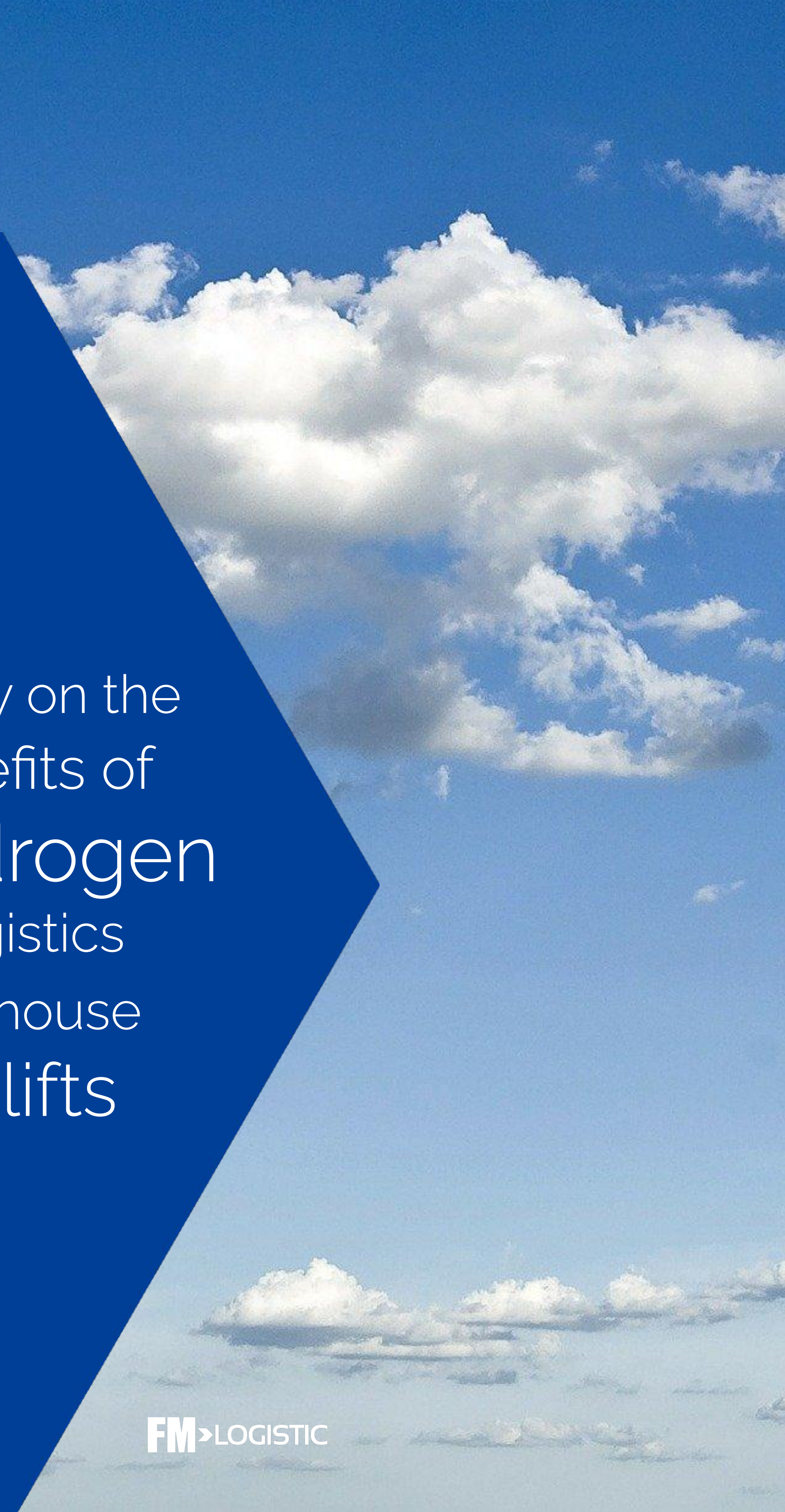

Study on the benefits of hydrogen in logistics warehouse forklifts

FM LOGISTIC

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This study has been promoted and coordinated by the environment and sustainable development department of FM Logistic Ibérica. Images: FM Logistic Ibérica and Pexels.

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About FM Logistic

Founded in France in 1967, this family-owned company is one of the leading **supply chain services companies in Europe and Asia**, serving customers in the **FMCG, retail, beauty and cosmetics, industrial manufacturing** and **pharma** sectors.

Its services include **warehousing, omni-channel** services, **co-packing, national and international transport, urban logistics operations and e-commerce**, as well as supply chain control tower services.

FM Logistic operates in more than **14 countries** in Europe, Asia and Latin America. It has annual revenues of around EUR 1.4 billion and more than **27,000 employees. FM Logistic Ibérica**, which includes Spain and Portugal, has more than **1,000 employees** and revenues of EUR 110 million.

Supporting the development of sustainable omni-channel supply chains is central to FM Logistic's strategy, as illustrated by its motto: "**Supply Change**". This sustainable development strategy is based on three pillars: **taking care of its people, developing sustainable supply chain services and improving the environmental footprint** of its activities. In line with this plan, the company is committed to hydrogen at the Illescas Logistics Platform (Toledo), aimed at energy transition through the installation of a hydrogen production, storage and dispensing station to supply forklift trucks and delivery vans.

