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The transition to the electric car: timing and reasons

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Index

Abstract

The history of the developed countries is strictly intertwined to the history of the automotive industry. Between 1985 and 1990 the Massachusetts Institute of Technology (MIT) carried out the largest survey in history of the so called "the industry of industries". The title of the final report is evocative: *The Machine that Changed the World*: it was, in fact, around the changes induced by the car industry that modern societies have been structured, and this symbiotic relationship has come down to the present day.

The pervasiveness of the impact of the automotive industry on our societies justifies the study of the historical evolution of this sector and the analysis of its moments of transition (related to technology or to organizational aspects). This thesis aims to investigate the possible evolving scenario for the automotive industry deriving from the deployment of the electric vehicles. The first chapter analyses the history of the electric car from its first appearance, at the end of the nineteenth century, to the new millennium. The second chapter examines the more recent history of the electric mobility industry, focusing on the strategies of the major manufacturers. Finally, the third section shifts the attention to the use of hydrogen as a green engine.

The vast majority of vehicle operators see electric mobility as the future propulsion. Only a small minority, instead, is still in doubt. The innovation represented by the use of hydrogen in combustion engines appears today as the solution able to replace hydrocarbon-based propulsion, due to the fact that hydrogen, in order to transfer energy, does not need to bind to carbon molecules, ensures a zero environmental impact and achieves high energy efficiency. Problems related to the cost of electrolytic production of hydrogen, its high consumption if used in ICE (internal combustion engine), production difficulties and safety problems, tend, however, to delay its use and to direct its use towards the electric traction as energy carrier in fuel cells.

Introduction

In June 2022, the Council of Environment Ministers of the European Union countries set the time limit for the sale of cars with internal combustion engines at 2035. This measure is part of the European strategy aimed at achieving, by 2050, the objective of climate neutrality, through a drastic reduction of emissions related to vehicular traffic (now responsible for a fifth of CO2 emissions in the twenty-seven members of the Union). The European Parliament itself has accepted the Commission's proposal aimed at establishing the end of the so-called "Fordist era of the automobile", i.e. the long temporal phase, destined to last almost a century and a half, during which petrol cars effectively dominated the market.

The decisions of the European bodies are destined to accelerate the transformation process underway in the automotive industry, which has been engaged in the experimentation and production of electric cars for three decades. The current trend, in fact, is oriented towards the development of battery-powered electric vehicles since the costs of production, on the side of companies, and of ownership on that of buyers are lower than the alternatives.

However, strong perplexities remain that the thirteen years that separate from 2035 are sufficient to resolve some fundamental critical issues for the full replacement of petrol-powered mobility with electric. In the first place, research on accumulators is still far from identifying solutions capable of ensuring power and a duration of charge that allow reaching adequate speeds for long journeys. The batteries themselves, in addition to still requiring long recharging times (and unsuitable for long distances), currently use raw materials and rare earths whose supply for a global market appears problematic. The alternative solution, represented by hydrogen, has the advantage of almost unlimited availability, but is penalized by higher costs and limited energy content per unit of volume (due to its low density, which makes its storage and transport relatively difficult) . In order to be able to move it in reasonable volumes, in fact, hydrogen must be stored in the form of compressed gas at high pressure or liquefied gas at very low temperatures, or else chemically and physically bond it to other materials. It should also be considered that hydrogen batteries still have a volume and weight that are inadequate for the small size of cars.

Secondly, the replacement of the current petrol and diesel supply network with a geographically widespread electrical infrastructure appears equally critical. The traditional distribution structures have been created by the large oil majors, which have taken steps, over time, to create a network of proprietary distributors. The diffusion of the electric car should give rise to a "second mass motorisation", similar to that started in the 1960s, but characterized by uncertainty regarding the management and ownership of the recharging infrastructures.

This work aims to analyze the transition process of the car market towards electric cars, focusing attention on timing, motivations, advantages and critical issues. In this perspective, the first chapter intends to illustrate the history of the electric car. The discussion starts with the first prototypes and analyzes the reasons that initially led to the abandonment of the project and, more recently, to the rebirth of this market. The second chapter shifts the focus to the present history of the electric car. After having examined the government policies in support of electric cars, we intend to analyze the data relating to the global, European and Italian diffusion of electric cars. Finally, the third section of the work examines the future history of the electric car, comparing the solutions used in new generation accumulators and those involving the use of hydrogen.

Chapter One

The past history of the electric car

1.1. The first prototypes of electric cars (1830-1890)

In the new millennium, the growing ecological sensitivity together with an high volatility of oil costs have led to a vigorous change in the European legislators orientations and in the production strategies of some of the world's leading manufacturers. The choices made by these actors have in fact initiated an inversion of a centuries-old production trend, during which petrol propulsion was in fact the only option at the basis of public mobility.

In reality, the car industry, both in its debut phase and in its development, has experienced a constant revival of the electric car. This type of propulsion not only had design priority in the period of experimentation with "motor carriages", but has always been considered an advantageous alternative in terms of availability of the energy resource and the polluting impact[1].

The history of electric mobility actually began with the invention of the first energy storage system, namely the Volta battery. The first manufacturers of "motorized carriages" proposed, in fact, to replace the traction produced by the steam with the electric one, given the scarce practicality of powering the coal boilers on small vehicles[2]. Moreover, they found themselves having to face a relevant issue[3]. The energy accumulators or traction batteries differ from the so-called starter ones: the latter are designed to provide high power but for very short periods of time, while the former must deliver power for long periods of time. The traction batteries must

[1] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa*", Milano, Egea, 2016,
p.1 .
[2] Associazione italiana per la storia dell'Automobile, "*Le automobili a vapore*", Torino, Il cammello, 2021, p. 10 ss.
[3] O. Ruzicka, "*La storia dell'automobile*", Cornaredo, Il Castello, 2016, p. 22.

therefore have a high capacity, measured by the Ampére-hours (Ah) that can be stored, and a high voltage, as well as a low volume[4].

The Italian physicist Alessandro Volta, in 1799 created the first battery (static generator) capable of supplying direct electric current in a circuit. The voltaic pile used zinc (negative anode) and copper (positive cathode) as electrodes and, as electrolyte, felt soaked in brine (sulfuric acid in water)[5]. The Volta pile made it possible, at the beginning of the nineteenth century, to start the first experiments relating to the electric velocifer. These researches culminated in the creation in 1832 by the Scottish Robert Anderson of the first prototype of an electric vehicle, perfected in the following decade by the Dutchman Sibrandus Stratingh[6].

