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Electric vehicle batteries. Types, Raw materials, Source, Recycling, Pollution

Gheorghe NEAMȚU[1]
[1]Ph. D. Engineer, Associate Professor at Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, Romania.

Abstract. *The electric storage battery is one of the most important discoveries of science and technology. If storing alternating electrical energy (alternating current) is still a problem for mankind today, direct electrical energy (direct current) can be easily stored in electric batteries, which are increasingly used to power road vehicles, thus representing the viable, durable and sustainable solution for human mobility. This paper is the author's own scientific representation and original point of view on the technical acceptance of batteries that store the electrical energy required for the propulsion of electric vehicles. In this way, those interested can learn about the raw materials used in the manufacture of electric vehicle traction batteries, their origin, the factories or plants producing them in Europe to date, recycling techniques and the pollution they cause. The scientific research also presents the case study: the hydrogen fuel cell automobile versus the electric automobile. At the end of the scientific article, the conclusions in the field are presented.*
Keywords: *electric motor vehicle, electric battery, raw materials, processing, recycling, pollution.*

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I. INTRODUCTION

The transportation process, driven by the need for mobility, takes many forms, depending on the object (people, goods), the means or systems used for this purpose, and the vehicles by which the movement is made. Natural fossil fuel resources are likely to run out in the next 35-40 years. This will require mankind to find alternatives for mobility. Carbon-based fuels will have to be replaced by alternative ones. Environmentally friendly cars, hybrids, electric cars and more are gaining ground worldwide. The hybrid car is seen as the bridging element, the bridge, the interface between the conventional and the electric vehicle. It now represents a temporarily viable alternative to the classic internal combustion engine car. The electric motor is slowly but rapidly catching up and will be, alongside other types of environmentally friendly engines (e.g. hydrogen engines - fuel cells), the alternative propulsion for the cars of the future. It will be the foundation for the sustainable and sustainable development of the road transport system (Neamțu G. , 2023, p. 6). Compared to other sectors of the economy (energy, industry and construction), which have taken measures to reduce pollution since 1990, the transport sector has developed rapidly and chaotically, which has led to an increase in pollutant emissions from these activities and significant damage to nature. For this reason, the transport sector has become a major obstacle to the implementation of European environmental objectives. In this respect, authorities all over the world are coming up with proposals and drafting laws or regulations on environmental protection in the form of fuel quality standards, standards for pollutant emissions from car engines, the use of cleaner car manufacturing technologies, environmentally friendly cars (Neamțu, Tarnu , & Țîțu, 2022). We know that a car, regardless of its propulsion system or energy, pollutes from the beginning, from the ore from which its components are made, to the end of its life (when it is scrapped) when it is taken out of service. The electric vehicle is the most efficient and cleanest means of meeting people's mobility needs today. The electric drive system has been a long-standing concern of automotive specialists and researchers. Two of the basic advantages of electric motors are that they provide maximum torque at all engine speeds and are quiet in operation. However, in the world, the problem of range is far from solved. Electric cars are currently proving their efficiency only in urban environments. In order to be efficient outside urban areas, the range of electric traction batteries must be developed and extended. Its limited range is one of its biggest disadvantages (Neamțu G. , 2023, p. 65). The automotive industry is currently in a long transition phase from cars with internal combustion engines to battery-powered electric cars. One of the arguments in their favor is the complete elimination of emissions of carbon dioxide, nitrogen oxides and other harmful substances during driving, which helps improve air quality in big cities. On the other hand, one of the counter-arguments is that the traction battery of an electric car uses raw materials extracted from various places on many continents through processes that generate emissions of harmful substances into the atmosphere. Basically, there are currently 5 essential raw materials for the production of Li-ion batteries: lithium, nickel, cobalt, manganese and graphite. Of these, graphite is mainly used for the anode of a battery, and the other four raw materials for the battery cathode. Virtually all of these 5 raw materials are of major importance not only to the automotive industry, but to almost every branch of the electronics industry that uses batteries in one form or another to store electrical energy. This is why these raw materials have been included on a list of critical raw materials (European Commission, 2020), (Burton, 2022) by the European Union and the list is updated every three years, with the last update available online in 2020. In addition to these 5 materials, all electric car batteries are made of other materials, the most common of which are iron, copper, aluminum and steel, the last of which is used for the battery casing.

II. RAW MATERIALS USED FOR THE MANUFACTURE OF ELECTRIC TRACTION BATTERIES OF ELECTRIC VEHICLES

Depending on the materials used to produce the cathode, there are several types of Li-ion batteries. As of 2021, more than 80% of Li-ion batteries in electric vehicles sold worldwide were NMC, an acronym derived from the three main raw materials used in the cathode: Nickel, Manganese and Cobalt. Normally, the amount of manganese and cobalt in such a car battery is the same, but if it contains more cobalt than manganese, you will also find it under the acronym NCM. According to data provided by the AMT (Environment Agency for Transport and Environment) (AMT, 2021) and elaborated by Visual Capitalist, here is the typical composition of a 60 kWh capacity NMC Li-Ion battery according to the raw materials used and the mass of each raw material. Table 1, according to the data presented in Figure 1, shows that the following quantities of raw materials are needed to build a traction electric battery with a capacity of 60 kWh). Here you can see, in percentages, for each material, how much of the electric battery is made up of it.

Table 1. Raw materials required to build a 60 kwh electric storage battery.

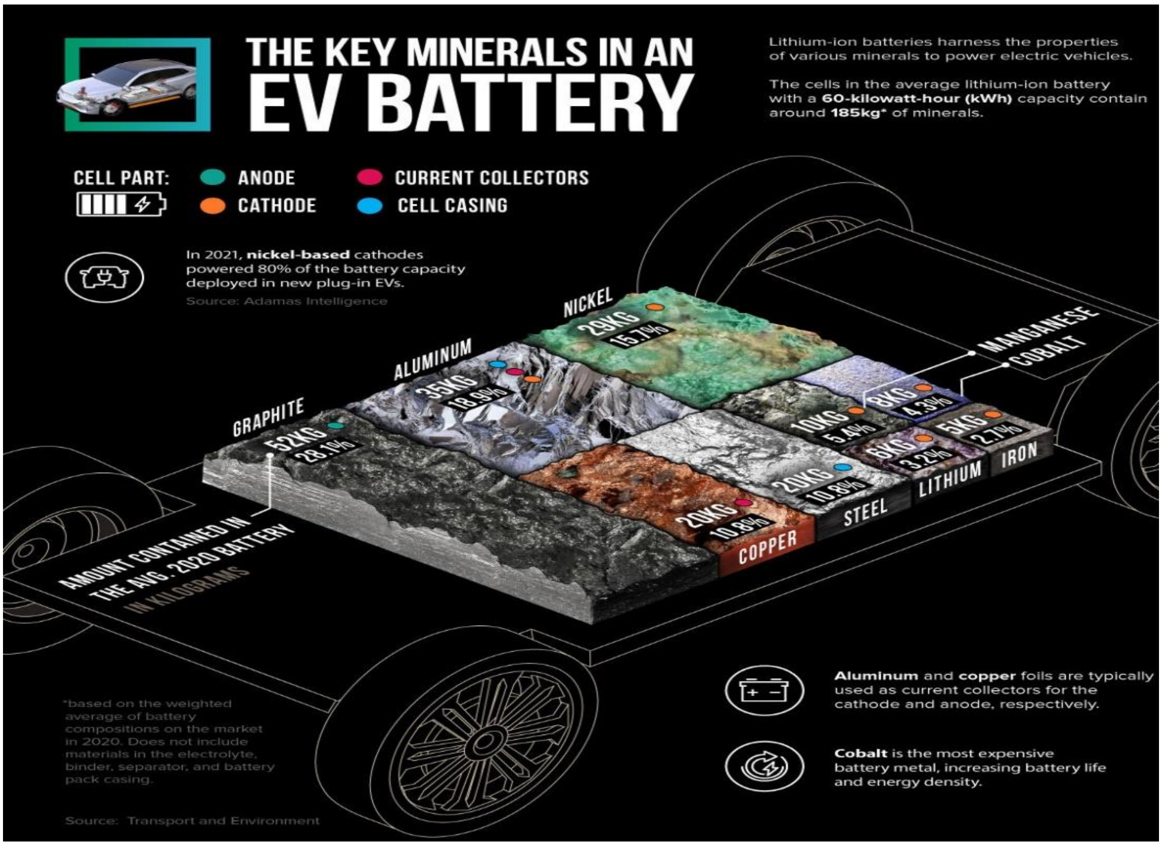
Type of raw material	Quantity (kg)	Percentage (%)
Graphite	52	28.1
Aluminium	35	18.9
Nickel	29	15.7
Copper	20	10.8
Steel	20	10.8
Lithium	6	3.2
Mangan	10	5.4
Cobalt	8	4.3
Iron	5	2.7

In recent years, a number of manufacturers have changed the composition of minerals in an attempt to eliminate some hard-to-source raw materials. This has given rise, for example, to NCA Li-ion batteries, an acronym for nickel, cobalt and aluminum. They don't use manganese at all, but offer no major advantages over NMC batteries in terms of energy density or number of charge-discharge cycles.

In Europe, they are mainly found in the higher-end versions of the Tesla Model 3 and Model Y, and the US automaker recommends that customers only charge the battery to 90% to prevent premature battery wear. In fact, premature wear and tear on a full charge has led most manufacturers to ignore this version of Li-ion batteries.

A more promising development, however, is the Lithium Iron Phosphate (LiFePO) Li-ion battery (LFP), which uses no manganese, nickel or cobalt in its composition. As a result, production costs are lower than for NMC or NCA batteries, and a major advantage is that the number of charge-discharge cycles is around 2,500, compared to the 1,000 to 2,000 charge cycles offered by NMC or NCA batteries.

Figure 1. The key minerals in an electric vehicle battery (Capitalist, 2021)**.**



But LFP batteries also have a major disadvantage: their energy density is lower and typically reaches around 160 Wh/kg, compared to around 200 Wh/kg for other technologies. This means that a 60 kWh LFP battery will give about 20% less range than an NMC battery of the same capacity fitted in the same car. LFP batteries are manufactured in particular by Chinese manufacturers, such as BYD Atto 3, MG ZS EV or GWM Ora, but also by Tesla, which offers them in standard versions of the Model 3 or Model Y. Incidentally, 68% of LFP batteries available globally on cars sold in the first 9 months of 2022 equip BYD and Tesla models. Most recently, the large German automaker Ford (Ford, 2023), has announced that it will offer LFP batteries in Europe on the Mustang Mach-E SUV, starting in 2023 (Figure 2).

Figure 2. Ford Mustang Mach-E, one of the first LFP battery electric models in Europe (Ford, 2023)**.**

According to a report conducted by Adamas Intelligence, imprinted "Evs Btteries and Battery Matterials", the market share of LFP batteries has steadily increased from 17% in January 2021 to 26% in January 2022 and to 31% in September 2022. However, specialists anticipate that NMC batteries will remain the most common battery in the future. By now, in order to prevent problems with lithium sourcing from ore, manufacturers have already developed new technologies to produce more economical automotive batteries in terms of raw material, ranging from solid-state batteries that are expected to offer much higher energy density to Sodium-Ion batteries, which use Sodium replacing Lithium.