Going green hydrogen

Transport accounts for about **20% of global carbon dioxide** (CO_2) **emissions**, according to the World Economic Forum. Road travel, i.e., cars, trucks, buses and vans, is the main contributor with **three-quarters of transport emissions**. Decarbonising transport is therefore critical to achieving the Paris Agreement's objective to limit global warming to well below 2 degrees Celsius, compared to pre-industrial levels.

FM Logistic has long proposed pooling solutions to reduce empty miles. In addition, it is testing a variety of alternative fuel solutions to help reduce greenhouse gas emissions. FM Logistic has been distributing with **hydrogen trucks in China** for years and has had a **warehouse in Neuilly with more than 50 hydrogen trucks** since 2015. Green hydrogen is increasingly being considered for use in transport to fuel trucks and not pollute the environment**.** FM Logistic has therefore started to produce green hydrogen at its **Illescas logistics centre**, taking advantage of the **solar panels** deployed on-site. A similar project is ongoing in the **Loiret region of France**.

Green hydrogen offers several **advantages**. It is a gas, so it can be **transported and stored**. **Refuelling** is **as fast as** with a diesel vehicle. Above all, its use generates **neither pollutant emissions nor noise**.

For now, FM Logistic is mainly using green **hydrogen to fuel some of its forklifts**. But it is also considering using this energy for **long-haul transportation**, either in fuel cell electric vehicles or as a range extender in battery electric vehicles. Public support, cooperation, and the development of the hydrogen infrastructure will be key to broader implementation.

Although hydrogen is not the only lever for decarbonisation, it is an essential element that FM Logistic is committed to. In fact, it is one of the ten companies that have formed the **Green Hydrogen Cluster of Castilla-La Mancha**. This is an initiative that was created with the idea of promoting the strategic development of green hydrogen technology and to position the Autonomous Community at national and European level as a reference in this renewable energy.

Purpose of the study

- The purpose of this study is to compare the characteristics of electric batteries and **hydrogen cells** from the point of view of how they can be used in the transport of goods in logistics warehouses. To this end, the advantages and disadvantages of each system are explained in general terms, from the perspectives of economics, energy and the environment.

The study is divided into the most relevant aspects and characteristics of the different systems as outlined below:

1. Greenhouse gas emissions

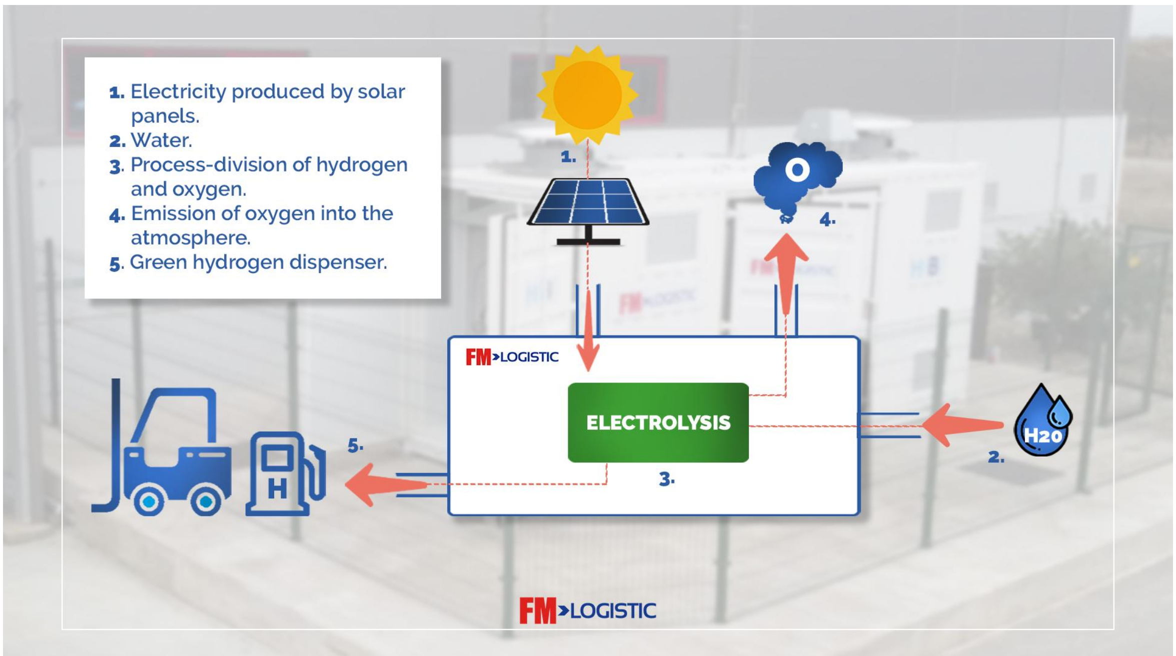
Batteries and hydrogen cells don't emit any gases when they are in use. In addition, in our specific case, the energy they use to operate comes from on-site renewable sources, which also reduces losses related to the transport of electrical energy.