In the second half of the nineteenth century, the improvement of electric cars went hand in hand with the study and development of increasingly powerful and reliable batteries. In 1836 the British chemist John F. Daniell created a new cell that would have solved the problem of the appearance of "hydrogen bubbles" in the voltaic pile. The production of hydrogen bubbles at the base of the copper electrode limited, in fact, the duration and use of the battery, causing an increase in the internal resistance and therefore a lower current delivery when the battery was inserted in a circuit[7]. The electric potential of the Daniell cell has become the basic unit for voltage, that is, one volt. Subsequently, in 1859, the French physicist Gaston Planté provided mechanical engineers with the first rechargeable (lead-acid) battery[8].
The two advantages of this accumulator consisted in the fact that it was a very economical battery capable of providing high starting currents for a few seconds (suitable for starter motors). The accumulators that paved the way for modern technology were, however, the nickel-cadmium batteries, invented in 1890 by the

[4] In fact, small, light and powerful batteries reduce the mass of the vehicle and improve its performance.
[5] The potential of a voltaic cell was 0.76 volts.
[6] O. Ruzicka, "*La storia dell'automobile*", cit., p. 23.
[7] The Daniell cell used a copper container filled with a copper sulphate solution which was put in contact, via a potassium chloride salt bridge, with a terracotta container filled with zinc sulphate with a zinc electrode immersed.
[8] In the charged state, each cell contains a spongy lead anode and a lead dioxide cathode $PbO2$ in an aqueous electrolyte solution containing sulfuric acid $H2SO4$.

Swedish engineer Waldemar Jungner[9].

Advances in the field of accumulated electrification have meant that, in the first phase of the development of the automobile, that is to say at the turn of the last decades of the nineteenth and early twentieth centuries, electric mobility competed with other technologies (especially the one based on the petrol endothermic engine) to continuously move the new means of transport[10]. The various propulsive solutions presented strengths and weaknesses which for a long time favored their coexistence. If gasoline cars were more powerful, electric ones were less noisy, presented greater functional simplicity and were suitable for urban mobility (reaching forty km per hour). These features, combined with a particular ease of driving, justify the wide popularity of electric cars among the bourgeois and wealthy classes of the large western metropolises[11].

The mass production of electric cars began in the 1880s. This production used part of the technique employed by Robert Davidson to create an electric locomotive and the solutions identified by Thomas Edison for the assembly of an electric vehicle powered by alkaline batteries.

If in 1886 Giuseppe Carli created a workshop specializing in the production of two-seater electric tricycles, in 1889 Jeantaud started the production of electric cars characterized by a range of thirty kilometers in France[12]. In a short time, electric mobility became prevalent in Anglo-Saxon urban transport services: in 1897 the London Electrical Cab Company was inaugurated, operating with fifteen electric taxis, and two years later the Electric Vehicle Company began its service in New York, equipped with one hundred electric-powered cars[13]. The development of motor technology in this area too is attested by the speed record (105.88 km / h) set in 1899 by Camille Jenatzy with the Jamais Contente electric car[14].

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[9] Abandoned in the first half of the twentieth century due to the toxicity of cadmium.
[10] L. Maugeri, "*L'auto elettrica: un sogno antico*, in *Equilibri*", 2009, 2, p. 220.
[11] A. Varesi, "*La storia dell'automobile: dai tricicli a motore ai giorni nostri"*, Rozzano, Domus, 2014, p. 26.
[12] O. Ruzicka, "*La storia dell'automobile"*, cit., p. 25.
[13] Ivi, p. 26.
[14] L. Brun, "*L'invenzione dell'automobile"*, Torino, Edizioni Lina Brun, stampa 2010

Fig. 1: **The Jamais Contente car**

The demand for electric cars, at the end of the nineteenth century, came from the big US cities and from those of the major European countries. It was a "commissioned" production, since "the buyers were asked to pay an advance that covered the costs of finding the materials"[15]. However, the demand for electric-powered vehicles has grown steadily, so much that it has been the prevailing demand for future global automotive industries (such as Benz in Germany) for decades.

1.2. The competitiveness of electrical technology at the beginning of the twentieth century

At the beginning of the twentieth century, the evolution of the three different propulsion technologies (steam, electricity and gasoline) gave rise to a situation of strong competition between the production players competing for the nascent automobile market[16].

[15] O. Ruzicka, "*La storia dell'automobile*", cit., p. 26.
[16] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa*", cit., p. 7.

As already mentioned, electric cars have had a wide diffusion as they had, compared to gasoline propulsion, the advantage of quietness, lower vibrations and greater operating reliability. Petrol engines had, in fact, the drawback of a greater difficulty of ignition (which took place through an incandescent tube), the ease of overheating and the fact that their use caused smoke and unpleasant odors.

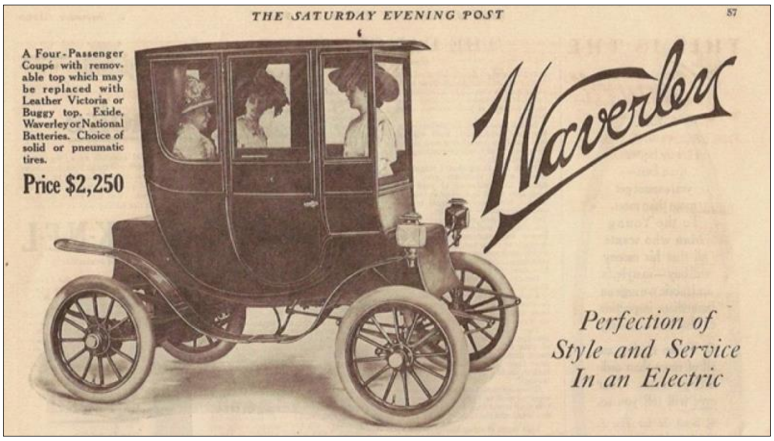
In 1900, more than a third of cars produced in the United States were electrically powered[17]. Baker Electric, Anthony Electric, Detroit Electric and Columbia Electric were able to assemble reliable and quiet "city cars". These industries also marketed vehicles that were primarily used for public transport and deliveries, proving cheaper than vans and gasoline cars. The following table summarizes the performance characteristics of some electric cars of the early twentieth century.

Name	*Features*	*Production Year*	*Units produced*
Baker Electric	Max Speed: 35 km/h Autonomy: 80 km.	1899-1915	12.000
Camona tipo “Ausonia”	Max Speed: 30 Km/h Autonomy: 60 Km	1899-1906	-
Detroit Electric	Max Speed: 28 km/h Autonomy: 200 km	1907-39	5000
STAE	Max Speed: 30 km/h Autonomy: 80–90 km	1909	1.500

[17] Ibidem.

