# Tesla electric vehicles batteries

## for students

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## STEP AHEAD II

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# Tesla electric vehicles batteries

**The aim of the lesson:**
To gain knowledge about the constitution and function of electric vehicles batteries cells.

**APPENDIX 1**

## Tesla Electric Vehicles Batteries


*(Source 2019-11-15 https://es.m.wikipedia.org/wiki/Archivo:Tesla_Model_S_(Facelift_ab_04-2016)_trimmed.jpg)*

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## Tesla Batteries

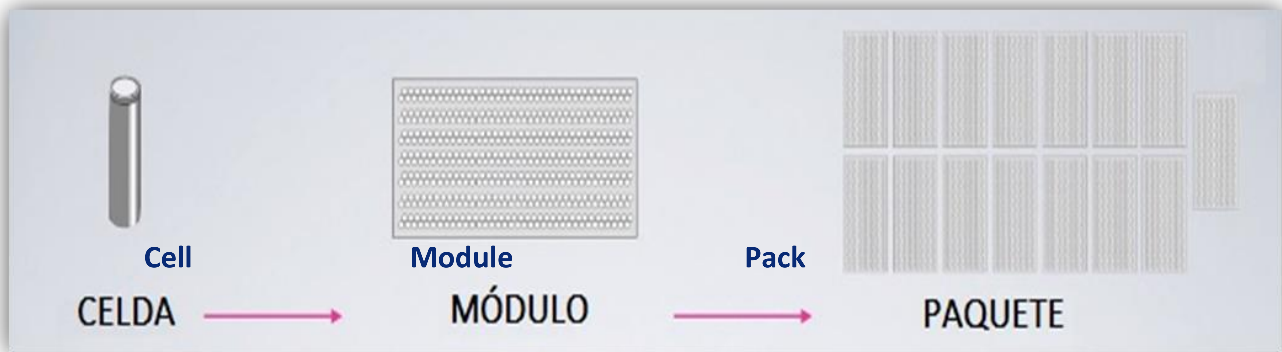
### Introduction

Tesla is a North American company situated in Silicon Valley (California), under the leadership of Elon Musk who designs, manufactures and sells electric vehicles.

Tesla was founded to speed the transition towards sustainable transport with the aim to fight global warming and reduce the deaths caused by pollution.

The company core is focused on the electric vehicle propulsion system engineering, which includes: battery packs, engine, power electronics and control software.

In this teaching unit we are going to focus on the battery pack, learning about the three parts it is composed by.  We will explore the chemistry and the cells format. We will also have a look at the modules pack model, as well as their design. To finish we will focus on how these battery packs are assembled.




Tesla claims they have the battery with the highest energy density in the market, but also de lowest cost per kilowatt/hour (from now on, kwh).

To test to which extent this is true, we will explain the different parts of a Tesla battery, as well as its characteristics and its functioning.

### Cells

For a start we will talk about cells, which is the main component of these batteries.

### Types

Cells can be found in three different formats: cylindrical, prismatic and cartridge cells.


*Cylindrical cells. Tesla Model S*

### Cylindrical cells

These cells are made by winding up the electrodes materials and inserting them on a aluminium cylindrical capsule.

Cylindrical cells are the cheapest option, compared to those prismatic or cartridge cells, because they can be manufactured in huge quantities in standard sizes.

As there are several companies manufacturing this type of cell with a standard size from the very first moment of lithium-Ion batteries commercial application (in 1991 by Sony company) the manufacturing process and the internal design of those cells have been highly optimized. This greatly improved design reduces the non-active components, that is, those which do not directly combine energy storage with reduction of space which is not used to store it. That is why, cylindrical cells usually have the highest volumetric power density.

Nevertheless, not everything is positive, as these cells are very difficult to cool and this problem means a reduction in efficiency and a shortening in the cell life. Moreover, cylindrical cells have a further inconvenience, which is, geometrically speaking, cylindrical cells are not ideally packed in battery modules with cuboidal shapes.

### Prismatic cells

They can be presented with several settings. However, automotive prismatic cells have cuboidal shapes to fit better within the module.


***94Ah and 37Ah Samsung prismatic cells***

Internally they have a quantity of windings similar to those of cylindrical cells which are compressed afterwards to fit the cell inner volume. Prismatic cells can present a certain design complexity for their manufacturer, but they make things easy for the car assembler as they adapt easily to modules, and they are relatively easy to cool thanks to their geometry, whether internal or external, which helps to heat transfer. Manufacturers such as BMW assemble them in highly automated batteries in models such as i3.

Although bigger size cell terminals help to reduce resistance and allow a greater heat transfer, both add moisture content, which at the same time reduces the energy density in cells. In addition, as we are compressing the cylinders around two electrodes, the compression is not the same at all points. This implies some problems with the lifespan after repeated charging and discharging cycles.