2. Energy efficiency

Battery systems are more energy efficient than hydrogen fuel cells. **90-95% versus 60-65%**. The batteries directly transform the energy that provides them with power to run the vehicle. In contrast, in the case of a hydrogen cell, solar photovoltaic energy is used to generate the hydrogen which, once again, is then used to generate electricity to run the vehicle, thus resulting in an energy loss during the process.

However, in terms of energy density (Wh/kg), there can be no doubt that hydrogen offers an undeniable advantage over battery systems. That is why, if you want to increase the distance a vehicle can travel, it **involves such a major increase in weight and space** the advantage in terms of the greater efficiency of batteries compared to cells virtually disappears.

On the other hand, it should be noted that although hydrogen fuel cell technology is in its infancy, it's developing at a high rate, as are the processes that generate hydrogen by electrolysis. For example, processes based on concentrated solar thermal energy **can achieve up to 85% energy efficiency**. Projects are already underway to obtain hydrogen directly from solar radiation without prior energy generation (photoelectrocatalysis), which will also increase energy efficiency.



3. Autonomy

In this regard, hydrogen cells and lithium batteries offer an advantage against lead batteries, in that they last longer. It's interesting to note the **influence of temperature**, which is negligible in hydrogen cells, while in batteries there is a certain decrease, resulting in a lower operating capacity at low temperatures.

In relation to this we should also comment on an aspect that is sometimes overlooked, the process of self-discharge. This refers to the loss of charge that occurs in batteries even when they aren't in use. It's true that this self-discharge is low in modern electric batteries if the periods of time involved are short, but **it's practically non-existent in the case of hydrogen cells**.

4. Charging time

Similarly, as far as the time needed for charging is concerned, lead-acid batteries have the most disadvantages given that, due to their long charging time, whenever a battery runs out of power, spare batteries need to be available to replace them so the forklift truck can continue to be used. Lithium batteries also need between 2 and 4 hours of charging time, depending on how much the battery is discharged. The situation is quite the opposite with hydrogen cells, because in order to continue working, we can have a **full tank of hydrogen** in **less than 2 minutes**, which is one of the most advantageous characteristics of this system.

5. Charging capacity

In terms of charging capacity, batteries have certain disadvantages compared to a hydrogen cell. Lead-acid batteries, for example, shouldn't be discharged below 20% of their charge as this can result in damage to the battery. Similarly, if intermittent charging is done, the efficiency of the battery gradually decreases. In the case of lithium batteries, the power decreases as the battery is discharged, which results in a decrease in speed. Similarly, partial charges aren't recommended as the battery's efficiency will be affected due to the memory effect which, although it has been greatly reduced to what are now really low levels, is an inherent aspect of these systems that isn't found in hydrogen cells for which **there are no limits as far as charging is concerned**, i.e., they **can be partially charged** as required (similar to refuelling a traditional diesel/petrol vehicle).

6. Average lifespan

Battery lifespan is normally expressed in charge cycles and in this respect, with an average lifespan of as much as 10 years, lithium batteries allow many more cycles than lead batteries but fewer than **hydrogen cells**, which have a **useful life of around 15 years**. Although in any case, the useful life will depend on the specific design of each system and, of course, on their correct operation and proper maintenance. For this reason, a wide range of data can be found in the documentation currently available.

7. Maintenance and safety

In terms of maintenance, lead-acid batteries also come out worst, as they require intensive maintenance and also present significant health and environmental risks due to the lead and acid they contain. Lithium batteries and **hydrogen cells don't present such risks** (although having said that, lithium batteries do present a certain risk of overheating during charging) and require less intensive maintenance.

8. Life cycle

There are **three distinct phases to consider** in this section: the procurement of raw materials and manufacture, the operating stage, and disposal at the end of the battery's useful life.

8.1 Raw materials and manufacturing

Metals are one of the components needed to manufacture both batteries and hydrogen cells and their mining has significant impacts on both the environment and on people. To this we must add the significant amount of energy and resources consumed during their processing and manufacture. The difference lies in **the diversity and the quantities of the metals** each system requires.

As the name suggests, the major components of lead-acid batteries are lead and sulphuric acid, both of which can cause significant harm to people and the environment, both during their production and manufacture and during their use and recycling. The activities that have the greatest impact on the environment therefore occur during the extraction of lead and during the production process.

RAW MATERIAL	COMPOSITION
Lead (lead, lead dioxide, lead sulphate)	65-75%
Electrolyte (sulphuric acid)	15-25%
Plastic separators	5%
Plastic box	5%

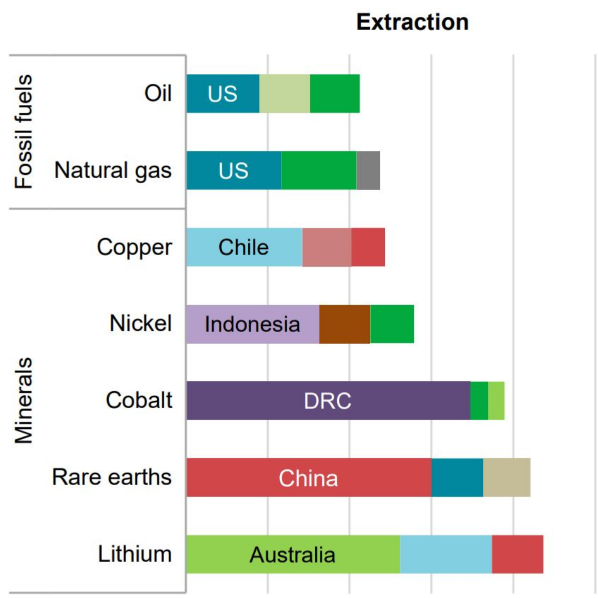
Table 1. Percentages by weight in lead-acid batteries (F. J. de Caldas 2015)