Although they have completely different names, the cells in a solid-state battery use basically the same chemical reaction for lithium ions as Li-ion battery cells. The major difference is the electrolyte used to separate the anode and the cathode to allow the lithium ions to move. Specifically, the Li-ion battery cells available today in every electric car rely on a liquid electrolyte, which is often a lithium salt suspended in an organic solvent. In contrast, solid-state battery cells use a solid electrolyte made of ceramic, glass or polymer. Obviously, this solid electrolyte is also the name of the technology: solid-state. Using a solid electrolyte instead of a liquid electrolyte has at least four major advantages for the automotive industry compared to the liquid electrolyte in Li-ion batteries (Popescu D. , 2022):

- ***solid-state battery cells are lighter and smaller***. In practice, manufacturers can take advantage of this advantage in two ways: they can either develop a battery of the same capacity but with a lower mass and smaller size, or they can produce a battery of the same size but with a larger capacity, which obviously allows for increased autonomy;
- ***solid-state battery cells charge faster.*** Regardless of the technology used, there is a tendency for some lithium ions to deposit on the anode surface and not be absorbed into the anode in time. Tests to date have shown that solid-state battery cells are more resistant to this process;
- ***the risk of fire is significantly lower.*** Sometimes, the cells of a battery can be defective or deteriorate over time for some reason. In such a situation, with Li-Ion batteries, the liquid electrolyte is exposed to the environment, which increases the risk of a fire. In contrast, solid electrolytes are resistant to fire and explosion, even if they deteriorate over time;
- ***simplified production process.*** Theoretically, solid-state batteries will have a simplified production process with fewer intermediate steps, which will translate into higher production capacities. At least that's the theory of the engineers, who admit that this remains to be proven in practice once mass production of these components is available.

Basically, based on these advantages, solid-state batteries charge in just 10 minutes, offer an estimated range of at least 800 kilometers and are lighter. They charge in 10 minutes and offer ranges of more than 800 kilometers. But they have one drawback: a low number of charging cycles prevents their introduction in electric cars. Researchers hope to overcome this last obstacle in time. However, in the immediate future, available in nature as a salt, sodium could replace lithium in electric car batteries. Sodium-ion batteries promise fast charging, good low temperature performance and energy efficiency.

III. SOURCE OF RAW MATERIALS FOR ELECTRIC TRACTION BATTERIES FOR MOTOR VEHICLES

International statistics show that there is sufficient raw material to meet the growing demand for battery production. However, some raw material reserves are not cost-effective, as extraction and processing costs with current technologies are higher than potential revenues at current prices. In addition, many of the raw materials are available in countries that are less politically friendly to Europe and the United States, and this may lead to numerous supply problems over time.

Table 2 shows the sources of the most important raw materials used in Li-ion batteries in electric vehicles.

Table 2. Sources of origin for the most important raw materials used in Li-ion batteries in electric vehicles (Vranken, 2023)**.**

Raw materials	Critical stage	Main global producers	Main EU sourcing[1] countries	Import reliance[2]	EoL – RIR[3]	Selected Users
Bauxite	Extraction	Australia (28%) China (20%) Brazil (13%)	Guineea (64) Greece (12%) Brazil (10%) France (1%)	87%	0%	Aluminium production
Cobalt	Extraction	Congo DR (59%) China (7%) Canada (5%)	Congo DR (68%) Finland (14%) French Guiana (5%)	86%	22%	Batteries Super alloys Catalysts Magnets
Lithium	Processing	Chile 78(%) China (39%) Argentina (13%)	Chile (78%) United States (8%) Russia (4%)	100%	0%	Batteries Glass and ceramics Steel and aluminium metalurgy

Raw materials	Critical stage	Main global producers	Main EU sourcing[1] countries	Import reliance[2]	EoL – RIR[3]	Selected Users
Natural Graphite	Extraction	China (69%) India (12%) Brazil (8%)	China (47%) Brazil (12%) Norway (8%) Romania (2%)	98%	3%	Batteries Refractories for steelmarking

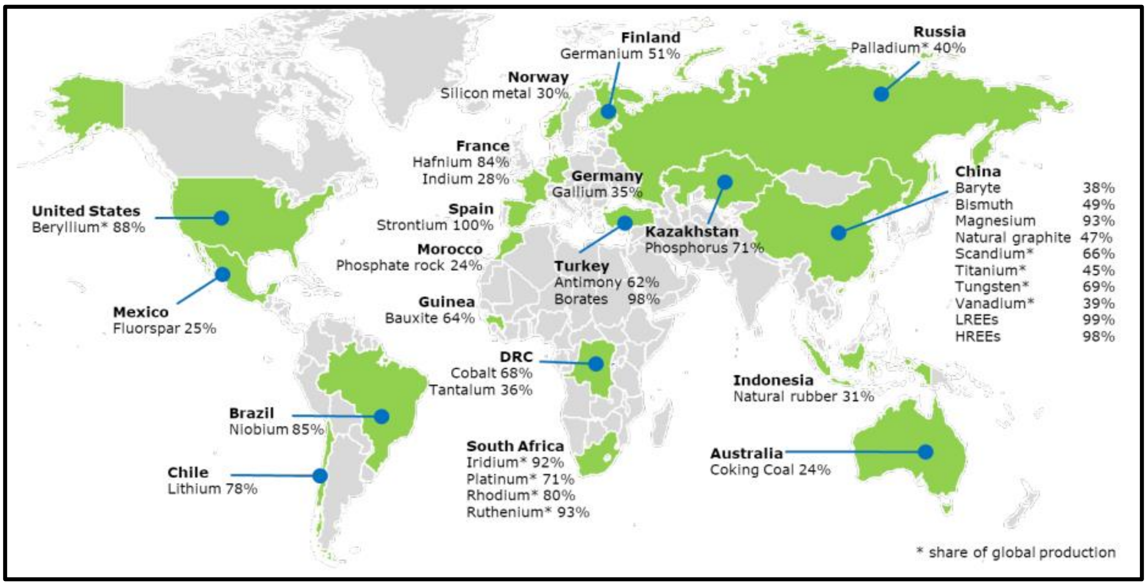
[1]Based on Domestic production and Import (Export excluded);

[2] IR = (Import – Export) / (Domestic production + Import – Export);

[3] The End-of-Life Recycling Input Rate (EoL-RIR) is the percentage of overall demand that can be satisfied through secondary raw materials. Data from: Study on the EU's list of Critical Raw Materials (2020) Final Report.

Graphite is used in the production of the anode of a Li-ion battery and is the most important raw material in a battery in terms of quantity. It accounts for about 30% of the total raw material mass of an electric battery. Globally, China is the leading producer of graphite, with a 69% market share, followed by India (12%) and Brazil (8%). Data is also available on the countries from which the EU sources graphite, but this is less relevant as the data only shows imports of graphite as a raw material. Graphite in an electric battery produced in China is not included in the statistics. Romania owns graphite deposits from which it has exploited about 40,000 tons of graphite per year in two mines in Baia de Fier in Gorj county. The two mines were closed in 1994 and 2005 on the grounds that they were unprofitable, but the Romanian state announced in the summer of 2022 that it intended to reopen the mines during 2023, following the major interest in graphite at European level. In the absence of modern extraction technologies, the central authorities adopted a project in March 2023 called Romania's Strategy for Non-Energy Mineral Resources (Bursa.ro, 2023), (Economy, 2022), which allows private companies to exploit the country's graphite reserves.

Figure 3. Biggest supplier countries of CRMs to the EU (Vranken, 2023)**.**



Meantime, Europe has only minor nickel deposits in countries such as Finland, Greece and France. Statista shows that globally the biggest "owners" of nickel reserves are Australia and Indonesia with 21% each, followed by Brazil with 16% and Russia with 7.5%. Just over 2% of global reserves are also available in China (Statista, 2024).

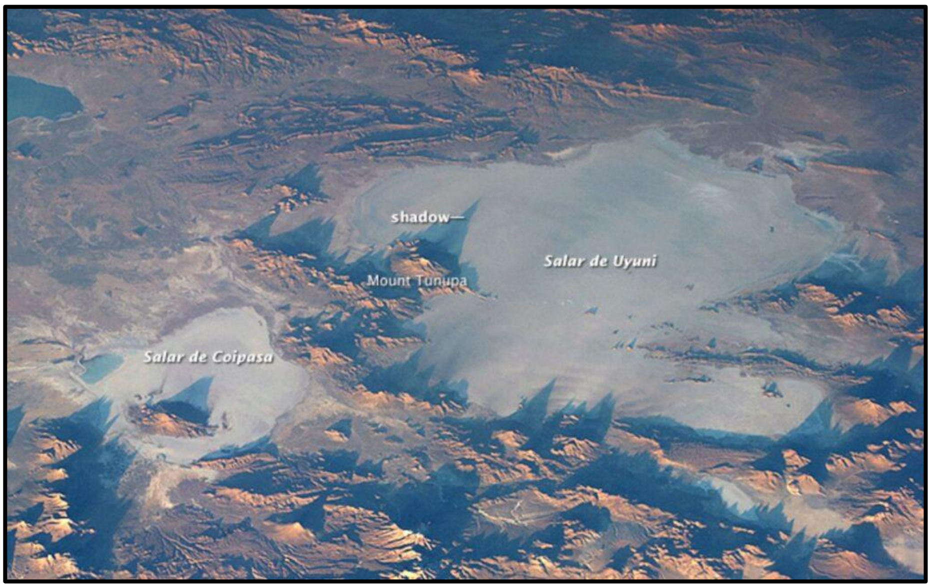
In the case of manganese, according to data published by the United States, the biggest reserves are in South Africa (around 40%), Brazil and Australia (20% each), but the biggest manganese mines are currently in South Africa, Australia and the African state of Gabon. The United States imports most manganese from Gabon (Survey, 2021).

For cobalt, battery producers have to look to the Congo, which holds almost 60% of the world's supply. The remaining 40% is dispersed in many countries around the world, with the largest deposits in China (7%) and Canada (5%). In Europe, there are minor deposits in Spain and Sweden. and Canada

(5%). In Europe, there are minor deposits in Spain and Sweden. As can be seen on the map in Figure 3, Europe is dependent on foreign countries for many of these CRMs.

For some of these CRMs, sources are very concentrated in a few countries or, sometimes, even in just one specific country (e.g., Chile, which is responsible for 78% of the EU's lithium supply, or the Democratic Republic of Congo, which is responsible for 68% of the EU's cobalt supply).

Figure 4. Bolivia's Salar de Uyuni, the salt flats from which lithium is extracted for electric batteries (Times, 2024)**.**



Even if you name some of the electric batteries now used in electric cars and almost every electronic gadget, lithium is used in quite small quantities. For example, an electric car battery needs 6-7 kilograms of lithium, whether we're talking about NMC or LFP batteries. Theoretically, globally, two countries together hold about 83% of lithium reserves: Chile (44%) and China (39%), while Argentina rounds out the podium with 13%. However, most experts believe that Bolivia is actually the country with the world's largest lithium deposits, with around 25% of the world's reserves. The explanation for this controversy is that Bolivia's lithium is actually found in the Salar de Uyuni (Figure 4), a flat area of land of one million hectares that is covered with salt. In the crust of this salt composition, however, are large amounts of lithium that is already being mined. By contrast, Europe has about 7% of the lithium deposits, and lithium is currently exploited only in Portugal. Figure 5 shows the ore from which lithium is extracted.