Prismatic cells also tend to offer high capacity to keep non-active material at a minimum. That is why BMW i3 from 2016 uses 94Ah prismatic cells or Volkswagen e-Golf from 2017 assembles 37Ah prismatic cells. These data stand out if we compare them with the 3.4 Ah prismatic cells used by Tesla. All this situation limits the final capacity of manufacturers to offer battery packs in different sizes.

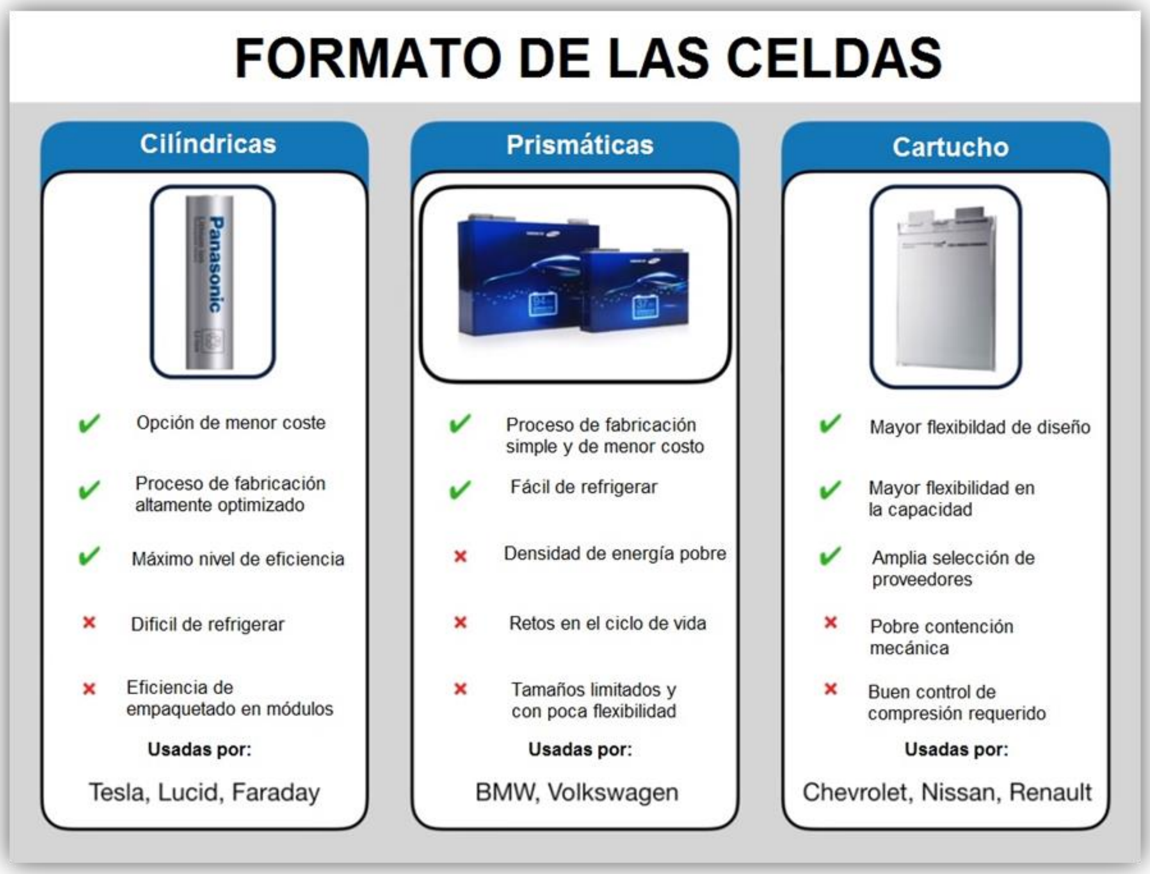
**Cartridge cells**

These cells use stacked electrodes and separators which are afterwards inserted in a polymer sheeting.

***Cartridge Cell***

Cartridge cells offer a maximum flexibility in their design, as they can usually be scaled to different sizes and the manufacturer can easily modify their capacity, by adding or removing layers.

An important number of battery manufacturers offer this type of cells because their gravimetric energy density is very competitive if compared to cylindrical cells. Gravimetric energy is the quantity of energy stored in a battery per kilo. This means, the higher this value, the higher capacity, autonomy and power we get. It can also be said that in a battery with the same capacity we get a lower weight and that is very important as well.




The main disadvantage of this type of cells is that they are much more complex to get them integrated in modules. Their cooling process also needs a very careful control.

**Which type of cells does Tesla use?**

*Tesla Model S.*

Tesla uses **cylindrical cells**, and the question is, why did they decide to assemble them in the battery pack of Model S? The answer is easy.

Cylindrical cells offered the greater energy density per cell. It should also be highlighted that at that time cylindrical cells were manufactured in huge quantities for the portable electronics. This meant that those cells had a lower price per kwh, which implied a reduction of the initial capital investment, something essential for a new company with a limited capital available.