In the case of lithium batteries, although that is the name they commonly go by, all types of such batteries contain other critical metals (Ni, Co, Mn) in percentages significantly higher than the actual lithium itself (see table). Here it is important to note that the European Union considers **critical raw materials** (CRM) to be those which combine their great importance for the EU economy with the high risk associated with their supply. The latter refers to the **significant environmental and human impacts** during the mining and refinement of metals, processes which are mainly carried out in countries that are still developing or prone to potential social instabilities (Congo, Indonesia, Chile) (See graph).

Although new technologies and models of such batteries continue to be developed, it is still unlikely that the quantities of these metals will decrease in a truly significant way.

TABLE 1 INTENSITY OF CRITICAL METALS IN THE CHEMISTRY OF THE MOST COMMON BATTERIES (kg/kWh)				
	Li	Ni	Co	Mn
NCA	0,1	0,67	0,13	0
NMC 111	0,15	0,4	0,4	0,37
NMC 433	0,14	0,47	0,35	0,35
NMC 532	0,14	0,59	0,23	0,35
NMC 622	0,13	0,61	0,19	0,2
NMC 811	0,11	0,75	0,09	0,09
LFP	0,1	-	-	-

Table 2. Metals in the main types of lithium batteries (De La Torre Palacios 2020)



Graph 1. Percentage of mineral extraction by countries (IEA 2021)

Finally, hydrogen cells have an appreciable impact on the environment **during metal extraction and refinement**, but fewer metal are used (see table) and in smaller quantities. Nickel (also used in lithium batteries), platinum and other metals of its group (PGM) are the main metals.

The latter (iridium, osmium, palladium...) are the so-called **noble or transition metals**. They are rare and hence more expensive. Although this can be seen as a disadvantage as far as the composition of the cells is concerned, it is interesting to note that the amount of platinum used in fuel cell vehicles is approximately 10-20 grams per vehicle, whereas catalytic converters in internal combustion vehicles require approximately 5-10 grams of platinum for a diesel vehicle of similar size.

Moreover, there is evidence that it is the vehicle manufacturers themselves (Honda and Toyota, for example) that are still striving to reduce the quantities of platinum required, primarily to reduce the costs associated with manufacturing. Thus, in the last decade, the amount of **platinum in fuel cell vehicles has been halved**.

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◉	○	●	◉	●	○	◉
Hydro	◉	○	○	○	○	◉	◉	○	◉
CSP	◉	○	◉	○	○	●	◉	○	●
Bioenergy	●	○	○	○	○	○	◉	○	◉
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◉	○	◉	○	○	◉	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◉	○	○	●	◉

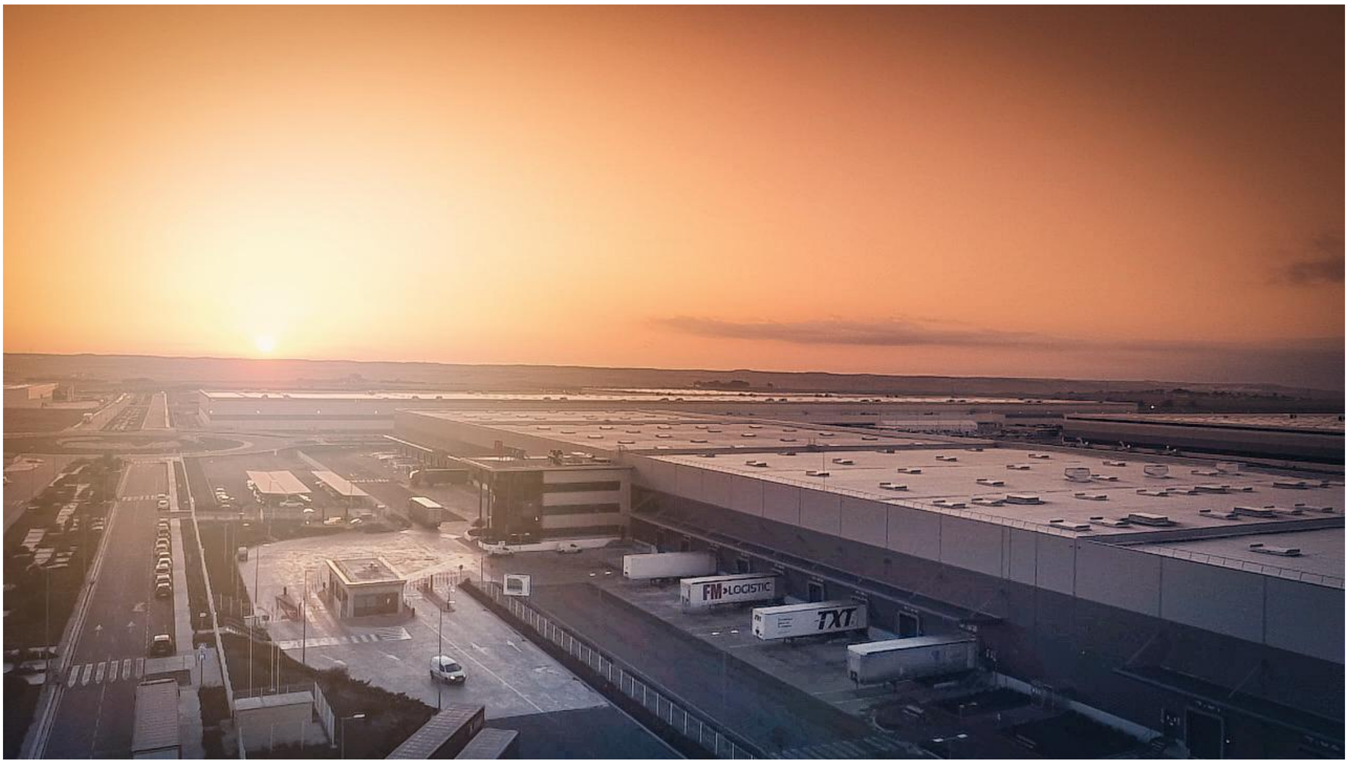
Table 3. Critical minerals required for different types of technologies (IEA, 2021)