As can be seen, these were vehicles that reached a maximum speed of 30 kilometers per hour and which on avarage had a range of 60-80 kilometers. These characteristics made them particularly suitable for urban travel, as well as the ease of driving and maintenance made them a suitable means of transport for a female clientele. The advertising communication of the electric car manufacturers was aimed at a range of wealthy women who, usually accompanied by a driver, wanted to move around the city avoiding the fumes produced by petrol cars and moving quietly and comfortably (the posters published, in fact, used to associate the electric car with bad weather situations)[18].

Fig. 2: **Electric car advertisement, 1908**



The functional advantages of electric vehicles (constantly improved by the twenty manufacturers) justify the high prices requested, four times higher than gasoline cars. The "electric fashion" was also motivated by the design of these vehicles and their performance. In 1902 Walter Baker's electric Torpedo attempted unsuccessfully to break the speed record set three years before from Jamais Contente, while in 1917 a range test was organized for electric cars, won by a car that, with an average of 33

[18] A. Zana, "*Strumento o sogno: il messaggio pubblicitario dell'automobile in Europa e Usa 1888-1978"*, Vicenza, Sei, 2009.

km / h, it covered the two hundred kilometers that separate Atlantic City from New York[19].

The sales of the so-called *electrics* has favored the spread of a network of vehicle recharges. Since 1910, urban regulations have allowed owners to place stations on their properties, while numerous workshops have made parking spaces available for overnight charging[20]. Electric propulsion seemed destined, therefore, to prevail over petrol, also thanks to the development of increasingly innovative and powerful batteries. The possession of an electric, as has been pointed out, "had become a status symbol and allowed the association of non-polluting and silent mobility with a distinct and dynamic lifestyle"[21].

1.3. The reasons behind the abandonment of the project

At a time when the electric car seemed destined to prevail in the competition relating to propulsive energy, the second revolution, linked to the birth of the Fordist factory, resulted in a rapid reversal of the trends in the automotive market.

Born in 1863, Henry Ford moved to Detroit at a very young age and worked in various mechanical companies, showing an innate interest in motors. A technician at Westinghouse, he then became employed by the Edison Illuminating Company and in 1896 presented his first hand-built car, a two-cylinder petrol engine[22]. Three years later he participated in the formation of the Detroit Automobile Company (the future Cadillac Company), which he left in 1902 to devote himself to the construction of racing cars. Thanks to sporting successes, Ford managed to find, in 1903, a group of financiers with whom he then founded the Ford Molor Corporation, which by the end

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[19] O. Ruzicka, "*La storia dell'automobile*", cit., p. 27

[20] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa*", cit., p.

[21] C. Gerino, "*Il ritorno al futuro delle auto elettriche. Nei primi del '900 negli Usa erano il 38 per cento dei veicoli circolanti. Ma poi....*", in https://www.repubblica.it/motori/sezioni/attualita/2021/08/28/news/auto_elettriche_le_prime_alla_fine_del_1800_e_negli_usa_erano_il_38_dei_veicoli_a_motore_-315560874/

[22] O. Ruzicka, "*La storia dell'automobile*", cit., p. 36.

of 1904 had already produced a few hundred cars. After unveiling a series of affordable four-cylinder models (Model B was used for the London taxi fleet) Ford set about launching the Type N at five hundred dollars (one-fifth the price of the cheapest electric car), built in over eight thousand units in 1907. Thus the idea of the car for everyone was clarified, then translated into the T model presented in 1908 at the Olympia Motor Show in London. The four-cylinder car had a power of 20 hp and was sold for $ 1,200. It was a simple and essential vehicle, in which sturdiness and reliability prevailed over technical innovations, so much so that it won the New York-Seattle endurance race[23]. Ford's intuition started the mass motorization of the United States, marked by the production of eighty thousand cars in 1912 (one third of the domestic market) and stimulated by foreign demand. To reduce costs (the T-type dropped to a price of $ 295) and cope with growing demand, the first assembly lines were introduced at the Detroit plant, accompanied by component standardization. In 1915, Ford built 250,000 cars, surpassing the combined production of all other US manufacturers. In addition, to fuel a greater volume of consumption, Ford not only reduced the prices of cars but established in 1914 an increase in the daily wages of its workers from 2.3 to 5 dollars, bringing the working day from nine to eight hours[24].

In the years preceding the First World War, therefore, the commercial production "displacement" of electric cars took place. The electrics have suffered the setback caused by the drastic reduction in prices (favored by the Fordist production system) and by some technical inadequacies that limited their power and reliability. The lack of transistors (invented in the 1950s) and the volume of the batteries affected both the speed of electric cars (which could reach a maximum speed of about 30 kilometers per hour) and their operational range (limited to 50 kilometers)[25]. On the contrary, petrol cars not only recorded a rapid evolution in terms of speed and range, but also recorded a significant improvement in the two characteristics that tended to orient buyers towards the electric: noise and overheating. The first was reduced thanks to

[23] M. Bowler, G. Guzzardi, "*Il grande libro dell'automobile*", Vercelli, White star, 2003, p. 22.
[24] O. Ruzicka, "*La storia dell'automobile*", cit., p. 37.
[25] A. Varesi, "*La storia dell'automobile*", cit., p. 41.

the installation of silencers on the mufflers, while the second was solved with the placement of a fan and a radiator in front of the engine. This has allowed gasoline cars to cover considerable distances at an ever lower cost. If in fact the diffusion of electricity was still incomplete and remained at high prices for a long time, the continuous discovery of new fields made petroleum derivatives increasingly cheaper. The discovery, in 1913, of thermal *cracking* was certainly another factor that had a heavy impact on the lowering of gasoline costs, allowing in fact (through an innovative crude oil refining system) to extract greater quantities of it from the same barrel of oil.

An event that could definitively "displace" the electric car, on a commercial level, was certainly the outbreak of the First World War and the decision, mainly for strategic reasons, to set aside most of the electrical components of the vehicles[26]. On the contrary, the war interlude favored the gasoline car industry, induced to devote itself to the production of aircraft engines, tractors and armored vehicles, trucks and military versions of civilian models.