Since the cost of these cells is still the lowest of the three formats, these are still used in Tesla new models such as Model 3 or even today at the mega-factory.

Before Model S was released big battery packs were used to produce an enormous quantity of energy. However, they were very expensive and they needed electric cars to be more reachable for most customers.

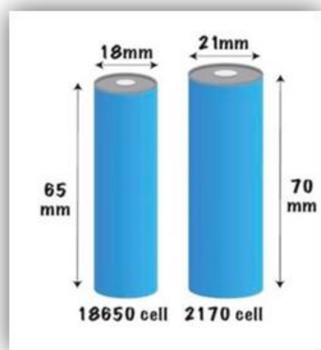
To produce a battery pack extendable to multiple capacities, it is necessary to have small capacity cells, and connect a great number of those cells connected in parallel.

***BMW i3 with 94 Ah prismatic cells***

Let's consider BMW i3 for example. This car uses very big prismatic cells by Samsung, all of them connected in series to build a 33kwh battery pack. To offer a 45kwh it is not possible to simply add cells in series because the voltage would change. So, the Battery Management System (BMS) and the inverter should be changed as well. However, if we add a chain of cells connected in parallel, we are doubling the number of cells, which will result in an increase capacity of the pack to reach 66 kwh, although this will be impossible to fit within the car chassis.

When we use small capacity cells and change the number of cells connected in parallel, Tesla gets greater flexibility: the 100kwh battery pack includes 96 cells connected in series and 86 in parallel, the 75kwh battery has 86 cells connected in series and 63 in parallel.

Among cylindrical cells used by Tesla there are two types: 18 650 type, used in models like *Model S and Model X*; and the 21 700 model, used in *Model 3*. Both types are manufactured by Panasonic.



*Cells size 18 650 and 21 700.*

18 650 cells have this name because their diameter is 18 mm and are 65mm long. The same way, 21 700 cells have a diameter of 21mm and are 70mm long. This additional length, apart from the bigger diameter, offers an increase of 33% of active material to store energy within the cell.

A 18 650 cell has a capacity of 3,4Ah or 12,4Wh and a nominal voltage of 3,66V. The resistance changes with the battery's state of charge and with its temperature, although in general it is over 30mΩ.

Giving a cell a volume of 16mL and a mass of 49gr, the cell reaches the impressive energy density of 254Wh per Kg or 755Wh por L.


***NCA cell composition***

If we have a look inside a 18 6500 cell, we can observe the different layers of the battery, which has a cathode composed by 80% nickel (Ni), 15% cobalt (Co), approximately 4% aluminium (Al) and less than 1% lithium (Li). On the other hand, the anode composition includes graphite although there is a tendency to replace it with silicon. The electrolyte is a solution of Li and the rest of components are made of Al and copper (from now on Cu).

Both, the anode and the cathode are two rolled sheets meant to occupy the shortest possible volume. Tesla calls it *Jelly Roll*.

On the positive terminal side, there is a compound made of carbon fibre which keeps the Jelly Roll placed. The fact that it is made of carbon fibre is to reduce the cell weight in a small proportion. When considering a huge number of cells, as we find in a complete battery pack, the weight loss is important helping to improve the battery energy density.

The positive terminal also has three ventilation openings, which help to free pression when there is a change in altitude or when there is an inner error in the cell. It also has an O ring to ensure sealing.

If we would unwind the *Jelly Roll*, we would be able to observe the anode and cathode sheets previously mentioned, separated by another plastic sheet which used as insulator between them. Their measures are approximately 1 m long and 60 mm wide.

We should underline that the Li sheet is the one containing the potential of the batteries, but it also arises a problem, as it is highly inflammable. To solve this issue, some manufacturers use a flame retardant between the layers. This causes another inconvenience, as it increases the non-active material within the cell, just the opposite effect Tesla is looking for, together with Panasonic, as they focus their research in manufacturing these sheets as thin as possible keeping their capacity to store energy with materials such as graphene.

Keeping up with the chemistry within the cell, we should mention that main manufacturers are nowadays using cobalt oxide cathodes and nickel- manganese or NMC

Tesla, however, uses LiNixCoxAlxO2 cells, as we have previously said, also called NCA. These are similar to NMC cells but they use Al instead of manganese to stabilize the crystalline structure of the Li oxide.

NCA cells have a greater energy capacity, however, these will cause thermal exhaust at a lower temperature.  That is why they are considered appropriate for small 6A cells as maximum power. This explains why vehicles such as Nissan Leaf, Renault Zoe or BMW i3 use NMC.

As we have previously mentioned, the anode in almost of Li-ion batteries is made of graphite, but they are willing to change it to Si, because of their greater storage capacity.

In each new cell generation, Tesla has increased the quantity of Si in the anode, which ensures that 21 700 cells for Model 3 will have a bigger quantity of Si than the current 18 650.

***NOTES:***

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