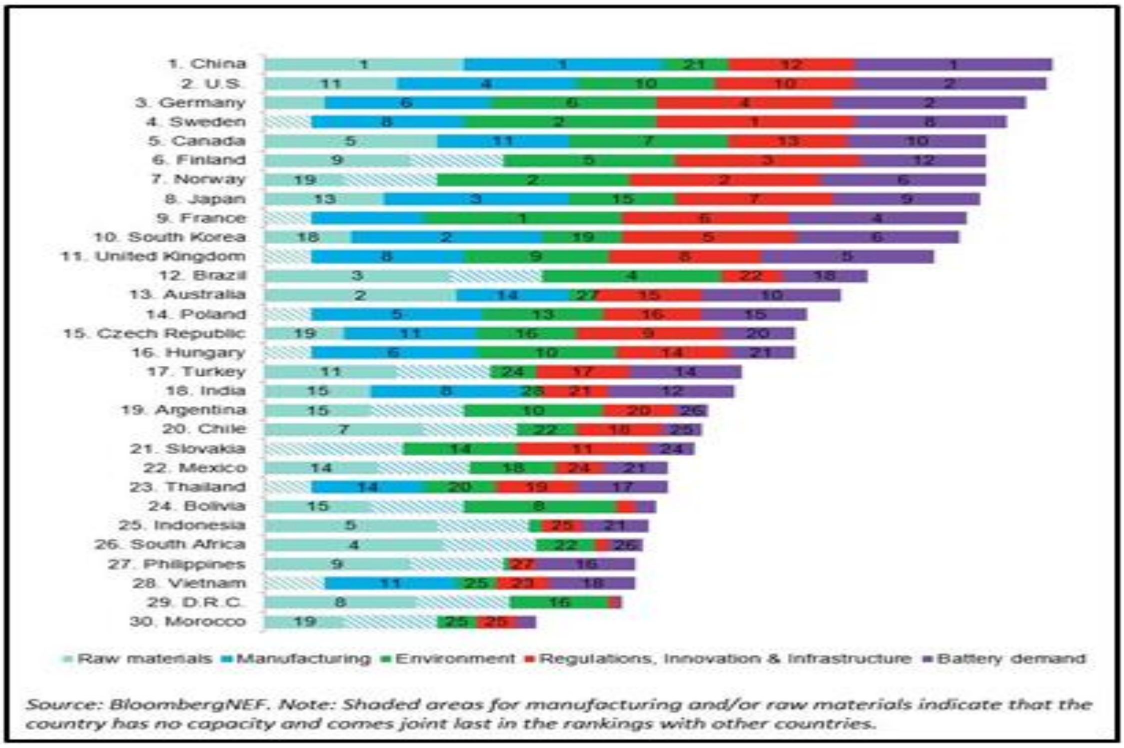
Figure 5. The ore from which lithium is extracted (Şocariciu, 2022)**.**

On the other hand, the world's powerful states are struggling to gain access to the world's largest resources of raw materials, even if they are not on their own territories. A report published by Swiss bank UBS, for example, shows that by 2025 the Chinese state could control a large part of Africa's lithium reserves (Bloomberg, 2023). his is often done by buying mines outright or by taking them over after African countries fail to repay their Chinese government loans.

IV. LI-ION BATTERY FACTORIES IN EUROPE

According to a report entitled Global Lithium – Ion Battery Supply Chain (BloombergNEF, 2021), a Bloomberg's annual report shows that, by 2021, the largest producers of electric batteries for cars are, in order of capacity, China, the United States and Germany (Figure 6). Each electric traction battery plant is more simply known internationally as a Gigafactory, a term quickly adopted due to the fact that a Li-ion battery factory has an annual production capacity expressed in Gigawatt-hours (GWh).

Figure 6. BNEF 2021 global lithium -ion battery supply chain ranking (BloombergNEF, 2021)**.**



Here's what it means if a factory produces 1 GWh of batteries per year. If we assume that a particular plant produces 100 kWh batteries for a particular electric model, this means that the plant is producing enough batteries to power 10,000 electric cars every year. Of course, the capacity of a battery depends on the requirements of car manufacturers, who are looking for the ideal compromise between range, mass and performance, which is why you won't often find estimates of the actual number of batteries made in a given factory.

Among the few existing Li-ion battery plants in Europe today are the 15 GWh unit developed in Poland by LG Energy Solutions (a division of LG Chem), which is in the process of a major expansion to 65 GWh, and the unit developed by Samsung SDI in Hungary, which had a production capacity of 2.5 GWh when it opened in 2017. Meanwhile, despite being the "engine" of the European economy, Germany has been slow to move up the ladder, and when it has, it has done so with extremely small steps. QuantumScape, an American company whose investors include Volkswagen as well as Bill Gates, owns a 1 GWh plant in Salzgitter, while their compatriots from Microvast operate a 1.5 GWh plant in Brandenburg.

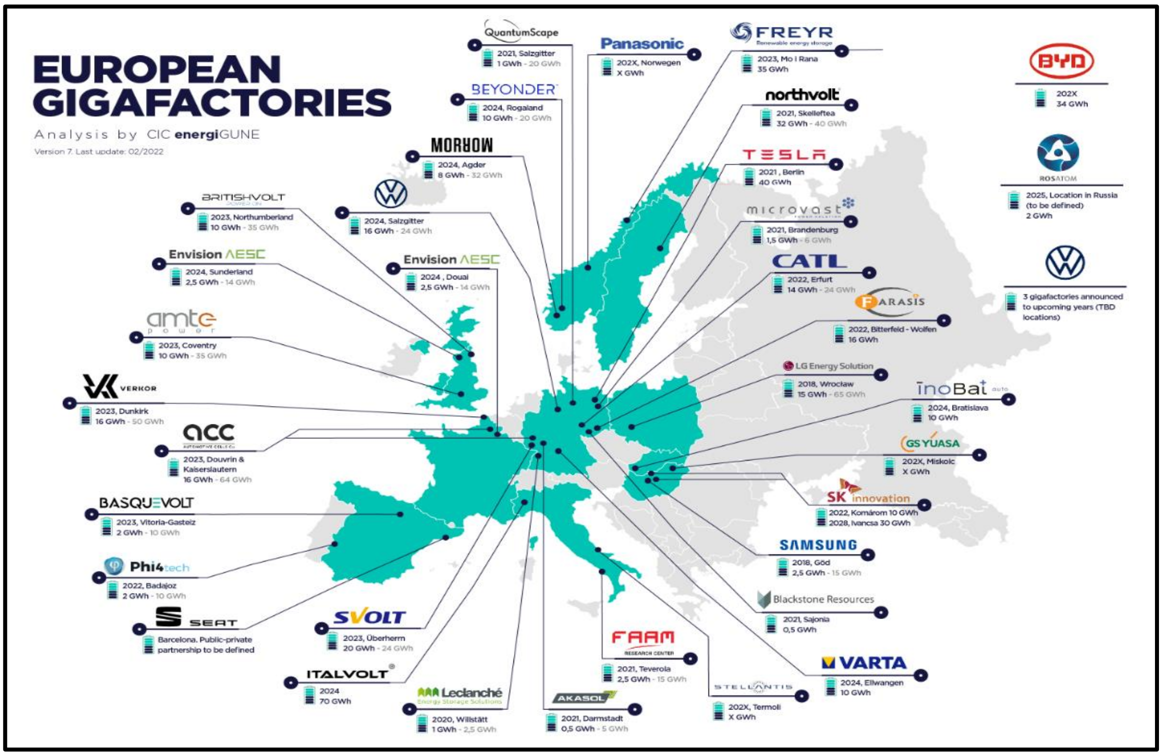
Switzerland's Blackstone Resources has taken experimentation to an even more extreme level by building and commissioning an electric battery factory with a capacity of up to 500 MWh in Saxony (Yilmaz, 2022). In this case, we can't even call it a Gigafactory, if we characterize it by its production capacity and/or power in MWh, compared to the power of factories measuring power in GWh.

After numerous delays and amid environmental controversy, US automaker Tesla opened a new automotive battery factory near Berlin at the end of March (Tesla, 2024). It will have a production capacity of 500,000 Model Y units per year, but more important for our subject is that it will also produce the batteries for this model. Officially known to have a production capacity of 40 GWh, some sources say the real number is 50 GWh. Elon Musk proposed 100 GWh at this date, and for the future expansion to 200 GWh. Indiferent din ce unghi este rpivită problema, un lucru este cert: comparativ cu uzinele de acumulatori auto existente în prezent, Tesla Gigafactory este net superioară la nivel european.

Figure 7 shows the development projects for electric vehicle battery battery factories and plants. The infographic is valid until February 2022, and there will be a series of regular updates thereafter.

The Volkswagen Group, which since the end of last year has had a separate European company dealing strictly with this business. In total, the Volkswagen Group wants to build six electric battery production plants by 2030 (Northvolt, 2021). The first one will be inaugurated in 2025 in Salzgitter - Germany and will initially have a capacity of 20 GWh, which will be doubled to 40 GWh later. This factory will supply electric battery cells for Volkswagen volume models.

Figure 7. Map of Li-ion battery factory projects in Europe (energiGUNE, 2021).



Another plant will be built in Barcelona - Spain under the Seat brand, while the exact locations of three other factories have not yet been decided, but they are said to be located in Eastern Europe, with a decision to be made in the future. The sixth Volkswagen plant is already under construction and is in fact being built by Swedish start-up Northvolt, in which the German group owns a 20% stake. The plant is located in Skellefteå -Sweden, and the first electric battery cells were realized in December 2021 (Northvolt, 2021). Northvolt prides itself on being the first plant to produce batteries fully assembled by a European company, and has an initial production capacity of 32 GWh. The first batteries are to be delivered this year, and customers include premium models sold by the Volkswagen Group. The Swedes at Northvolt have already announced plans for two more battery plants: one in the Borlange region of Sweden , which will reach up to 100 GWh in its final stage, and another of up to 60 GWh in Germany (Northvolt, 2021). The other major carmaker planning such investments is Stellantis, which brings together no fewer than 13 brands, including Peugeot, Citroen and Fiat. For such projects, Stellantis has set up the Automotive Cells Company, which it co-owns with TotalEnergies/Saft and in which the Mercedes Group will be co-opted as a shareholder. As a first step, the current Termoli plant should be capable of producing electric traction batteries for cars with a total capacity of up to 120 GWh of batteries per year by 2030 at the latest (Stellantis, 2022). The other major car manufacturer planning such investments is Stellantis, which brings together no fewer than 13 brands, including Peugeot, Citroen and Fiat. For such projects, Stellantis has set up the Automotive Cells Company, which it owns jointly with TotalEnergies/Saft and in which the Mercedes group will be co-opted as a shareholder. As a first step, the current plant in Termoli should be capable of producing electric traction batteries for cars with a total capacity of up to 120 GWh of batteries per year by 2030 at the latest.

The Chinese at CATL (Contemporary Amperex Technology Co, Limited), the world's largest automotive battery maker, will this year complete a 14 GWh profile plant in Erfurt, Germany (Electrive, CATL boosts battery cell factory in Germany to 100GWh, 2019), which will later be expanded to 24

GWh. For their part, the South Koreans from SK Innovation are betting heavily on Hungary with two plants: at Komarom with 10 GWh from 2022 and at Ivancsa with 30 GWh from 2028 (SK, 2023). Also here, Samsung SDI plans to increase the God plant's capacity from 2.5 GWh to 15 GWh (Electrive, Samsung SDI expands battery production in Hungary, 2024). On the other hand, in addition to the traditional automakers and manufacturers in the field, the electric car battery business has also attracted a number of smaller players in the field. And while Northvolt has teamed up with Volkswagen, others are betting on independence, which also means smaller production capacities. Here are just a few examples: Norway's Beyonder is planning a 10 GWh plant in Regaland by 2024, along with a series of investments in developing a battery using wood sawdust.

Morrow's countrymen to produce 8 GWh of electric batteries/year at angder in Norway from the end of 2026 (Morrowbatteries.com, 2023), while Freyr is debuting a similar project at Mo i Rana in Norway where it will produce up to 43 GWh in 2025 and up to 83 GWh by 2028. Panasonic will also arrive in Norway at some point, but the Japanese have not yet given details about production capacity or starting year. In Bratislava, InoBat promises an initial capacity of 1 GWh in 2024 and two more factories to be built later, one of them in Germany (InoBat, 2022).

