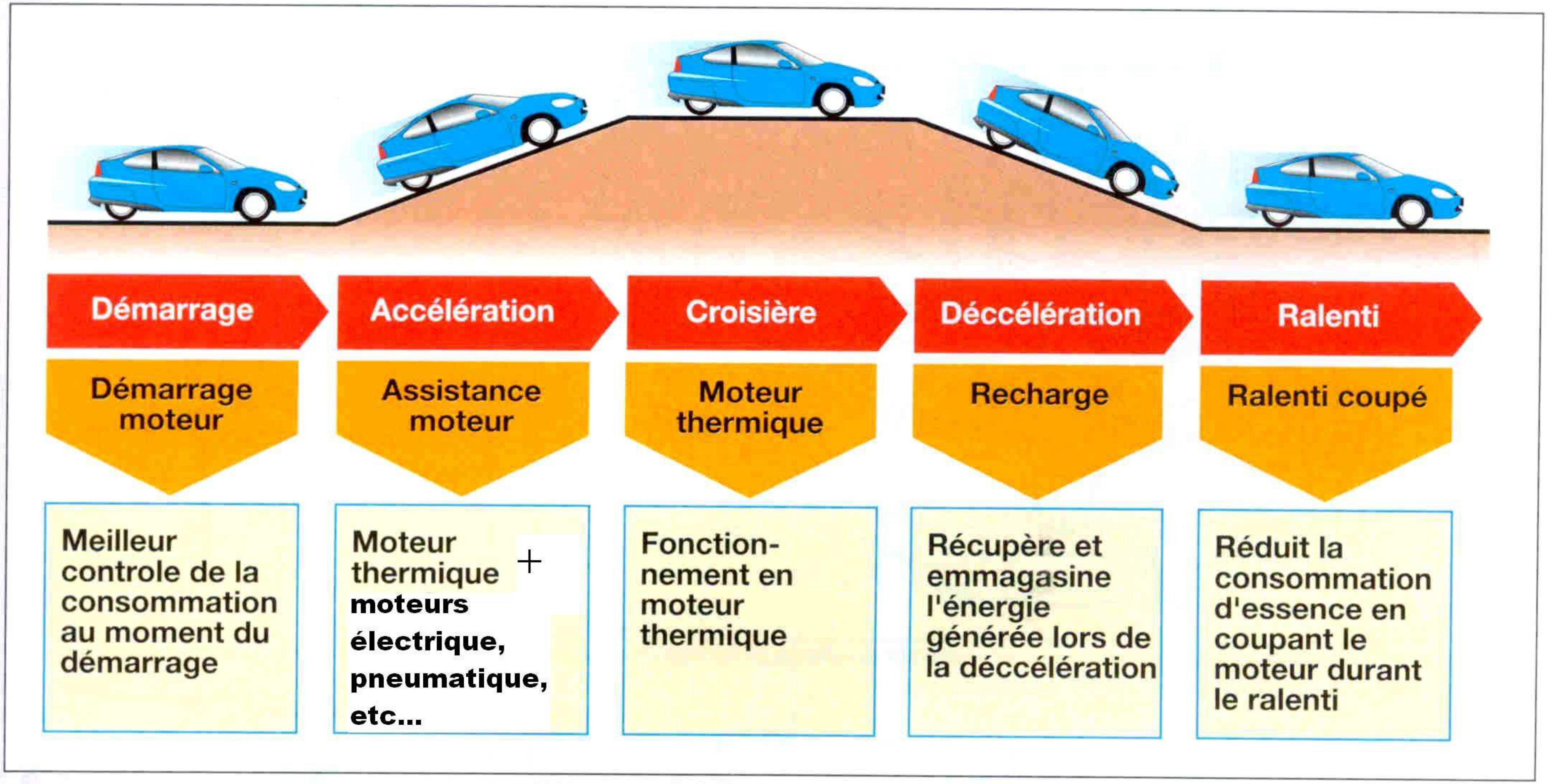
The synchronous motor consists of a magnetic rotor (usually permanent magnet) which rotates inside the stator, which has three coils out of phase by 120 °. Feeding a coil creates a magnetic field that attracts the rotor to align with it. By successively feeding the three coils, the rotor is rotated.