After the war, relying on the T model and on a mass market, also fueled by the installment sales system, Ford resumed its rise (in 1919 the annual production exceeded one million units for the first time), arriving in 1926 to touch the two million cars sold. On the contrary, if in 1912 the electric cars in circulation in the world were thirty thousand, only a decade later they were practically zero[27]. In fact, the great crisis of 1929 acted differently on the various specializations of the automotive industry. The exit from production of the outdated petrol models has prompted production upgrades and the launch of new models. This strategy could not, however, be followed by the manufacturers of electric cars, struggling with a zeroing of demand and with complex technical problems[28]. Between 1925 and 1932 Columbia

[26] M. Marchiano, "*Auto elettrica: ieri, oggi, domani*", in AA.VV., "*Elettrica. Il futuro della prima auto*", Milano, AEM, 1990, p. 12.
[27] Tesi di G. Marrazzo, *Lo sviluppo della mobilità elettrica in ambito corporate: il caso Alphaelectric*, LUISS, 2017-18, p. 6.
[28] A. Varesi, "*La storia dell'automobile*", cit., p. 43.

Electric, Baker Electric and Detroit Electric went out of business, stopping the mass production of electric cars in the United States.

Only in some European countries did the production of electric vehicles continue in the 1930s for specific social purposes. In the UK, for example, door-to-door postal and commercial deliveries were carried out by industrial electric vehicles. In fact, these vehicles have proved to be more convenient from an economic point of view, thanks also to the development of accumulators that made it possible to store energy during the journeys made. On a global level, however, gasoline production recorded a further boost due to war orders relating to the Second World War and the low price of oil.

The gasoline car industry also recorded a second process innovation, also intended to make the production system and the quality of the offer more efficient. This is the industrialist "philosophy" developed in Japan after the Second World War and called Toyotism. The Toyota Motor Corporation, founded in 1937, has in fact grown dramatically by reinventing its production processes and giving life to the so-called “Toyota system”[29]. The main objective of this system was, through the reorganization of time, space and company philosophy, to greatly accelerate the company's ability to grow and innovate with respect to three key factors: quality (as value for the customer), cost and time (such as reliability and speed). The commercial success of the company therefore lies in the ability to offer customers services of a better perceived quality, at a more advantageous price and in a faster and more reliable delivery than the competition is able to do[30].

The so-called "lean production" is the fulcrum around which Toyotism develops with particular leverage on two fundamental aspects: just in time and the self-activation of all employees. The first aims at the almost total elimination of warehouses / stocks and production waste through a "pull" production system. The second concerns the search for an ever greater involvement of employees in the

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[29] G. Perrella, “*Il sistema Toyota per la nuova competitività”*, Milano, Guerini, 2009, p. 14.
[30] R. Pascale, A. G. Athos, “*Le sette S. Ovvero l’arte giapponese di gestire con successo l’azienda”*, Milano, Mondadori, 1982, p. 77.

production system, who become an active part in the implementation of production techniques and waste reduction in order to create a mentality of continuous improvement within all company departments. One can immediately grasp the difference with the production system, until then, more widespread, namely the Taylorist-Fordist one. In this model, the worker's tasks are highly repetitive and not very diversified, easily replaceable by robots or machines when, on the other hand, in the Toyotist model, the interdependence between man and technology becomes central.

1.4. The experimentation fields of battery electric traction

The rise of petrol or diesel engines did not mean the end of electric trucking technology[31]**.** In fact, battery-powered electric traction has been maintained through use in closed environments (factories, warehouses, airports, railway stations) or in protected areas where low levels of pollution were essential for the conservation of natural heritage. The 1950s were also characterized by the discovery of the modern alkaline battery. This device uses solid zinc and manganese dioxide electrodes, significantly increasing the energy density achieved (80-160 Wh / kg)[32].

The first half of the nineteenth century is defined by Baccelli, Galdi and Grea as the "age of the beginning" of the electric car, the second half of the nineteenth century witnessed the creation of the first generation of such vehicles. The period between 1901 and 1950 is qualified as "the replacement phase", during which the production of petrol cars has progressively marginalized the offer of electric vehicles. The fourth phase, between 1950 and 2000, was characterized by the "second generation" of electric cars, often at the level of a simple prototype.

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[31] In this paper only battery-powered vehicles are taken into consideration and not those such as trolleybuses, trams, subways, etc. (for the transport of people and goods) whose traction is supplied directly by the electricity distribution network.

[32] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility*", cit., p. 11.

Tab. 1: **The evolution of the electric cars**

Periodo	*Anni*	*Descrizione*
L'inizio	1801-1850	I primi veicoli elettrici sono stati inventati in Scozia e Stati Uniti.
La prima generazione	1851-1900	Le auto elettriche debuttano sul mercato riscuotendo un certo successo.
La fase di sostituzione	1901-1950	Le auto elettriche raggiungono uno storico picco di produzione per poi essere sostituiti dai veicoli alimentati a petrolio.
La seconda generazione	1951-2000	Le forti oscillazioni del pezzo del petrolio e una nuova sensibilità generano del nuovo interesse per le auto elettriche.
La terza generazione	>2001	Il settore pubblico si affianca alle case automobilistiche e alle società di distribuzione elettrica per la ricerca e lo sviluppo della *e-mobility*

Source: O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility",* cit., p. 2.

The new interest in electricity-powered vehicles was mainly due to two factors. On the one hand, the growing fluctuations in the price of oil have made the price of petrol fluctuating and have linked it in a worrying way to the geopolitical events of the areas of extraction. The wars and instability of the Middle East, the political mobilization of Arab countries and the Cold War[33] have meant that the energies of automotive propulsion became a random variable in its price, affecting the cost of ownership of the car. The decade of mass motorization, which fell in Europe between 1955 and 1965, was followed by a rethinking phase of traditional motorization, aimed at evaluating the possibility of following alternative routes to that of petrol propulsion[34].

On the other hand, the nascent environmental awareness played an equally (and increasingly) important role. The reflection on the nature and impact of the activity on it has relatively recent origins. Particular merit, in the overturning of the anthropocentric perspective, must be recognized in the 1864 work by George Perkins Marsh entitled *Man and Nature*[35]. As a cultural and associative phenomenon, environmentalism originated in the second half of the nineteenth century, when the first criticisms of the growing environmental degradation caused by rampant

[33] Russia has traditionally been one of the world's leading petrol exporters.
[34] O. Ruzicka, "*La storia dell'automobile"*, cit., p. 51.
[35] G. Perkins Marsh, "*L'uomo e la natura. Ossia la superficie terrestre modificata per opera dell'uomo"*, Milano, Angeli, 1993.

industrial civilization were formulated and environmental conservation associations began to arise. On the basis of these concerns, the Commons, Open Spaces and Footpaths Preservation Society was born in England, the oldest environmental association, still existing, followed in 1892 by the American Sierra Club. From this moment on, reflections on nature were increasingly confronted with the results of the investigations of the natural sciences. In particular, at the beginning of the sixties of the last century, the publication of the volume *Silent Spring* by the American biologist Rachel Carson[36] contributed to the awareness of the environmental problem and the birth of the *environmental philosophy*, widespread especially in the Anglo-Saxon world[37].