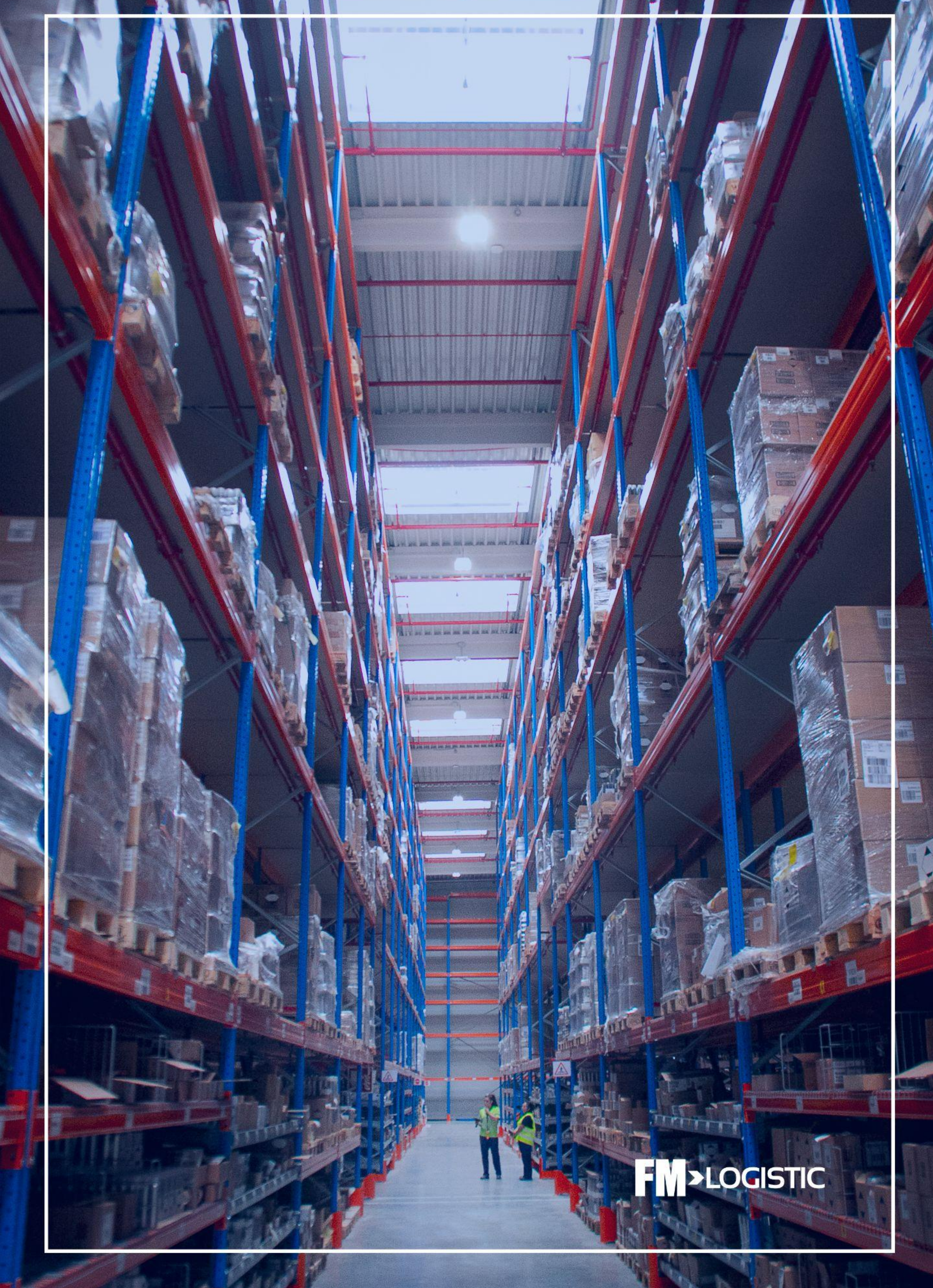
As we have stated, hydrogen fuel cell technology **is still in its early stages**, advancing and developing continuously and at a significant pace. This means that the amounts of these rare metals vary significantly from one generation to the next.