Braking energy recovery

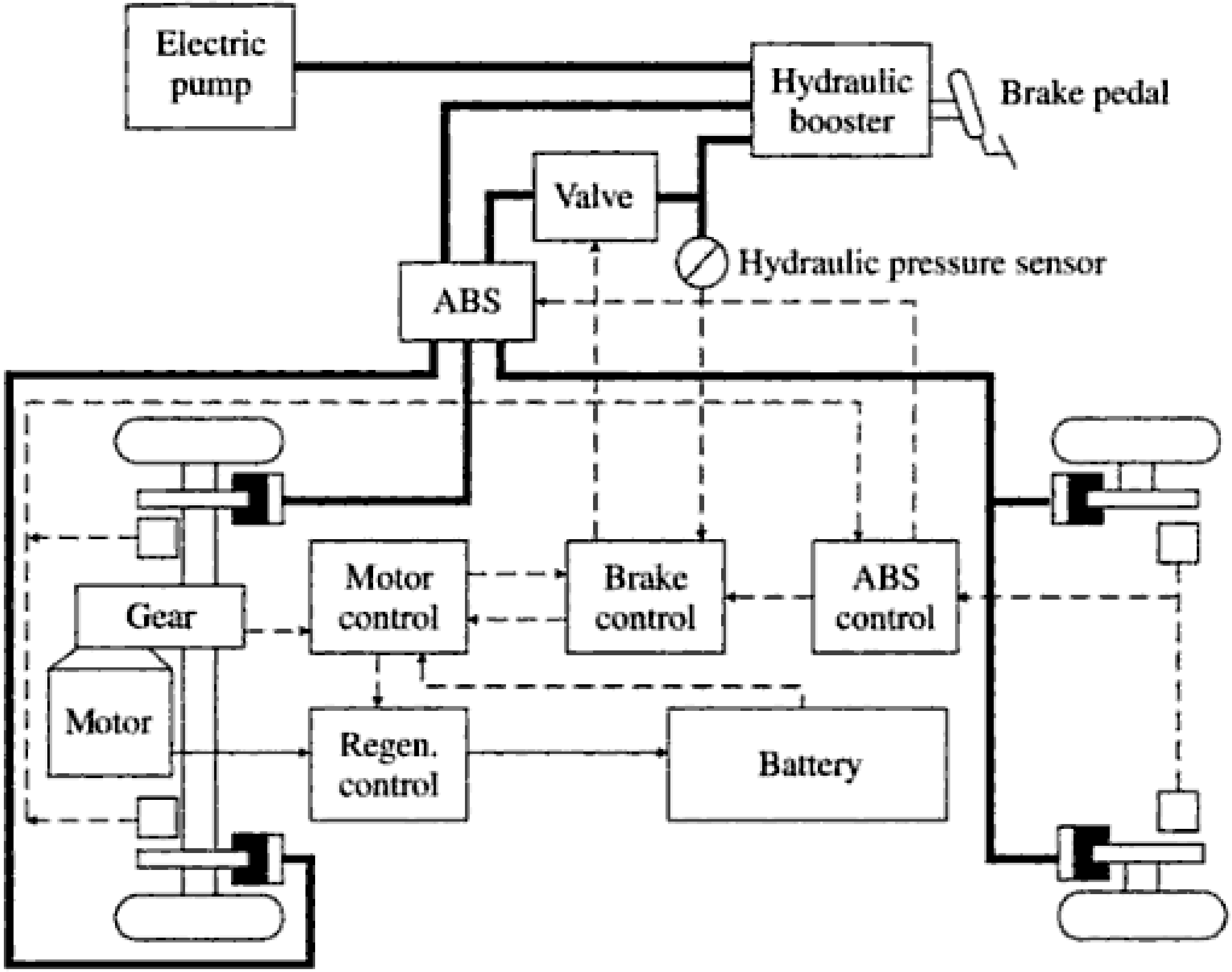


Principe



Energy recovery strategy and engine assistance of a hybrid vehicle

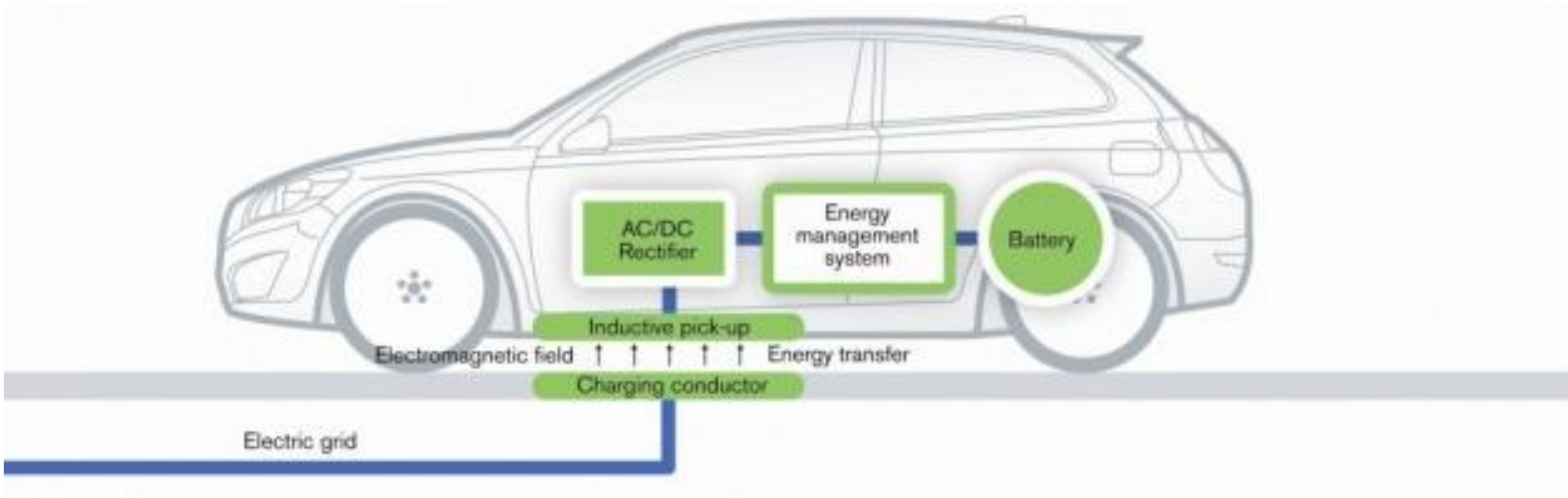
Principe



Electric pump
Hydraulic booster
Brake pedal
Valve
Hydraulic pressure sensor
ABS
Motor control
Brake control
ABS control
Gear
Motor
Regen. control
Battery

Induction charging

Principle



- *Charging plates in the road in order to be able to load continuously on the vehicle*
- *The charge of a battery pack of the power of the one that equips the Volvo C30 Electric should take about 1h20 in the case of a fully discharged battery (24kWh, autonomy of 163km)*

Electric and Hybrid Vehicle

Electric powertrain - sizing

The components of electric and hybrid vehicles

(Battery, Fuel cell, converters, electric motor, induction charging and energy recovery)

El-Hassane AGLZIM – MCF 63

November 2019

Institut Supérieur de l'Automobile et Transport

Département de Recherche en Ingénierie des Véhicules pour l'Environnement

49, rue Mademoiselle Bourgeois

58027 NEVERS