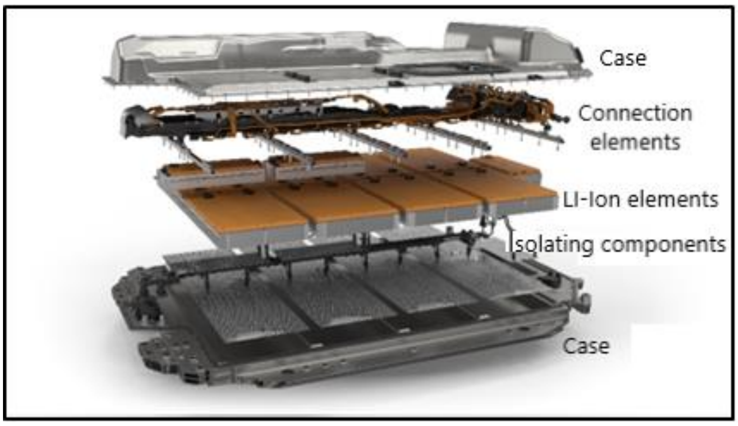
Another large scale project is in the pipeline in Italy, where start-up Italvolt aims to build a 70 GWh capacity plant, while China's Svolt is targeting a 20 GWh plant in Germany (Dunn, 2021). In France, where local companies Verkor and ACC are planning 16 GWh profile factories (ACC, 2022), while in Spain there are also two minor 2 GWh projects. Last but not least, the UK is targeted by two 10 GWh projects by BritishVolt with government funding and Amte Power, both to be completed in 2023.

These are the main factories (plants) producing electric traction batteries for green cars in Europe today. The information has been collected by the author from online and specialized literature following extensive and laborious bibliographical research.

V. RECYCLING OF MATERIALS FROM THE SCRAPPING (DISMANTLING) OF ELECTRIC TRACTION BATTERIES

A big problem of environmental waste pollution is how to recycle used batteries from electric cars. Those working in the automotive industry have identified two broad directions for end-of-life batteries in electric cars: **reuse** and **recycling.** The reuse of such a battery can be integrated in a variety of areas: from putting it into a household or industrial circuit to store energy from sustainable sources, to integrating it into various electrical appliances as a backup power source. Many manufacturers are already doing this and it is no longer a major novelty. Figure 8 shows the composition of a car battery from a BMW i4 car. The picture shows a large amount of recyclable materials with lithium as the basic raw material to be recovered. As a rule, the recovered materials are used in other industries. For example, some manufacturers are already doing this. In particular, Renault together with Veolia and Solvay have been working together for a decade. But for things to go in the right direction, more than one is needed.

Figure 8. BMW i4 body and components battery cells
(Şocariciu, 2022).



In January 2018, the Faraday Institute announced the ReLiB (Recycling of Lithium-Ion Batteries) project, (Figure 9), which is working to identify ways in which electric vehicle traction batteries can be efficiently recycled and thus create a circular economy around electric batteries. Both scientists and specialists have come up with an answer, but we can't expect something simple. Following their experiments, they concluded that physical separation will be an important step in their recycling. This shows that there will be no change in the chemistry and structure of the materials. Then the amount of raw materials that will become available will increase and the production process will be less dependent on extraction. Separation will also take place differently, depending on the materials

All in all, the experts concluded that the physical separation process does not require a lot of energy, operating costs are lower, and the idea behind it is based somewhat on a technology already used in the electronics industry.

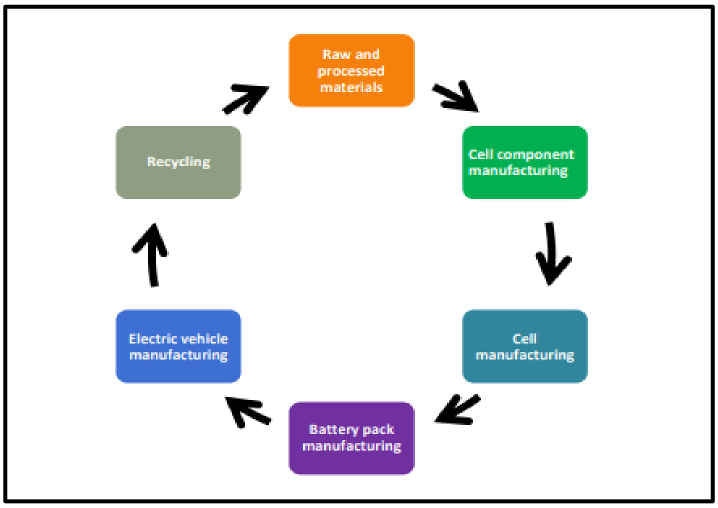
It all starts with the actual shredding of the battery cells (after the electrolytes have been removed). The next step is the separation of ferrous and non-ferrous materials, and for this purpose, specialists have indicated the separator that works on the basis of Focault currents (turbional currents). The process produces three broad categories of products: ferrous metals, non-ferrous metals and inert materials. Then comes the separation of rare earths using, of course, a dedicated aggregate. Simply called the Rare Earth Roll Separator, it uses a series of powerful magnets to generate a magnetic field. The last part of the process is called electrostatic field separation. The process is precise and relies on the conductivity of the materials in the battery structure (Figure 10).

Now all that remains to be done is to scale up the processes mentioned above and make them suitable for the industry. How much it will cost to reuse recycling centers to cope with the new requirements is unknown at this stage. In Romania the process of switching to electromobility is at an early stage. The problems of electric car battery recycling will become more acute in 8-10 years' time, when the electric traction batteries in cars will wear out and then the question of replacing

Figure 9. Scrap car batteries shredded under the ReLib project (Şocariciu, 2022).

Figure 10. Batteries shredded in a separator used by Li-Cycle in Canada (Şocariciu, 2022)**.**

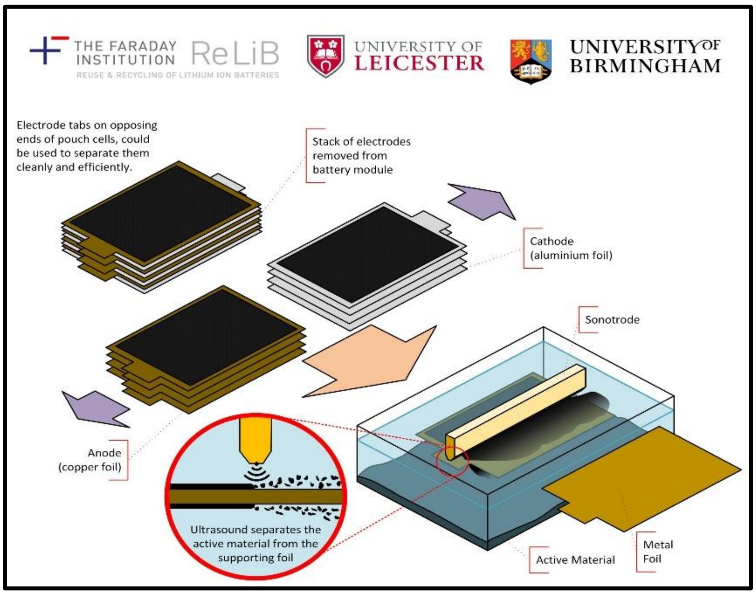
Figure 11. Strategic value chain according to the European Battery Alliance (Commission, 2017)**.**



them will arise. The projects continue, and the people involved in the ReLiB program have even recently identified an ultrasonic recycling method.

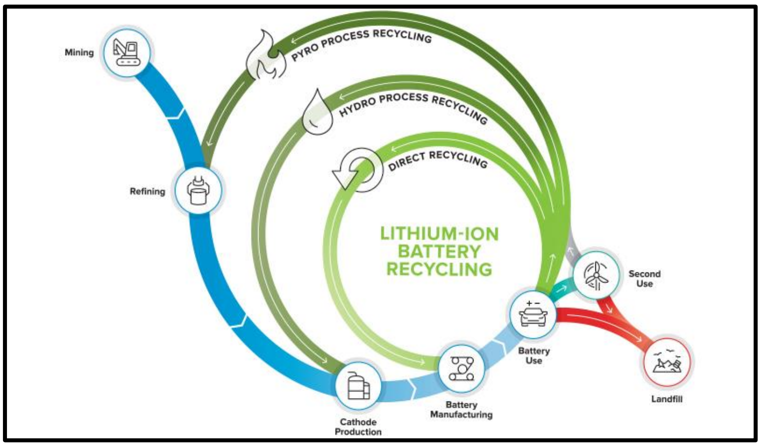
The European Union has set itself ambitious targets to recycle all electric traction batteries in cars in all EU countries by 2025, and has allocated billions of euros in state aid to attract investment in the battery supply chain. At first sight, the above objective seems utopian if we look at the current situation in the market for Li-ion batteries for electric cars. Currently, China hosts 80% of the global production capacity for Li-ion batteries for electric cars, and in the next 5 years this capacity will more than double to more than 2 TWh.

Figure 12. The American ReCell project (Şocariciu, 2022)**.**



However, at the European level, a wide-ranging program has already been launched with the ultimate goal of meeting the entire demand for electric car batteries through in-house production. It all started in 2017, when the European Battery Alliance was set up (Commission, European Battery Alliance, 2017), an association of EU national authorities, research institutes and manufacturers in the battery supply chain. Figure 11 shows the strategic value chain according to the European Battery Alliance. Over the past year, however, the alliance's activity has become much more intense. On the one hand, the semiconductor crisis affecting the production and sales of new cars has convinced Europe that it needs its own production facilities, whether for semiconductors or Li-ion batteries. On the other hand, the war unleashed by Russia in Ukraine is prompting Europe to look for new sources for raw materials and, at the same time, is generating much speculation about China's economic and political interests in favoring a trade relationship with Russia at the expense of the European Union and the United States. The latter is now very important in the context of China's 80% market share of electric car battery production.

Figure 13. The recycling model identified by ReCell (Şocariciu, 2022).



In the case of electric cars, things are currently a bit more complicated as recycling is a challenge due to the variety of raw materials used for the cathode. Recycling processes for Li-ion batteries also involve major costs for various solutions to separate cobalt, nickel and magnesium. In fact, the IEEE (Institute of Electrical and Electronics Engineers) Spectrum association estimates that only 50% of Li-Ion automotive batteries in electric vehicles were recycled in 2019. In that year, the total amount of Li-Ion batteries scrapped from the automotive industry was 180,000 tons. There are currently about 100 battery recycling companies globally, but most are in China and South Korea, the main producers of Li-ion batteries, according to data compiled by consultancy Circular Energy Storage (Popescu D. , 2022).

The Americans haven't ignored the recycling issue either, and the US Department of Energy recently invested $15 million in the ReCell Center. Basically, a project has been set up to coordinate studies by scientists, industry and laboratories (Figure 12). Linda Gaines, is one of the scientists directly involved in the project. She has identified a complete process by which batteries can be integrated into the circular economy (Figure 13). To shorten the radius of the circle as much as possible, according to her, direct recycling would be most ideal.

VI. POLLUTION FROM RAW MATERIAL EXTRACTION

One of the issues with the materials used in Li-ion batteries is the sustainability of the extraction process. From the mines, the materials go through a refining process and then on to the factories that produce the cathode. Only then come the factories that produce and assemble the batteries. The extraction of raw materials of all kinds, whether for use in car batteries or any other devices, generates emissions of carbon dioxide and other harmful substances that affect the environment both locally and globally. For example, extraction processes usually result in waste products containing chemicals, which if not properly managed can lead to soil and water contamination. In addition, extraction processes require large amounts of water, and in many areas rich in essential raw materials, drinking water supplies are limited, a problem that is exacerbated globally by global warming. One of the issues related to the materials used in Li-ion batteries is the sustainability of the extraction process. Cobalt, nickel and lithium are extracted using methods that are harmful to the environment, and there has always been a social issue about how these processes take place. Of course, in recent years there has been continued investment in developing cleaner extraction methods, but the industry is still looking for solutions to the problem (Șocariciu, 2022). Such problems have frequently led to protests from local people who feel directly threatened by such operations. A similar problem has also arisen in Europe, as a section of the population in the Hungarian city of Debrecen is against a project in which CATL, the world's biggest producer of batteries for electric cars, wants to invest over 7 billion Euro in a Li-ion battery factory for electric cars (France24, 2023). Calculating the exact emissions generated in extraction processes for raw materials is difficult due to the different technologies used. However, according to some studies, the extraction of 7 kilograms of lithium, enough to produce a Li-ion battery, generates about 120 kilograms of carbon dioxide into the atmosphere. That's not a lot when you consider that many cars with internal combustion engines emit more than 120 grams of carbon dioxide per kilometer - the equivalent of 120 kilograms for every 1,000 kilometers driven.