It is important to remember how, alongside theoretical reflection, a practical dimension of ecological commitment has also developed. The literature has identified three lines of development of ecological movements. The first, called "conservationism", developed in the 1950s and was characterized by the absence of organizational forms and voluntary work. The second, called "political ecology", originated from the social commitment promoted by the movements of the sixties and seventies, presenting a strong political connotation. The third, referred to as "environmentalism", was promoted above all by the radical movement and introduced a mode of action based on campaigns aimed at pursuing specific objectives. The automotive sector has been identified as one of the main culprits of environmental degradation, arousing growing social distrust and suffering from media criticism and boycott actions[38].

In this climate of demonization of petrol cars, research on electric cars has started again, albeit at a prototype level. Although the discovery of the fuel cell dates back to 1839 and had a substantial improvement in the 1930s, it was not until 1958 that Harry Ihrig, engineer of Allis-Chalmers, presented a 14.7 kW tractor powered by fuel cells. Historically it was the first hydrogen-powered road vehicle. This power system "is based on the idea of breaking the fuel molecules (usually atmospheric oxygen) into positive ions and electrons. The electrons, passing from an external circuit, supply an electric current proportional to the speed of the chemical reaction and usable for any purpose (propulsion of vehicles, industrial, electronics)"[39].

The fuel cell is a kind of engine that converts the chemical energy of the fuel (H2) into electricity and water vapor. The battery is just a converter and does not contain any form of energy. It follows that fuel cells produce direct current like common batteries and the reactions follow the laws of electrochemistry. The essential

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[36] R. Carson, "*Primavera silenziosa*", Milano, Feltrinelli, 1999.

[37] In 1948 the International Union for the Protection of Nature was founded in Fontainebleau, then renamed the International Union for the Conservation of Nature and Resources (IUCN) on whose example was born the same year, in Italy, the Italian Movement for the protection of nature (refounded in 1959 as Pro natura italica, today the national federation pro nature), which was followed in 1955 by the formation of Italia nostra, a national association for the protection of the Italian historical, artistic and natural heritage.

[38] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility*", cit., p. 14.

[39] GreenPedia: "*Fuel cell, la tecnologia del futuro*", https://www.logtogreen.it/greenpedia-fuel-cell-la-tecnologia-del-futuro/

difference is where the energy is stored: in a battery, the energy is stored in the battery itself which constitutes a complete energy storage and conversion system; in a fuel cell, energy is stored outside the battery, for example in a compressed hydrogen tank placed on board the vehicle[40].

The development of the hydrogen and oxygen fuel cell has aroused the interest of some major automotive manufacturers. De Soto, (a research company belonging to the Chryster group) a year after Ihrig's discovery, proposed a prototype car called "Cell I", able to move thanks to a fuel battery, reaching 80 km / h and covering a maximum distance of one hundred and fifty kilometers. In the 1960s, studies and proposals for electric cars multiplied, in parts promoted by car manufacturers, partly sponsored by universities, research centers, simple inventors. One of the most innovative prototypes was the Henney Kilowatt, the first electric car controlled by transistors and capable of reaching 90 km / h[41].

The projects pursued in this period, however, have led to the construction of a reduced number of cars. In the case of Henney Kilowatt, for example, the seventy cars produced were acquired by research centers, distribution industries and government bodies which tested their characteristics in view of their further development.

1.5. The rebirth of the electric car (1970-2000)

The "second generation" of electric cars experienced a more significant development in the last thirty years of the twentieth century. During this period there have been important efforts to relaunch electric cars.

Interest in this technology first awakened after the energy crisis caused by the oil shocks of the early 1970s. The 1973 Arab-Israeli Kippur War led, in fact, to the immediate reaction of the Arab League and oil producers, who established a selective embargo and a fourfold increase in the price of crude oil. This measure had an immediate impact on European economies, which are heavily dependent on crude oil as their primary energy source[42]. This measure had an immediate impact on European economies, which are heavily dependent on crude oil as their primary energy source. For the mobility of large industrial countries, the increase in oil prices has had significant repercussions. In Italy, in particular, the ban on using cars on Saturdays and Sundays has come into force, in a situation of generalized shortage of fuel[43].

The need to diversify energy sources, especially in the transport sector, has favored experimentation in the electric mobility sector. Between 1974 and 1979, numerous prototypes were presented which, thanks to the evolution of mechanical technology and accumulators, had much higher performance than the cars of the first

[40] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility*", cit., p. 18.
[41] O. Ruzicka, "*La storia dell'automobile*", cit., p. 24.
[42] Cheap oil (from $ 1.7 in 1950 to $ 1.8 ten years later) played a key role in the growth of Western economies after World War II. Over the course of twenty years, a real revolution had taken place for the transition from coal to oil as the main source of energy.
[43] M. Ginsburg, "*Storia dell'Italia contemporanea*", Torino, Einaudi, 2011, p. 114.

generation. In 1974 the Gurgel Itapu was presented at the Motor Show, three hundred of which were marketed the following year, and in the same year the Fiat Research Center created an electric variant of the Fiat City Car.

Name	*Features*	*Production Year*
Gurgel Itaipu E150	Two seats and a weight of 440 kg (300 kg of 3,2 kW batteries).	1974-1979
Fiat City Car X1/23	Equipped with nickel-zinc batteries and direct current motor.	1974-1979
Pilcar	Four-seater quadricycle.	1977-79

Subsequently, during the 1980s, the main promoters of battery-powered vehicles were *utilities*, i.e. companies that produce electricity in different countries. For them, in fact, any growth in demand for electric means of transport was an interesting opportunity for the expansion of their market[44].

Starting from the nineties, however, the growing awareness that the automotive market had to support environmental issues has meant that even the large car manufacturers started a specific experimentation in the electric field. Fiat, General Motors, Chrysler, Honda, Toyota, Chevrolet Ford and Nissan, as the table below illustrates, have built innovative prototypes or converted gasoline models in order to exploit the operational advantages of the *first mover* in the field of electric mobility.