Compared to previous generations of batteries, **the amount of PGM metals has been reduced** from 8 mg/cm2 to 1 mg/cm2 and **is expected to go down to 0.3 mg/cm2** for future generations. Although still in the laboratory phase, there are even projects that have actually eliminated platinum altogether in battery manufacture by using other materials as catalysts.

8.2 Operation

In this step, the impact of both electric batteries and hydrogen cells is determined by the origin of the energy and the hydrogen, respectively. When the hydrogen is generated by renewable energy sources, and this same type of energy is supplied to the batteries, the result is a life cycle with a lower carbon footprint. As mentioned above, no greenhouse gas emissions are produced during their use.

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8.3 Disposal

Once the useful life of batteries and cells has expired, they must be withdrawn from use and disposed of, with **reuse and recycling** being, of course, the most desirable destinations.

In the case of lead batteries, as the most mature technology, their recovery and recycling processes have for some time now been more developed and controlled by specific legislation governing lead itself and other components such as aluminium. This doesn't mean that they aren't still processes that **require significant consumption of resources and generate environmental impacts** (emissions and discharges). It's clear that, no matter what the waste, the first option should be to reuse it for a different purpose. However, in the case of batteries, and specifically lithium batteries, there are still a series of technological and regulatory challenges before reuse can become the priority option and grow in scale.

The main challenge is their limited ability to compete on price, given the rapidly declining cost of new systems. In addition, before they can be used in new applications, withdrawn batteries must undergo costly reconditioning processes. And **the lack of transparency surrounding used batteries** (e.g. their storage status, remaining capacity, design) further complicates the economics.

As for recycling, several methods for recycling lithium batteries currently exist commercially or on a pilot level. Before they are recycled, battery packs must be discharged, stabilised and then dismantled to at least module level. Once discharged, **the battery components can then be separated into different types of material for further processing**. Battery recycling techniques currently fall into three broad categories, used either on their own or in combination.

These are mechanical pre-treatment, pyrometallurgical processes, and hydrometallurgical processes. **Mechanical pre-treatment** primarily consists of shredding and separating the plastic from the metal-enriched liquid and metal solids. However, **it must be combined with other methods**, usually hydrometallurgy, which can recover metals such as nickel, cobalt and lithium from the cathode by leaching. Currently, only a few companies are engaged in this process.

On the other hand, pyrometallurgical recovery uses high-temperature smelting to reduce the component to an alloy of cobalt, nickel and copper. **This method is frequently used** to extract such valuable metals as cobalt and nickel (but not lithium), but it has significant impacts on the environment (such as the production of toxic gases) and high energy costs.

Technological barriers preventing the improvement and optimisation of reuse and recycling include **the lack of standardisation of the designs** of battery packs, modules and cells. Different manufacturers have adopted different battery chemistries and tend not to disclose information on the design and chemistry of their cells. This wide variety of battery types and chemistries on the market poses a **major challenge as far as recycling is concerned**, and especially for process automation.

In the case of hydrogen fuel cells, as is also the case with design and manufacturing technologies, recovery and recycling techniques are still in their infancy. This, together with the fact that **the number of depleted cells is currently low**, means that at present and generally speaking, materials from fuel cell systems aren't being recycled on a large scale.

Instead, **obsolete components tend to be incinerated or buried**, resulting in environmental damage and wasted resources. However, we should bear in mind what we have already said about the fact that there is a mature supply chain for the use and, therefore, the recycling of platinum in traditional vehicle catalytic converters, which can also be used for batteries. Similarly, it should be remembered that the quantities of **precious metals** to be recovered are significantly smaller in this case, and may even disappear, which can significantly facilitate recycling.

An example of high efficiency is **Ballard's current technology** which, using appropriate recycling processes, **recovers 95% of the precious metals** from the used fuel cells they handle.

On the other hand, work is already underway on new techniques to allow the **bipolar carbon plates** of the fuel cell to be reused when the battery is recycled.

In the case of both lithium batteries and hydrogen cells, what is quite clear in the different studies is **the need for support and investment by governments in the development** of better and more efficient recovery and recycling processes and the implementation of specific regulations to guide them.

8.4 Impact of Life Cycle - Carbon Footprint

There are quite a few studies on the life cycle of different types of batteries from which general ideas or trends can be obtained but it's very difficult to come up with quantitative data that can be directly extrapolated. For example, and by way of illustration, the following table shows the results of different studies on battery production associated with **a range of 56 to 494 kg CO2/kWh** battery capacity for electric vehicles. This broad range clearly shows the degree of uncertainty in the assessment of emissions during a battery's lifespan and the variety of methods and materials used in the manufacture of batteries.