6.1 **The carbon footprint of extracting the raw materials needed to make an electric battery**

In order to be extracted or processed, all these raw materials require procedures that generate carbon dioxide emissions. Whether we are talking about an electric or heat engine, the emissions from the extraction and/or production of raw materials such as steel, plastic or glass are in principle similar. The differences are in the emissions from the extraction of the raw materials needed for the production of batteries in electric cars and the production of gasoline and diesel respectively. This is because cars with internal combustion engines use gasoline or diesel throughout their lifetime, and these fossil fuels are based on petroleum as a raw material, the extraction of which and conversion into gasoline and diesel generates, you guessed it, carbon dioxide emissions.

In recent years, the automotive industry has been plagued by eternal controversy about what generates higher emissions. It is not known which pollutes more, lithium, cobalt and nickel mining or oil extraction. There are numerous studies on the subject and, having pieced the information together, the conclusions are quite clear. The study carried out by the non-governmental organization Transport and Environment shows that, over its lifetime, a car with a thermal engine consumes and burns on average about 17,000 litres of gasoline or 13,500 litres of diesel fuel (AMT, 2021). According to independent research by Stanford University researchers (StandfordReport, 2018) and a group of researchers who published the results in the Science Direct editorial (Gavenas, Rosendahl, & Skjerpen, 2015), extracting the amount of oil needed to produce one liter of fuel (gasoline or diesel) generates 370 grams of carbon dioxide. Thus, if we consider the consumption of 17,000 liters of gasoline over the lifetime of a car with a thermal engine, the use of this type of fuel generates 6,300 kilograms of carbon dioxide just for its extraction and production (without taking into account emissions during the actual use of the car). On the other hand, the metals used to make a battery for an electric car weigh about 160 kilograms, of which 130 kilograms can be recycled, so only 30 kilograms of metals are lost. A typical electric car battery has about 8 kilograms of lithium, 35 kilograms of nickel, 20 kilograms of magnesium and 14 kilograms of cobalt, according to data in a study by Nature (Castelvecchi, 2021).

At the same time, data from the consultancy Minviro cited by the BBC show that extracting one kilogram of lithium releases between 5 and 15 kilograms of carbon dioxide into the atmosphere, depending on the type of mining (underground reservoirs or quarries). For example, extracting the 8 kilograms of lithium needed for an electric car battery releases about 120 kilograms of carbon dioxide into nature. In short, extracting the oil needed for a car with a thermal engine over its lifetime generates 6,300 kilograms of carbon dioxide, compared with only 120 kilograms of carbon dioxide generated by extracting the lithium for the battery. Clear advantage for electric cars..

6.2 **The carbon footprint of electric car manufacturing**

In the following, I will present what the carbon footprint is for each electric car manufactured. In 2020, the production process generated 560 kg of CO_2 per electric car that left the factory gates in Europe (ACEA, 2023). As an example, for an average value calculated by ACEA (European Automobile Manufacturers Association), association which was founded in 1991, on the basis of individual data submitted by car manufacturers, including both cars with internal combustion engines and electric cars.

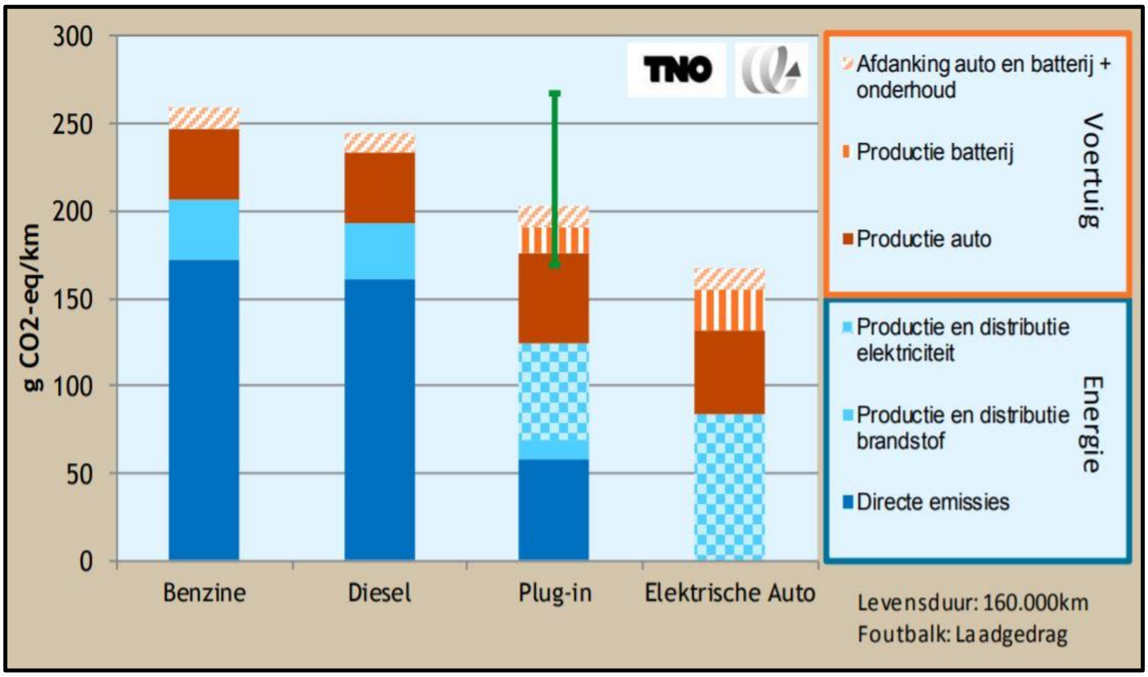
But there are significant differences between brands. At the 2019 level, the average emissions/vehicle for the BMW Group was 400 kilograms of CO_2, significantly less than the 490 kilograms per Nissan unit, or the 720 kilograms average recorded by Volkswagen. ACEA notes that together, all cars produced at plants in Europe generated a total of 6.66 million tons of CO_2 in 2020, down 49% from 2005. This halving in the amount of carbon dioxide from production came despite the fact that annual output of road cars varied less. For example, 12.4 million road cars were produced in Europe in 2009, 14 million in 2019 and 10.8 million in 2020 (a sharp drop caused by plant closures in the first part of the year after the outbreak of the coronavirus pandemic). Thus, the dramatic drop in total emissions, despite relatively constant annual production, was due in the end to significant investments by European car manufacturers, which led to a significant decrease in total emissions. road emissions varied less.

So, when calculating the amount of CO_2 produced by a car, whether it is a combustion-engined or an electric car, not only the CO_2 emissions during use, but also the emissions generated during production, must be taken into account. The production of an electric car is less environmentally friendly than that of an internal combustion engine car, and the level of emissions from electric vehicles varies depending on how the electricity that powers the car is produced. However, considering the average energy mix in Europe, electric cars are proving to be cleaner than those that burn fossil fuels to produce the energy needed for propulsion. As the share of electricity from renewable sources increases in the future, electric cars will become even more environmentally friendly.

6.3 **Carbon footprint of electric cars**

A combustion-engined car has carbon dioxide emissions and, as you probably know, for every model they put on the market, manufacturers are obliged to state the emissions figure. According to the latest ACEA report, new cars sold in Europe last year had average emissions of 122.3 grams of carbon dioxide per kilometer, but this includes electric carsBut researchers at the University of Delft in the Netherlands have carried out an extensive emissions study broken down by the type of propulsion of road cars (Figure 14) (Gijlswijk, Koornneef, Essen, & Aarnink, 2014). The study found that, on average, a gasoline-engined car actually emits about 170 grams of carbon dioxide per kilometer during use, while diesel cars emit around 155 grams of CO_2. In contrast, electric cars with Li-ion batteries emit no carbon dioxide in use. However, the electricity charged in electric car batteries does not come entirely from renewable sources. For this reason, accurately calculating carbon dioxide emissions from the electricity production process is difficult because they differ significantly from country to country, depending on the country's energy mix. Researchers at Delft University have calculated that an average electric car emits about 80 grams of carbon dioxide per kilometer during use (emissions "generated" in the production of the electricity, not by the car itself).

Figure 14. A car's total emissions by type of propulsion (Popescu D. , 2022)**,** (Gijlswijk, Koornneef, Essen, & Aarnink, 2014, p. 11)**.**

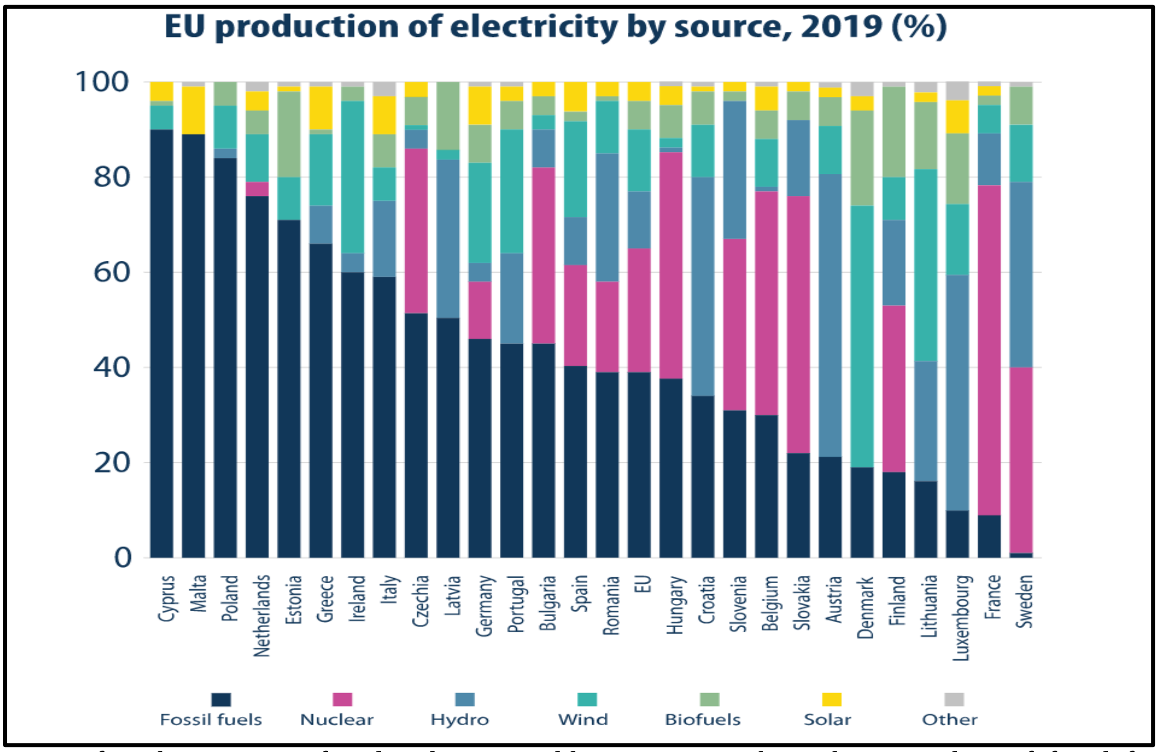


If we work with a scenario where a car is used for about 10 years and the owner drives about 20,000 kilometers per year, this means that a car with a combustion engine will emit on average about 34 tons of CO_2 into the atmosphere over its lifetime. In contrast, based on the same scenario, an electric car produces a total of about 16 tons of carbon dioxide from electricity generation. Another important point worth mentioning here is that electric cars do not pollute at all in cities, as the electricity they use is usually generated far from populated areas. On the other hand, cars with internal combustion engines generate carbon dioxide and other harmful substances, especially in large conurbations. In this sense, my personal view on electricity sources is that, in order to prove their efficiency in the transportation market, green cars need to be powered by and use green, renewable energy. Otherwise, they are considered to be polluting in the same way as cars with conventional engines. Unconventional energy refers exclusively to clean, renewable sources and not to fossil fuel power factoris.