Name	*Features*	*Production Year*	*Units Produced*
Sinclair C5	Small three-wheeled *recumbent* single-seat vehicle	1985	> 12000
Fiat Panda Elettra	Electric “conversion” of the petrol model	1990	-
General Motors EV1	Prototype not commercialized	1996-2003	>1000

[44] In those years, the tests carried out in Europe, the USA and Japan were essentially aimed at confirming the technical feasibility of using electric vehicles.

Twike	Three-wheeled electric vehicle	1996-2001	>750
Chrysler EPIC minivan	324 Volt lead-acid batteries Maximum speed: 128 km/h Autonomy: 110-144 km	1997–2000	<351
Honda EV Plus	Batteries NiMHPrimo Maximum speed: 130 km/h; Autonomy: 130–180 km	1997–99	~300
Toyota RAV4 EV	Prototipo non commercializzato	1997–2002	1249
Fiat Seicento Elettra	Electrification of the petrol model	1998	-
Chevrolet S10 EV	Nickel-cadmium batteries Maximum speed: 110 km/h; Autonomy: 100 km	1998	100
Citroën Saxo Electrique	Nickel-cadmium batteries Maximum speed: 91 km/h	1998-2005	>5000
Citroën Berlingo Electrique	Nickel-cadmium batteries Maximum speed: 90 km/h	1998-2005	
Ford Ranger EV	Vendita limitata	1998-2002	1500
Nissan Altra EV	First BEV vehicle to use Li-ion batteries; Maximum Speed: 12 km/h Autonomy: 192 km	1998–2000	~133
Think Nordic TH!NK City	Batteries Ni-Cd B Maximum speed: 90 km/h Autonomy: 85 km	1999-2002	1005

The greater interest in the electric car is due to the fact that technological evolution has made it possible to increase both its speed and range, as well as making it more reliable and significantly reducing the size of the battery intended to move the vehicle. These innovations initially created a market niche, characterized by innovative customers, and subsequently gave rise to a real "broader demand", extended to all those who link the use of the car to a low environmental impact. The second generation of electric cars was therefore the vanguard of a rebirth of this specific vehicle, now able to erode growing market shares of traditionally propelled cars.

Scholarly contributions focused on the sustainability of means of transport have also increased. Most of the studies focus on so-called "hybrid vehicles", that is, vehicles that combine a conventional internal combustion engine with an engine powered by another energy source (such as electricity or LPG[45]). There are also several studies concerning the broader category of so-called "alternative vehicles". The latter refers to all means of transport powered by energy sources other than oil (either through a hybrid system or completely), such as hydrogen or biofuel[46]. The greatest scarcity of contributions, however, is found in the field of pure electric vehicles (*Battery Electric Vehicles* - BEV)[47], although there is, in any case, an increase in sector surveys and market research commissioned by institutions and manufacturers.

Chapter Second

The present history of the electric car

2.1. The new electric cars typologies

The essay by Womack, Jones and Roos entitled *The machine that changed the world*[48] underlines how modern societies have evolved thanks to the innovations introduced in the transport industry. Steam powered traction was at the origin of the first industrial revolution, just as the mass industry was inaugurated by the Fordist

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[45] C. Yang, "*Launching strategy for electric vehicles: Lessons from China and Taiwan*, in *Technological Forecasting & Social Change"*, 2011, 77, pp. 831-834.
[46] J.K. Dagsvik, T. Wennemo, D.G. Wetterwald, R. Aaberge, "*Potential demand for alternative fuel vehicles*, in "*Transportation Research"*, 2012, 36, pp. 361-384.
[47] C. Midler, R. Beaume, "*Project-based learning patterns for dominant design renewal: The case of Electric Vehicle*, in *International Journal of Project Management"*, 2014, 28, pp. 142-150.

[48] J.P. Womack, D.T. Jones, D. Roos, "*The Machine That Changed the World: The Story of Lean Production",* New York, Harper Perennial, 1990.

production of cars with internal combustion motorcycles. The relationship between innovation of means of transport and social evolution is still operating, so much so that the fourth industrial revolution (defined Industry 4.0) is characterized by the progressive (and desired) abandonment of thermal traction (*Internal Combustion Engine*, ICE) and by the diffusion of electrical technology (*Battery Electric Vehicle*, BEV).

The transition to electric mobility is not determined by reasons of a competitive nature or product improvement on a commercial level. On the contrary, it is induced by an environmental urgency and by the need to develop a product that respects the sustainability and decarbonisation objectives that have been imposed over the last four decades[49]. The pollution of the planet and climate change are also influencing the attitude of car buyers, who have shown a growing favor for innovations in the electrical field and a widespread willingness, in the presence of certain conditions, to adopt low-cost means of transport (or zero) environmental impact. Electric vehicles, since they do not emit pollutants or produce noise during use, are an ideal tool to solve (at least in part) the problems deriving from the increase in traffic in urban areas[50].

The need to encourage electric mobility, as well as for reasons of sustainability, is also imposed by a near future decrease in oil supplies, determined by the depletion of oil fields in Arab countries and Latin America. The discovery of the techniques related to the so-called US *shale revolution* (which allows the extraction of oil from *shale* and other types of rocks using their hydraulic fracturing) involves a very high use of water, the creation of high slag deposits and cracking of the subsoil with the risk of landslides[51].

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[49] In line with the United Nations Conference on "Environment and Development", held in Rio de Janeiro in 1992, the 2030 Agenda aims to change a development model that is not only obsolete but also harmful, in which a situation of exploitation of resources and pollution continues, leading the planet towards dangerous climatic changes.
[50] G. Fontanelli, "*Autoshock: viaggio nella rivoluzione dell'auto elettrica che rischia di distruggere l'industria più importante del mondo*", Milano, Mind, 2018, p. 6.
[51] F. Di Benedetto, "*Oil & bio trading*", Milano, Angeli, 2015, p. 15.

Since the 2000s, both private manufacturers and the public sector have decided to invest more and more resources to encourage this type of motorization innovation and promote its adoption by private individuals. This is confirmed by a parallel and growing sensitivity towards the issues of environmental impact of emissions and vehicular congestion[52].