Authors	Year	Battery production emissions (kg CO2e/kWh)	Additional notes
Messagle	2017	56	Assumes vehicle with 30k"h battery constructed in the European Union, finding that BEVs will have lower life-cycle emissions than a comparable diesel vehicle when operated in any country in Europe
Hao et al.	2017	96-127	Uses China grid for battery manufacturing. Finds substantial differences between battery chemistries. Batteries produced in U.S: create 65% less GHGs.
Romare & Dahllöf	2017	150-200	Reviews literature, concluding manufacturing energy contributes at least 50% of battery life-cycle emissions. Assumes battery manufacturing in Asia.
Wolfram & Wledmann	2017	106	Models life-cycle emissions of various powertrains in Australia. Manufacturing inventories come primarily from ecoinvent database.
Ambrose & Kendal	2016	194-494	Uses top-down simulation to determine GHG emissions for electric vehicle manufacturing and use. Manufacturing process energy represents 80% of battery emissions. Asumes manufacturin grid representative of East Asia.
Dunn et al.	2016	30-50	Uses bottom-up methodology, with U.S electricity used for manufacturing.
Ellingsen, Singh & Stromman	2016	157	BEVs of all sizes are cleaner over a lifetime than conventional vehicles, although it may require up to 70,000km to make up the manufacturing "debt".
Kim et al.	2016	140	Study based on a Ford Focus BEV using real factory data. Total manufacturing of BEV creates 39% more GHGs than a comparable ICE car.
Peters et al.	2016	110 (average)	Reveals significant variety in carbon intensities reported across literature based on methodology and chemistry.
Nealer, Reichmuth & Anair	2015	73	Finds that BEVs create 50% less GHGs on a per-mile basis than comparable ICEs, and manufacturing (in U.S.) is 8%-12% of life-cycle emissions.
Majeau-Bettez, Hawkins & Stromman	2011	200-220	Uses combined bottom-up and top-down approach. Different battery chemistries can have significantly effects.

Table 4. Emissions studies for the manufacture of electric vehicle batteries (ICCT 2018)

The situation is the same in the case of hydrogen fuel cell systems, where multiple variables must be taken into account when studying and assessing the footprint or impact of their life cycle. But not only is there difficulty during the production phase, but also during the operation phase, where the carbon footprint of hydrogen cells is more variable. This footprint will be much larger, even larger than for batteries, in cases where the hydrogen isn't generated from renewable sources or in the same place where it's used, as the **impact** not only of its **production** but also of its **transport and storage** will have to be added. This is why in most studies involving life cycle comparisons, these are specific to the type of systems, the location and the applications of the systems.

As an example, the summary table extracted from the Deloitte study comparing the life cycles of **three types of vehicles** is presented, where no fixed values are given, but rather ranges for each phase and total emissions.

But the difficulty isn't only in the production phase, but also in the operation phase, where the hydrogen fuel cell has the greatest variability in its carbon footprint.