In Romania, it is now an easily achievable goal. Its geographical position, climate and topography fully allow it. Green energy is very important for powering electric cars. Be it from a wind power plant, wave, tidal, hydro or solar power, the important thing is that it is transported and routed to the filling stations of green cars, stored in batteries and converted into mechanical work by their engines, thus meeting people's mobility needs in a greener, cleaner and more efficient way. Renewable sources of energy from wind, sun, water, the seas and oceans, geothermal energy for electric-powered transport, then biomass and biofuels for heat-driven transport, are the basic alternative to fossil fuels and underpin clean and green automotive transportation. These two terms have features in common and are to some extent interdependent, as both are based on the use of renewable energy sources. Clean, green energy represents the triumph of human development against the harmful chemicals and noise produced by road transportation.

According to an analysis by Visual Capitalist, apart from Romania, hydroelectricity dominates production in Austria, Albania, Montenegro, Sweden, Norway, Iceland, Portugal, Sweden, Norway and Iceland. Coal dominates in Turkey, Bulgaria, Serbia, Northern Macedonia, Kosovo, the Czech Republic, Poland, Germany, Poland. Nuclear dominates in France, Finland, Switzerland, Belgium, Belgium, Slovakia, Hungary, Hungary, Ukraine, until the start of the war in Ukraine. According to the source, Europe has made a steady transition to renewable energy sources, making considerable progress over the last decade. In 2011, fossil fuels (oil, natural gas and coal) accounted for 49% of the EU's electricity production, while renewable energy sources accounted for only 18%. Figure 15 shows Europe's electricity generation by source in percent (%) for 2019. Hydropower plants have the highest share in electricity production in Romania.

Figure 15. EU production of electricity by source, 2019 (%) (Popescu D. , 2022)**.**



After the passage of a decade, renewables are approaching the equivalent of fossil fuels (renewables - 32% of EU electricity generation compared to 36% - fossil fuels in 2021). The expansion of wind and solar generation have been the main drivers in this process, going from generating only 8% of EU electricity in 2011 to 19% in 2021.

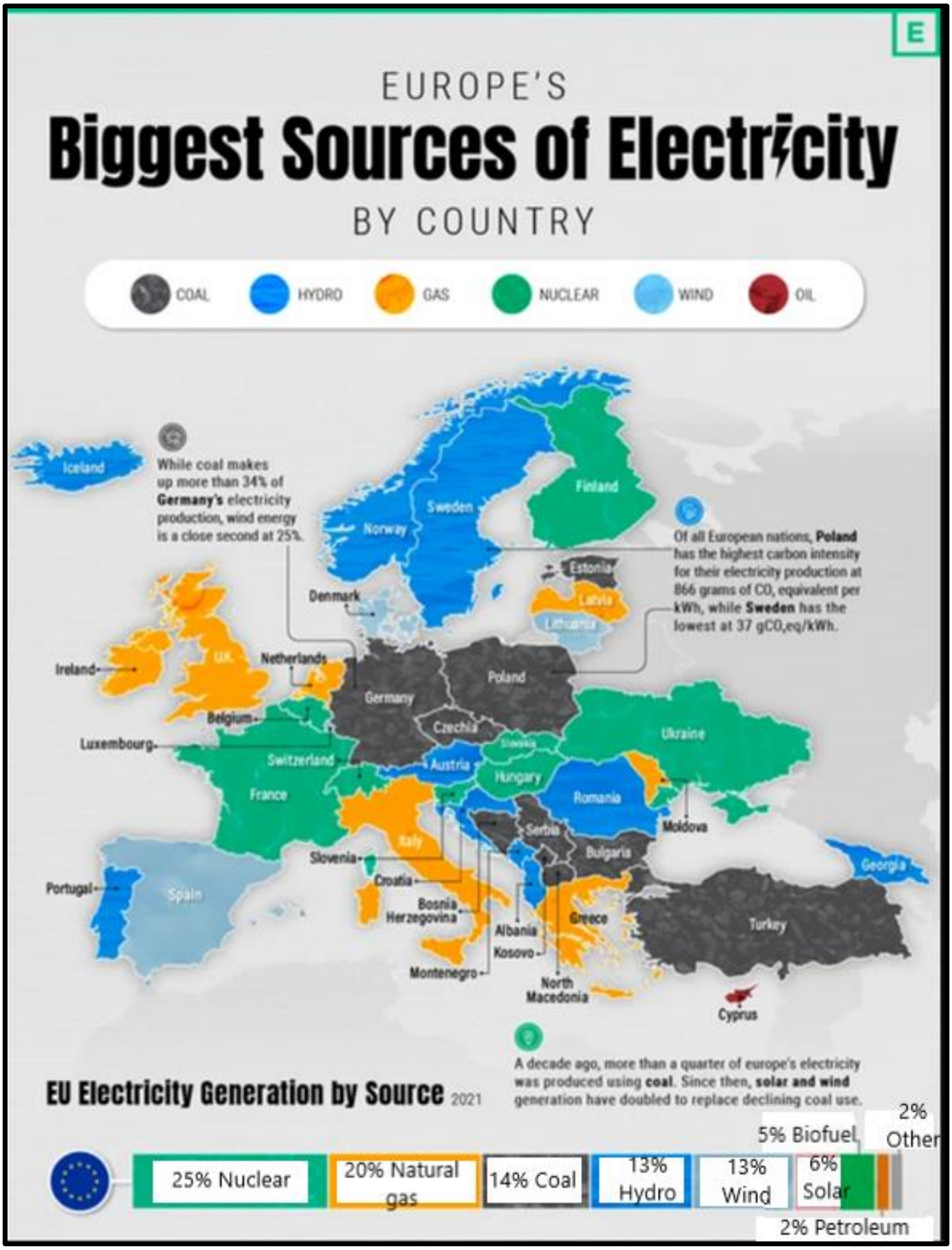
In 2001, nuclear power accounted for a third (33%) of the EU's electricity generation, falling to 25% over the next 20 years. Electric cars reduce brake pollution. First, conventional cars with internal combustion engines mainly use disc brakes and engine brakes to slow down, and they emit ultrafine particulate pollution (PM 2.5). Electric cars, on the other hand, are able to use less disk brakes and more electric motor braking (regenerative braking) to slow down, reducing the need to use brakes and therefore reducing particulate emissions

Pollution from tires comes from all cars. When it comes to pollution from tires, many reports suggest that the switch to electric cars will increase particulate pollution due to their heavier weight compared to conventional cars. However, extensive studies have measured particulate emissions from electric cars. Electric cars are mostly equipped with specially designed tires, which are aerodynamic, thinner and are reinforced to cope with specific needs, including the higher weight.

At this time, mankind is constantly searching for energy sources to replace the harmful ones that will soon run out. Its widespread use helps to stop pollution, reduce the contamination of the air we breathe and substantially reduce greenhouse gas emissions. Clean, green energy is much cheaper than burning carbon-based fuels. Renewable energy is derived from sources that have the capacity to replenish, regenerate, are not tied to specific areas of the globe and are not finite like fossil fuels.

Figure 16 shows the largest sources of electricity across European countries in 2023. Although this might still seem small, the EU's share of wind and solar electricity generation ranks alongside Oceania as the largest in comparison with other regions of the world. While hydropower does not have as large a share as other sources, it is the most common primary source of electricity generation in Europe, playing an important role in renewable energy supply. Nuclear power is the largest single source of electricity generation in the EU and Europe as a whole, despite its decline over the last two decades.

Figure 16. 2021 Europe's biggest sources of electricity by country (Adevărul.ro, 2023)**.**



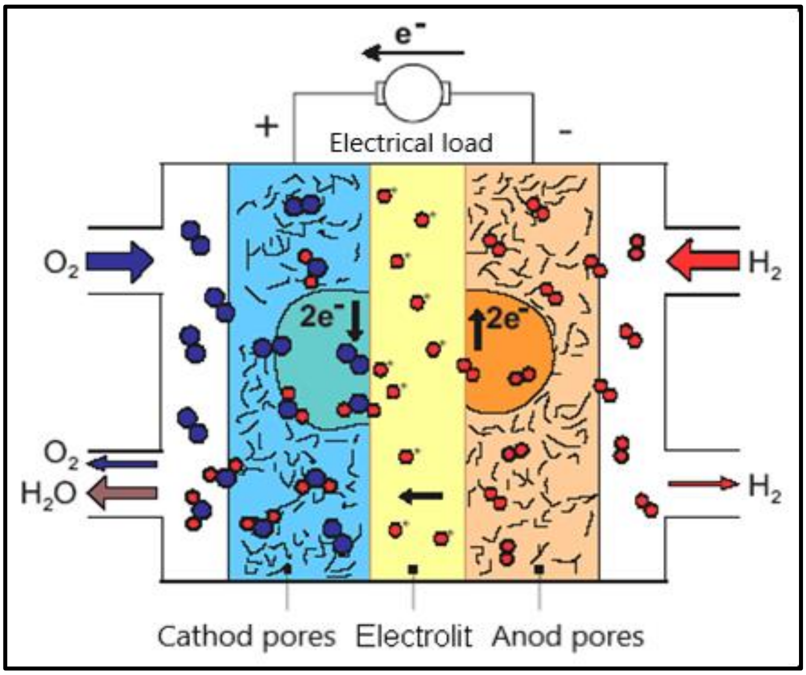
VII. THE HYDROGEN FUEL CELL AUTOMOBILE VERSUS THE ELECTRIC AUTOMOBILE. CASE STUDY

The idea of obtaining electrical energy by direct conversion of chemical energy arose when the problem arose of reverse electrolysis of water (which produces the components of water), i.e. obtaining electricity from the reaction between hydrogen and oxygen. In 1801, Davy achieved this by using carbon as a fuel and nitric acid as an oxidizer. The research was continued by Ostwald Nerst, Haber etc. because the direct conversion of chemical energy into electrical energy avoids the thermal energy link and hence the conversion efficiency does not depend on Carnot limits. Fuel cells can be framed as *"soft"* energy systems due to the following characteristics:

- produce continuous electricity (DC) at low voltages and medium currents that can be used directly by end-users;
- do not pollute the environment;
- operates quietly, without vibration or noise, no moving parts, etc.

In principle, the energy released in the oxidation of conventional fuels, generally used as heat, can be converted directly into electricity with excellent efficiency in a fuel cell. Since in almost all oxidation reactions there is a transfer of electrons between the fuel and the oxidant, it is obvious that the chemical energy of oxidation can be converted directly into electrical energy. An oxidation-reduction reaction occurs in which oxidation of the fuel and reduction of the oxidizer take place with a loss of one and a gain of electrons for the other. Any galvanic element involves oxidation at the negative pole (loss of electrons) and reduction at the positive pole (gain of electrons) and, as with all galvanic elements, fuel cells tend to separate the two partial reactions in the sense that the exchanged electrons pass through a cxternal utilization circuit.

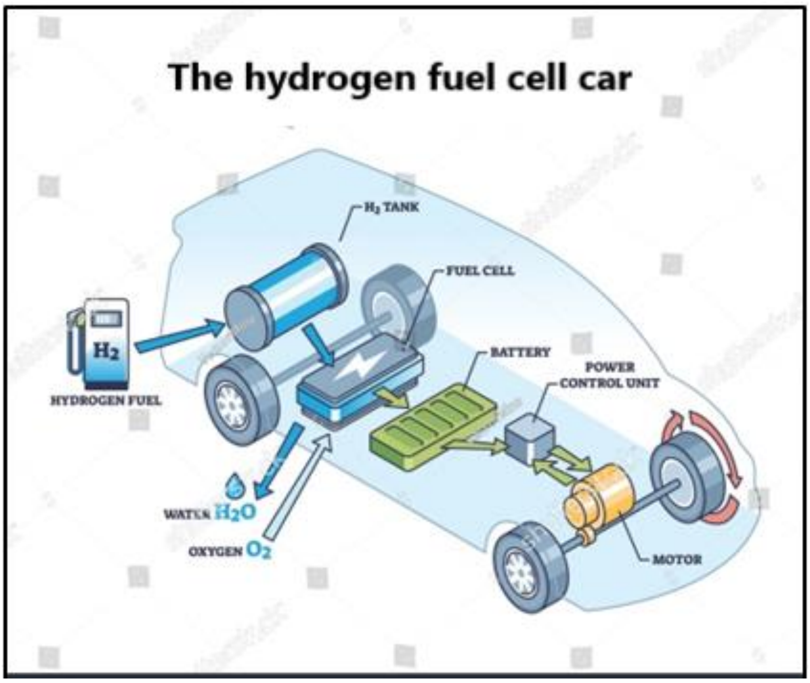
Figure 17. Schematic of how a hydrogen fuel cell works.