The new millennium has therefore seen the major car manufacturers engaged in redefining their industrial plans, through the introduction of a growing share of "electric" offerings. This transition is pursued through the development of new thermal / electrical technological solutions. These solutions cover six product areas:

- The *Battery Electric Vehicle* – BEV, cars with high potential battery
- The *Fuel Cell Electric Vehicle* – FCVE, electric vehicles with fuel cells
- The *Hybrid Electric Vehicle* – HEV, based on internal combustion engine (which recharges batteries while working) and on an electric engine which is only battery powered (without any possibility of connection to the distribution network)
- the *Plug-in Hybrid Electric Vehicle* – PHEV, that use batteries with greater autonomy allowing them to be recharged not only from the heat engine but also from the power supply network
- *the Extended range Electric Vehicle* – EREV, extended range vehicles, in which the internal combustion engine is used only as a power generator to recharge the traction battery when its charge level is low

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The reasons why "hybrid" cars have recorded, in recent years, a greater diffusion than fully electric cars are linked precisely to the presence of the thermal engine which, at the current state of research, makes them more efficient in terms of

[52] J. Jansson, A. Marell, A. Nordlund, "*Elucidating green consumers: a cluster analytic approach on proenvironmental purchase and curtailment behaviors,* in *Journal of Euromarketing",* 2009, 18 (4), pp. 245 - 267.

performance. In fact, if it is true that BEVs do not produce pollutants, their propulsion depends on batteries of limited power and to be constantly recharged. In terms of functionality, however, the BEVs are not characterized by substantial innovations: they are, in fact, similar to vehicles equipped with a thermal engine, both as regards the fittings and the mechanics. The only two exceptions are the transmission and engine volume. In fact, electric cars have simpler transmission shafts and do not have a gearbox. In addition, their motor is, with the same power, more compact and light, since "it is powered by a set of accumulators that transform the electricity taken from the batteries into traction energy"[53].

The limited autonomy of a charge of battery electric vehicles has been one of the major obstacles to their spread. It is in fact closely related to the energy density of the battery. Over the years, however, the storage capacity has constantly increased and therefore the distance that can be covered by the vehicle has increased.

The latest generation battery cars, in the small-medium class, already today allow an autonomy, with a recharge, of around 300 km in a real driving cycle and it is expected that, in the coming years, high-end BEV cars will reach 500 km[54]. The BEVs intended for predominantly urban or suburban use, on the other hand, have batteries suitable for a range limited to only 150/200 km, to the advantage of reduced cost and mass. This autonomy may seem inadequate, but in reality it is sufficient for many use cases (in 2019 in Italy, 68% of daily car trips were less than 10 km), assuming the restoration of full power every night or a topping up of the battery on dedicated roads[55]. It follows that on small-medium sized cars, the longer life guaranteed by the "*Fuel Cell Electric Vehicle*" technology - FCEV (electric vehicle with fuel cells), with higher costs, does not seem so relevant compared to that of the BEV technology[56].

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[53] O. Ruzicka, "*La storia dell'automobile*", cit., p. 65.

[54] As is already the case with Tesla's *Model 3*, *S* and *X*.

[55] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa*", cit., p. 42.

[56] G. Fontanelli, "*Autoshock*", cit., p. 32.

Furthermore, the battery-powered car is an efficient storage system when connected to the charging station. Once left in charge, a new generation electric car can dynamically adjust the charging power, even stopping and restarting it automatically, to adapt to the availability of the network. We usually talk about "destination charging" considering that the most appropriate times to charge the electric car are when you are not using it, especially at night[57]. In fact, it is in daily and temporary places of passage (therefore: homes, car parks, shopping centers, service areas, etc.) that battery-powered vehicles, including plug-in hybrids, are usually arranged for recharging.

The long times required for the recharging process of a battery-powered car, compared with the almost instant refueling of a petrol car, are still another obstacle to the adoption of the BEV car and in favor of the hydrogen car. With a 3kW charger, in six hours you can ensure a range of about 100 km, more than enough to restore what was consumed during the day at night, in most cases[58]. It is estimated that more than 80% of battery-powered car recharges are currently carried out in this way. While it is true that a full tank of about 500 km, with high-pressure hydrogen takes only three minutes to stop, the rapid public refueling is the only refueling method provided for the hydrogen car; on the contrary, for the electric car, fast or very fast recharging is complementary to the slow one carried out at home or in parking lots with the car stationary. For many users, high-power electric recharging could be completely sporadic: in this case, a thirty-minute stop to perform a partial recharge, only when needed, is considered acceptable as long as the number of recharging stations is adequate to minimize the risk of queues[59]. The way to refuel the vehicle will probably constitute the main difference in use between the different types of fuel.

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[57] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa*", cit., p. 44.

[58] With the BEV car, refueling times depend on the power of the charger. Referring to a nominal power of 50 kW (the most common size for fast charging today), a full tank of 400 km takes about 80 minutes. Switching to a power of 100/150 kW the time is reduced to 30/40 minutes, and to 300/350 kW to just 10/15 minutes. However, it should be remembered that recharging of over 300 kW will be reserved for a few high-cost BEV cars, and that of 100-150 kW will also have a limited diffusion.

[59] G. Fontanelli, "*Autoshock*", cit., p. 36.

In terms of operating costs, the BEV electric car allows significant savings on the cost per kilometer: half or less than a fossil fuel car. However, it should be noted that the greatest savings are obtained with private recharging (~ 0.05 € / kWh), mostly slow. In the case of public recharging, for obvious reasons, the cost is higher (~ € 0.40 / kWh); but, if the recharge is fast (at 50 kW) or very fast (at 120 kW), the costs still increase and could reach and exceed those of petrol or diesel cars[60].

2.2. **Government *policies* in support of electric cars**

The innovation of the electric car is encouraged, as we have tried to highlight, by a series of contingent factors which, beyond the market demand, require car manufacturers to implement a rapid conversion of production towards e-mobility. More specifically, the economic crisis of 2008, which was followed by the awareness of climatic criticalities and the greater environmental sensitivity of consumers, pushed the automotive sector both towards a progressive concentration of operators and towards a greater focus on the offer eco-friendly with, consequently, a considerable increase in resources invested (both by the public sector and by private producers) in this field.

Public *policies* have favored two different types of measures, often used jointly: the first relate to incentives for the purchase of electric cars; the latter refer to their use and circulation.

The countries most committed to this are those of Northern Europe. Norway has proposed to ban petrol and diesel cars from 2025, taking a pioneering position. This commitment is justified by the fact that in 2017 already 21.3% of newly registered cars were BEVs (38,264 out of 179,594) and 139,000 were in circulation, equal to

[60] Since a BEV car consumes on average ~ 18 kWh / 100km, the cost per 100 km varies between € 0.05 / kWh • 18kWh / 100km = € 0.9 from a domestic system, to 0.40 • 18 = € 7.2 from a public column.