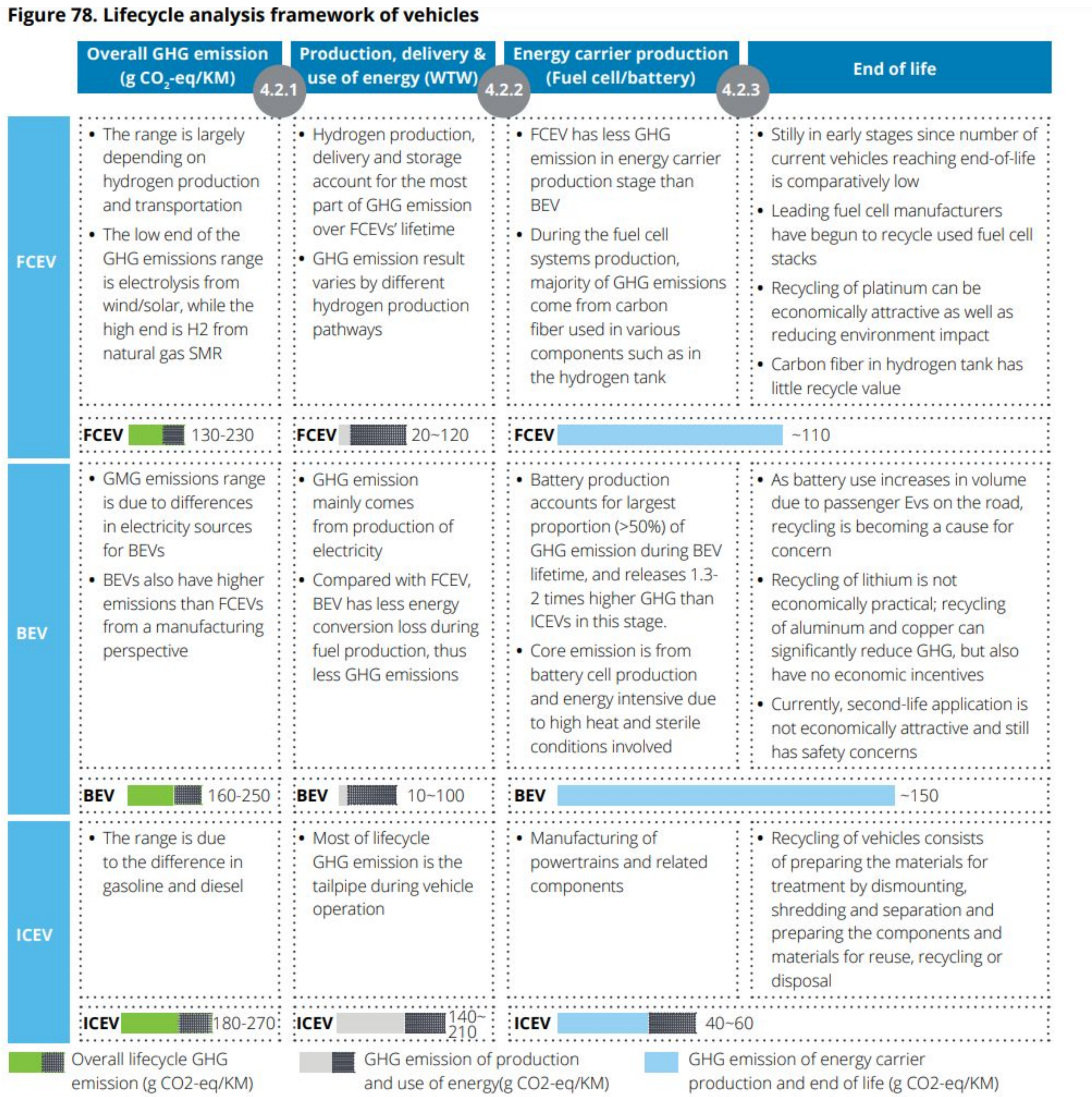

Figure 78. Lifecycle analysis framework of vehicles

	Overall GHG emission ($g\ CO_2$-eq/KM)	4.2.1 Production, delivery & use of energy (WTW)	4.2.2 Energy carrier production (Fuel cell/battery)	4.2.3 End of life
FCEV	• The range is largely depending on hydrogen production and transportation • The low end of the GHG emissions range is electrolysis from wind/solar, while the high end is H2 from natural gas SMR	• Hydrogen production, delivery and storage account for the most part of GHG emission over FCEVs' lifetime • GHG emission result varies by different hydrogen production pathways	• FCEV has less GHG emission in energy carrier production stage than BEV • During the fuel cell systems production, majority of GHG emissions come from carbon fiber used in various components such as in the hydrogen tank	• Stilly in early stages since number of current vehicles reaching end-of-life is comparatively low • Leading fuel cell manufacturers have begun to recycle used fuel cell stacks • Recycling of platinum can be economically attractive as well as reducing environment impact • Carbon fiber in hydrogen tank has little recycle value
	FCEV 130-230	**FCEV** 20~120	**FCEV** ~110	
BEV	• GMG emissions range is due to differences in electricity sources for BEVs • BEVs also have higher emissions than FCEVs from a manufacturing perspective	• GHG emission mainly comes from production of electricity • Compared with FCEV, BEV has less energy conversion loss during fuel production, thus less GHG emissions	• Battery production accounts for largest proportion (>50%) of GHG emission during BEV lifetime, and releases 1.3-2 times higher GHG than ICEVs in this stage. • Core emission is from battery cell production and energy intensive due to high heat and sterile conditions involved	• As battery use increases in volume due to passenger Evs on the road, recycling is becoming a cause for concern • Recycling of lithium is not economically practical; recycling of aluminum and copper can significantly reduce GHG, but also have no economic incentives • Currently, second-life application is not economically attractive and still has safety concerns
	BEV 160-250	**BEV** 10~100	**BEV** ~150	
ICEV	• The range is due to the difference in gasoline and diesel	• Most of lifecycle GHG emission is the tailpipe during vehicle operation	• Manufacturing of powertrains and related components	• Recycling of vehicles consists of preparing the materials for treatment by dismounting, shredding and separation and preparing the components and materials for reuse, recycling or disposal
	ICEV 180-270	**ICEV** 140~210	**ICEV** 40~60	

Overall lifecycle GHG emission (g CO2-eq/KM) — GHG emission of production and use of energy(g CO2-eq/KM) — GHG emission of energy carrier production and end of life (g CO2-eq/KM)

Figure 1. Vehicle life cycle analysis. (Deloitte China, 2020)

8.5 Costs

The conclusion with respect to this last point is very similar to the previous point. Costs will directly depend on the **design of the system**, the **type of vehicle**, the **energy source**, the **types of storage**, the **location** and the **use**.

Currently, the costs associated with the use of electric batteries are lower than those of hydrogen fuel cells, primarily due, as before, to the costs involved in producing, transporting and storing hydrogen, given that **it isn't a fuel that is readily available today**, in contrast to the charging of electric batteries.

However, experience and most of the documentary sources consulted also coincide in forecasting that **these costs will decrease in the years to come** as **hydrogen technology is developed, standardised and improved-provided** that investments are made in projects for its production, distribution and use. By doing so, the cost reduction potential of hydrogen will reduce or reverse the current economic difference between the two systems.

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