To ensure this process takes place, it is essential to realize an element containing an anode, a cathode and an electrolyte that can be directly supplied with a fuel and air (Figure 17). The oxygen required to burn the fuel is ionized at the cathode; the ions then migrate into the electrolyte to reach the anode where oxidation of the fuel takes place. I will now explain how a fuel cell works, using as an example the simplest fuel cell that works with oxygen and oxygen HYDROGEN - OXYGEN COMBUSTION CELL. The irreversible kinetic processes associated with a fuel cell consist of a series of oxidation-reduction reactions.

A fuel **A** is transported to the porous anode where it is absorbed on its surface, then dissociated into ions and electrons in an oxidation process. After that, the migration of electrons from the anode and the release of ionic gas at the anode surface takes place. In the electrolyte, the transport of $\mathbf{A^{Z+}}$ ions from the anode to the cathode must be ensured against the resulting electric charge on account of the electrochemical impressed field. At the cathode, ions (arriving via the electrolyte), electrons (arriving via the external circuit) and oxidant **B** meet. The reduction reaction takes place, resulting in the reaction product to be removed, water, which is removed through the vehicle's exhaust pipe. The fuel cell therefore consists of three elements: the electrolyte, the electrodes and the reactants (a fuel and an oxidizer). The catalytic oxidation-reduction phenomenon occurs in three phases (gas-liquid-solid), according to the overall reaction $H_2 + ½O_2 => H_2O$, and takes place at the surface of the catalyst. Individual fuel cells produce relatively low electric potentials (about 0.7 V) and the cells are usually connected in series to provide higher voltages or in parallel for high current with low voltage applications. In general, the output voltage of a fuel cell decreases as the current load increases, due to several factors including activation loss (a fundamental electrochemical phenomenon), internal resistance (analogous to the internal resistance of the battery), and mass transport losses due to the depletion of reactants at the anode and cathode under high current conditions. In addition to electricity, fuel cells produce water, heat, and very small amounts of other emissions. Hydrogen fuel cells for cars are designed to last for a lifetime of about 250,000 to 350,000 kilometers, while electric batteries have a lifetime expressed in recharge cycles, i.e. 1,000 and 1,500 recharge cycles, before the range starts to decrease. Compared with electric batteries, the autonomy of hydrogen fuel cells will never deteriorate. It remains constant throughout its lifetime. Once they have completed their lifetime, both fuel cells and electric batteries can be disassembled and the materials recycled.

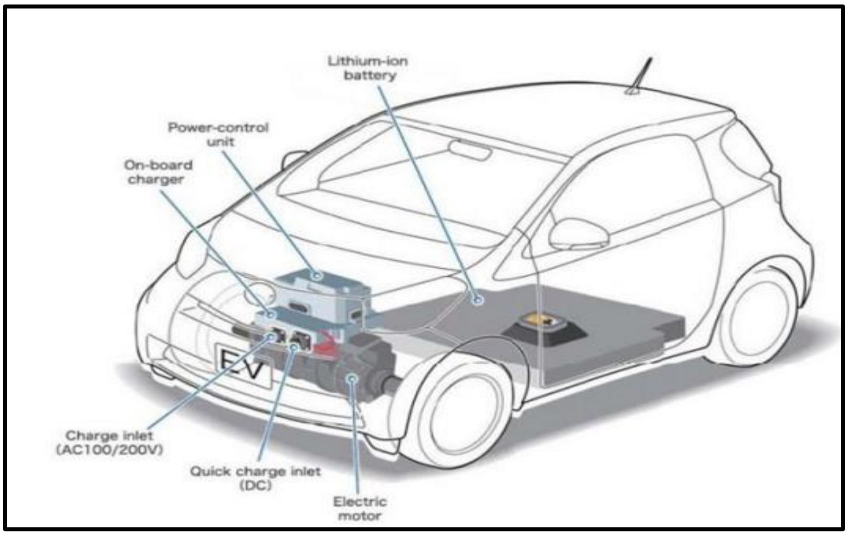
Figure 18. Principle diagram of an hydrogen fuel cell vehicle.



The operating scheme of a hydrogen fuel cell vehicle is shown in Figure 18.

See how the electric car works (Figure 19). Very briefly, the electric current from the battery and monitored by the (BPCM- Battery Pack Control Module) reaches the Power Control Unit from where the electric motor is energized as needed via the slider (accelerator pedal). Before the battery is completely discharged, the on-board Low SHOOC (Low State of Charge) is signaled similar to a combustion engine car where the fuel level reaches *"red"*. It's time to charge the battery via the On board charger which takes alternating current directly from the socket/mains (or charging station) and converts it into direct current for the battery.

Figure 19. Principle diagram of an electric vehicle (EV).



Knowing the working principles, advantages and disadvantages of the two propulsion systems of the future green car, in order to ensure a sustainable future of the modern, efficient and effective road transportation system, it is the personal opinion of the author of this paper that hydrogen will remain the energy source that will save electromobility. The hydrogen fuel-cell car will gain the lead over the electric car, with all the impediments of hydrogen's dangerous handling, storage and use.

I justify this affirmation by the following: at the moment, the range aspects of electric batteries are evolving slowly, and when taking into account factors such as low temperatures in winter (significantly decrease the capacity of an electric battery), driving at high speed, sudden acceleration of the car and going up ramps (quickly consumes battery energy), use of air conditioning in winter and air conditioning in summer (substantial energy consumption), and finally the physical wear and tear over time of the electric battery (similar to the electric battery in a cell phone, which, due to wear and tear, decreases in capacity over time), make the electric car unattractive. Add to all this the dependence on electric charging stations (in our country, few in number, located in the parking lots of large stores in urban areas and almost non-existent on highways, expressways or national roads). It is also easier and more comfortable for us, like any other user, to fill up the tank with gasoline or diesel and drive 1,000-1,200 km without stress and without worrying about refueling. At the moment, the hybrid car provides the greatest comfort from this perspective, but it is important to bear in mind that carbon-based fuels will soon run out. Research on hydrogen fuel cell cars will need to be stepped up. The safety of hydrogen involves technology, and this costs more than research into developing the autonomy of electric batteries to date. A hydrogen fuel cell is more reliable, has a longer lifespan, but is more expensive compared to an electric traction battery.

The cost prices of raw materials for manufacturing electric batteries, such as lithium, cobalt and nickel, as well as the cost price of electric battery components, have pushed up the value of energy packs to 151 USD/kWh. This is a 7% increase in 2022 compared to 2021. Their prices are expected to increase in the following years (152 USD/kWh in 2023 and so on). The electric car industry argues that the price of $100/kWh for an electric traction battery is the benchmark at which the electric car becomes competitive with the conventional, heat-engined car. Since the beginning of 2021, the price of the raw materials from which electric batteries are made have risen enormously (lithium has risen by about ten times, nickel has risen by over 74%, and the price of cobalt has doubled since 2020). All these increases become a big problem for the green car market. It is believed that these increases would have been even higher if the Chinese market had not stepped in with cheaper lithium iron phosphate (LFP) battery packs, which have a shorter range. By 2022, energy demand for manufacturing electric cars in the global market has doubled to 603 kWh for Li-ion materials. For this reason, an acute shortage of semiconductors was observed in 2022 and some electric vehicle manufacturers had to reduce their production. The cost price of electric battery packs on the world market varies significantly, so that in China the price is 127 USD/kWh, while in the USA the price has reached 157 USD/kWh, and in Europe the price has reached as high as 169 USD/kWh.

VIII. CONCLUSIONS

To reduce the emissions associated with the extraction of battery raw materials, one solution is to recycle used batteries. For this reason, the European Union has set a target that 65% of the mass of a battery produced in 2025 should contain recycled materials, rising to 70% in 2030. In addition, there are requirements for various raw materials: in 2030, batteries must contain at least 12% recycled cobalt and 4% recycled nickel and lithium, rising to 20%, 12% and 10% respectively in 2035. At the same time, many companies are working on different ways to recycle batteries, but the procedures are complex and require major improvements to become truly efficient.

In the long term, even lithium is likely to decline in importance in this field if researchers currently developing sodium-ion batteries solve their main problems: low energy density and low number of charge cycles.

An even more promising solution from a technical point of view is solid-state batteries, which charge in as little as 10 minutes but have a very low number of charge cycles. They have a lower mass but use largely the same raw materials as NMC Li-ion batteries.

Another method is for car manufacturers to choose their raw material suppliers also according to the processing methods they use. Adopting such a strategy is difficult as there are many intermediaries in the supply chain and contracts have confidentiality clauses.

A number of manufacturers have therefore developed blockchain projects in recent years in order to have a clear record of the raw material supply chain. Blockchain technology has been chosen because it allows data to be stored securely in a decentralized and transparent way in a network of computers that can be accessed by all who are granted access.

The major German car manufacturer Volkswagen has launched a project to make the process by which raw materials get from the point of extraction into cars completely transparent. In its initial phase, the project is being used to study how lead gets from galena deposits (a natural lead sulfide from which lead is extracted) to the higher stages of car production.

In contrast, BMW and Ford are using blockchain to ensure cobalt resources come from the most environmentally friendly sources, while Mercedes and Volvo also have plans to use the technology.

Over time, all of these methods will reduce emissions associated with the extraction of key raw materials over time, in line with the move away from raw materials such as cobalt as Li-ion LFP batteries gain increasing market share. However, as in many other industries, the complete elimination of emissions is almost impossible, at least with currently available technologies.

According to studies cited by researchers at the Massachusetts Institute of Technology (MIT), about 80% of a car's total mass is recycled after it is taken out of use. Tires, windshield, steel, iron, wheels, radiators, transmission, seats or belts are mostly recycled, while engine components are cleaned and reused. The rest of the bodywork is pressed and shredded and, if it were cube-shaped, would be smaller than a microwave oven. Although the data was collected in the United States, the study found that over its entire lifetime, from raw material extraction to decommissioning, an electric car emits 45% less carbon dioxide than a car with a combustion engine, while a hybrid car (whether a classic hybrid or plug-in hybrid) emits 27%-28% less carbon dioxide than a car with a combustion engine only.

A similar conclusion can be drawn from the Delft University study mentioned above. The Dutch researchers concluded that during the entire chain from raw material extraction to recycling, a gasoline-engined car emits the equivalent of about 260 grams of carbon dioxide per kilometer, compared to about 245 grams for a diesel car or 200 grams for a plug-in hybrid. Meanwhile, an electric car emits the equivalent of about 170 grams of carbon dioxide per kilometer. If the energy that powers the batteries of electric vehicles comes from sources other than renewable, clean, green, clean energy sources, the electric car is more polluting than the combustion-engined car.

The impact of lithium based batteries is remedied within about 2 years. This is why using an electric car continues to be a better environmental alternative to gasoline/petrol cars until their battery reaches the end of its life cycle.

Electric cars are 30% heavier and wear out tires faster, with tire emissions 400 times more toxic than exhaust emissions from internal combustion engines. However, the electric car remains the best option for reducing environmental pollution and is a viable, sustainable and durable alternative for human transportation needs.

In Romania, the electric car is currently making its debut. Its electric batteries will soon wear out and need to be replaced. The problem of dismantling (scrapping) them arises, and specialists are thinking about and looking for solutions to the problem. This will require urgent investment.

Both electric and hydrogen fuel cell cars are efficient only as long as their direct energy source (electricity and hydrogen) is obtained from clean, green, renewable sources. Due to the low autonomy of the battery that provides the energy for the propulsion system, electric cars are currently only efficient in urban environments. As a result, these cars are not attractive to the general public. There are also electric cars with a longer range (600-800 km), which could provide greater efficiency for extra-urban driving, but they are expensive (€ 50-80,000). Although the authorities in the European countries offer substantial eco-bonuses (€10,000) for the purchase of a new electric car, not everyone will have access to one.

The danger that hydrogen presents in use (transportation, transportation, storage), as well as the lack of infrastructure for its production and distribution, makes the hydrogen fuel cell car unattractive in Europe and Romania.

In addition to electricity, fuel cells produce water, heat and very small amounts of other emissions. The energy efficiency of a fuel cell is generally between 40-60% but if waste heat can be usefully applied, efficiencies of up to 85% can be achieved. Hydrogen fuel cells demonstrate their efficiency only if the hydrogen used for combustion is obtained from renewable sources (e.g. water electrolysis).

REFERENCES

[1] G. Neamțu, Contributions regard integration knowledge management in the sustainable development of automotive transportation - PhD Thesis, N. U. o. S. a. T. P. Bucharest, Ed., Bucharest: National University of Science and Technology Politehnica Bucharest, 2023, p. 499.

[2] G. Neamțu, L. Tarnu and A. Țîțu, "European policy on the quality of the environment in the context of the sustainable development of the road transport system," in *QIEM – ICNcT 2021, 18-19 November, Quality and Innovation in Engineering and Management & International Conference of Nonconventional Technologies, Series: Applied Mthematics, Mechanics, and Engineering*, Cluj-Napoca, 2022.

[3] European Commission, „Resilience of critical raw materials: mapping a model for improving security," European Parliament, Brussels, 2020.

[4] J. Burton, "U.S Geological Survey Releases 2022. List of Critical Minerals," USGS, science for changing world, 22 February 2022. [Online]. Available: https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals. [Accessed July 25, 2024].

[5] AMT, "From dirty oil to clean batteries. Batteries versus oil: a systematic comparison of materials requirements," AMT, March 2021. [Online]. Available: https://te-cdn.ams3.cdn.digitaloceanspaces.com/files/2021_02_Battery_raw_materials_report_final.pdf. [Accessed 25 July 2024].

[6] Ford, "LFP batteries to expand powertrain choice for Mustang Mach-e as Ford increases battery production capacity," Ford Media Center, 16 February 2023. [Online]. Available: https://media.ford.com/content/fordmedia/feu/en/news/2023/02/16/lfp-batteries-to-expand-powertrain-choice-for-mustang-mach-e-as-.html. [Accessed July 25, 2024].

[7] D. Popescu, „Solid-state batteries: the last hurdle?," AUTO CRITIQUE, 14 February 2022. [Interactiv]. Available: https://www.autocritica.ro/green-zone/bateriile-solid-state-ultimul-obstacol/. [Accessed August 1, 2024].

[8] T. Vranken, "Critical raw materialsin Li-ion batteries," InnoEnergy, 2023. [Online]. Available: https://www.innoenergy.com/uploads/2023/01/critical-raw-materials-in-li-ion-batteries.pdf. [Accessed 29 July 2024].

[9] Bursa.ro, „Romania's Strategy for Non-Energy Mineral Resources for 2023-2035 to be approved today," Bursa.ro, 15 March 2023. [Interactiv]. Available: https://www.bursa.ro/strategia-romaniei-pentru-resurse-minerale-neenergetice-pentru-perioada-2023-2035-va-fi-aprobata-astazi-81762949. [Accessed March 25, 2024].

[10] M. o. Economy, "Romania's strategy for non-energy mineral resources Horizon 2035," Ministry of Economy, 10 June 2022. [Online]. Available: https://www.mmediu.ro/app/webroot/uploads/files/STRATEGIE-%20orizont%202035.pdf. [Accessed July 25, 2024].

[11] Statista, "Chemical and Resources. Leading countries based on nickel reserves worldwide as of 2023," Statista, 21 May 2024. [Online]. Available: https://www.statista.com/statistics/273634/nickel-reserves-worldwide-by-country/. [Accessed July 25, 2024].

[12] U. G. Survey, "Manganese," U.S. Geological Survey, Mineral Commodity Summaries,, January 2021. [Online]. Available: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-manganese.pdf. [Accessed July 25, 2024].

[13] Bloomberg, "China Could Control a Third of The World's Lithium by 2025," Bloomberg, 13 March 2023. [Online]. Available: https://www.bloomberg.com/news/articles/2023-03-13/china-could-control-a-third-of-the-world-s-lithium-by-2025. [Accessed July 25, 2024].

[14] BloombergNEF, "U.S. Narrows Gap With China In Race To Dominate Battery Value Chain," Bloomberg NEF, 07 October 2021. [Online]. Available: https://about.bnef.com/blog/u-s-narrows-gap-with-china-in-race-to-dominate-battery-value-chain/. [Accessed July 29, 2024].

[15] S. Yilmaz, "Blackstone Resources acquires property for 5 GWh production," Blackstone Resource AG, 19 January 2022. [Online]. Available: https://www.blackstoneresources.ch/en/press/2022/01/19/blackstone-resources-acquires-property-for-5-gwh-production/. [Accessed 2024 July 29].

[16] Tesla, "Gigafactory Berlin- Brandenburg," Tesla, 2024. [Online]. Available: https://www.tesla.com/en_eu/giga-berlin. [Accessed July 29, 2024].

[17] Northvolt, "Northvolt assembles first lithium-ion battery cell at Swedish gigafactory," Northvolt, 29 December 2021. [Online]. Available: https://northvolt.com/articles/first-cell/. [Accessed 29 July 2024].

[18] Stellantis, "Stellantis Affirms Commitment to Italy with Automotive Cells Company's (ACC) Planned Battery Plant Investment," Stellantis, 23 March 2022. [Online]. Available: https://www.stellantis.com/en/news/press-releases/2022/march/stellantis-affirms-commitment-to-italy-with-automotive-cells-company-s-acc-planned-battery-plant-investment?adobe_mc_ref=. [Accessed July 29, 2024].

[19] Electrive, "CATL boosts battery cell factory in Germany to 100GWh," Electrive, 09 February 2019. [Online]. Available: https://www.electrive.com/2019/02/04/catl-plans-up-100-gwh-battery-factory-in-germany/. [Accessed 29 July 2024].

[20] SK, "SK Innovation," SK on Hungary, 2023. [Online]. Available: https://skonhungary.com/about-us/. [Accessed July 29, 2024].

[21] Electrive, "Samsung SDI expands battery production in Hungary," Electrive, 29 February 2024. [Online]. Available: https://www.electrive.com/2021/02/24/samsung-sdi-expands-battery-production-in-hungary/. [Accessed July 29, 2024].

[22] Morrowbatteries.com, "Manufacturing," Morrow Bateries, 2023. [Online]. Available: https://www.morrowbatteries.com/manufacturing. [Accessed July 29, 2024].

[23] InoBat, "INOBAT auto announces intention to build its third gigafactory in western Europe," InoBat, 25 March 2022. [Online]. Available: https://www.inobat.eu/newsroom/inobat-auto-announces-intention-to-build-its-third-gigafactory-in-western-europe/. [Accessed July 29, 2024].

[24] J. Dunn, "Italvolt to build southern Europe's largest gigafactory," Automotive Logistics, 13 September 2021. [Online]. Available: https://www.automotivelogistics.media/battery-supply-chain/italvolt-to-build-southern-europes-largest-gigafactory-/42272.article. [Accessed July 29, 2024].

[25] ACC, "Dans les coulisses de la construction de la première Gigafactory en France, à Billy-Berclau," Automotive Cells Co (ACC), 28 March 2022. [Online]. Available: https://www.acc-emotion.com/stories/dans-les-coulisses-de-la-construction-de-la-premiere-gigafactory-en-france-billy-berclau. [Accessed July 29, 2024].

[26] E. Commission, "European Battery Alliance," European Commission, October 2017. [Online]. Available: https://single-market-economy.ec.europa.eu/industry/industrial-alliances/european-battery-alliance_en. [Accessed July 29, 2024].

[27] D. Popescu, „Electric versus gasoline: The emissions duel," Auto criticism; Green Zone, 28 February 2022. [Interactiv]. Available: https://www.autocritica.ro/green-zone/electric-vs-benzina-duelul-emisiilor/. [Accessed July 29 2024].

[28] C. Șocariciu, „Battery recycling: The big challenge," Auto Critique, 21 July 2022. [Interactiv]. Available: https://www.autocritica.ro/green-zone/reciclarea-bateriilor-marea-provocare/. [Accessed July 25, 2024].

[29] F. 24, "Hungary protests against Chinese battery plant defy 'Orbanomics'," France 24, 10 February 2023. [Online]. Available: https://www.france24.com/en/live-news/20230210-hungary-protests-against-chinese-battery-plant-defy-orbanomics. [Accessed July 25, 2024].

[30] StandfordReport, "Stanford study finds stark differences in the carbon-intensity of global oil fields," Standford University, 30 August 2018. [Online]. Available: https://news.stanford.edu/stories/2018/08/measuring-crude-oils-carbon-footprint. [Accessed July 29, 2024].

[31] E. Gavenas, K. E. Rosendahl and T. Skjerpen, "CO2-emissions from Norwegian oil and gas extraction," *Energy,* vol. 90, no. 2, pp. 1956-1966, October 2015.

[32] D. Castelvecchi, "Electric cars and batteries: how will the world produce enough?; Reducing the use of scarce metals — and recycling them — will be key to the world's transition to electric vehicles," Nature, 17 August 2021. [Online]. Available: https://www.nature.com/articles/d41586-021-02222-1. [Accessed July 29, 2024].

[33] ACEA, "CO2 emissions from car production in the EU," ACEA, 29 September 2023. [Online]. Available: https://www.acea.auto/figure/co2-emissions-from-car-production-in-eu/. [Accessed 29 July 2024].

[34] R. Gijlswijk, G. Koornneef, H. Essen and S. Aarnink, "Indirecte en directe CO2-uitstoot van elektrische personenauto's," CE Delft, Van Mourik Broekmanweg 6, 2014.

[35] V. Capitalist, "The key minerals in an EV Bttery," Visual Capitalist, 2021. [Online]. Available: https://elements.visualcapitalist.com/wp-content/uploads/2022/06/VCE_OC_Composition-of-EV-battery_Mar_31.jpg. [Accessed July 24, 2024].

[36] T. N. Y. Times, "Salar de Uyuni," The New York Times, 2024. [Online]. Available: https://www.nytimes.com/2021/12/16/business/energy-environment/bolivia-lithium-electric-cars.html. [Accessed 25 July 2027].

[37] E. Commission, "Annex to the communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions," European Parliament, 17 May 2018. [Online]. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:0e8b694e-59b5-11e8-ab41-01aa75ed71a1.0003.02/DOC_3&format=PDF. [Accessed July 29, 2024].

[38] C. energiGUNE, "Gigafactories: Europes major commitment to economic recovery through the development of battery factories," CIC energiGUNE, 04 July 2021. [Online]. Available: https://cicenergigune.com/en/blog/gigafactories-europe-commitment-economic-recovery-battery-factories. [Accessed July 29, 2024].

[39] Adevărul.ro, „Europe's biggest sources of electricity. What the situation looks like in Romania," Adevărul Journal, 12 February 2023. [Interactiv]. Available: https://adevarul.ro/economie/cele-mai-mari-surse-de-energie-electrica-din-2241644.html. [Accessed July 30, 2024].