5.1% of the 2.7 million vehicles in the entire national vehicular fleet[61]. Norwegians can also take advantage of particular forms of government support that provide important economic incentives for the user who purchases an all-electric BEV or a hybrid. In fact, thanks to tax and fuel savings (free recharging), the entire cost of an electric car can be recovered within eight years. Furthermore, Norwegian legislation provides for two further systems of measures: on the one hand, a tax regime that penalizes the most polluting means while, on the other, the VAT exemption (equal to one quarter at the time of purchase) and indirect benefits such as free tickets for ferries and parking lots.

Also in Northern Europe, Sweden announced its plans to increase the number of fast charging stations by 600% in areas with the highest population density. This commitment is connected with the penetration of electricity which in the Scandinavian country should lead to a share of electric vehicles in circulation by 2035[62]. Faced with these data, the intention of the French government of wanting to ban diesel and petrol from 2040 or that of the German government to install columns for fast charging of electric vehicles and hydrogen stations along the country's motorways appears prudent. In addition, in the last fifteen years, almost all industrialized countries have launched measures to support innovation and aimed at encouraging the purchase of electric cars. Germany, in order to increase the non-polluting fleet of cars, has foreseen a total allocation of three billion euros for the period 2025-2030: the incentive amounts to nine thousand euros in favor of the buyers of electric cars and six thousand euros for buyers of plug-in hybrid cars[63].

France, also characterized by an automobile industry traditionally at the top of the world, has promoted a bonus of seven thousand euros for electric cars, which was accompanied by an incentive of two thousand euros for plug-in hybrids. The government plan provided for a "decreasing intensity" financial allocation. In fact, the French authorities intend to make the greatest incentive effort aimed at promoting

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[61] Fonte: OICA, 2021, https://www.oica.net/

[62] S. Oleffsen, "*Electric vehicles revolution: the case of Sweden,* in *International issues",* 2010, p. 21.

[63] S. Varesi, "*Gli incentivi a favore dell'auto elettrica",* mimeo, 2010.

the purchase of zero-emission vehicles in the short term (2020-2022), and then gradually reduce the appropriations (which will decrease by one thousand euros per year in the period 2023-2026)[64].

A similar incentive scheme has been activated in Great Britain. In this country, the government has provided a bonus of three thousand pounds until 2023, and then halved to fifteen hundred pounds in 2024 and 2025. Finally, in Spain, there is soon an incentive of seven thousand euros for those who scrap a car with at least seven years of life and buy an electric car. This figure is reduced to four thousand five hundred euros in the event that the purchase is not preceded by scrapping. Finally, the Spanish Government has provided for a specific support measure for urban *e-mobility*, assigning five thousand euros (with scrapping) and two thousand five hundred (without scrapping) to those who buy a *plug-in* car with an electric range between thirty and ninety kilometers[65].

Tab. 2: **The main support measures for the automotive sector**

Country	*Measure*
European Union	- Green-Cars Initiative, incetivation of low emission cars production and propulsed by alternative fuels. - Subsidized loans for R&D (CO2 emissions) from European Investment Bank.
Italy	- PII Sustainable Mobility - Scrapping of old cars and incentives to buy new ones
France	- Scrapping of old cars and incentives to buy new ones. - Investment fund and subsidized loans to Renault and Peugeot- Citroën, bound to non-relocation.
Germany	- Scrapping of old cars and incentives to buy new ones.

[64] Ivi, p. 8
[65] Ivi, p. 9.

	- Automobilistic and CO2 taxes reduction for electric cars - Credits coverage for R&D.
Spain	- Interest-free loans for the purchase of new cars. - Industry helps, subsidized loans.
United Kingdom	- Guarantee loans to car manufacturers. - VAT reductions.
Sweden	- Extraordinary loans and credit guarantees.
United States	- Subsidized loans to car manufacturers.

Source: S. Varesi, "*Gli incentivi a favore dell'auto elettrica",* cit., p. 9

The Italian government's commitment to e-mobility began with law no. 134/2012, which proposed to encourage clean technologies by recognizing support for the purchase of electric cars. Subsequently, the law of 7 August 2012 introduced a series of "provisions to encourage the development of mobility through vehicles with overall low emissions". Based on the latter, the Presidential Decree 26 September 2014 approved the "National infrastructure plan for the recharging of vehicles powered by electricity", launching a strategy aimed at pursuing two objectives: on the one hand, the creation of an infrastructure network adequate to support the growing demand for recharging points for vehicles powered by electricity and, on the other hand, to encourage public and private purchases of vehicles with overall low emissions, especially in urban environments. . For this purpose, a fund has been set up by the Ministry of Economic Development to finance the purchase of this type of vehicle by individuals and businesses[66].

[66] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa",* Milano, Egea, 2017, p. 128.

At the end of 2018, government authorities announced a support measure aimed at encouraging the purchase of electric cars. Law no. 145/2018 (budget law for 2019) provided, in particular, for the introduction of concessions for buyers of non-polluting cars and tax increases aimed at discouraging the purchase of vehicles deemed to be polluting. The legislator has therefore adopted the solution that tends to orient the demand for cars towards solutions characterized by a lower fiscal impact. More specifically, the 2019 budget law proposed to modernize the national car fleet, diverting purchasing choices towards low-polluting vehicles (hybrid or electric vehicles) and discouraging the purchase of ICE vehicles (including new ones), by means of three types of intervention:

a) incentives for the purchase of new hybrid and / or electric cars, increased in the case of scrapping of polluting vehicles;
b) tax deductions for the installation of charging stations;
c) introduction of taxes for the registration of polluting cars.

The incentives, in the form of a discount on the price, recognized a contribution between 1,500 and 6,000 euros for the purchase of a category M1 vehicle (with a price of less than 50,000 euros) from 1 March 2019 to 31 December 2021[67]. Two other measures concerned tax deductions for the purchase and construction of charging infrastructure for vehicles powered by electricity and the introduction of a tax for the registration of polluting cars[68].

Even outside the European context, government authorities have promoted initiatives to convert automotive supply and demand towards e-mobility. The Chinese government, for example, has decided to impose the obligation for car manufacturers that produce or import more than thirty thousand units a year to progressively switch from selling petrol and diesel models to marketing electric BEVs and hybrids PHEV. The government program has two main objectives: the first, more urgent, to reduce

[67] The contribution was recognized to the buyer by the same seller, who "compensates" it with the purchase price. In turn, the automobile lawsuits reimburse the seller the amount of the contribution and recover this amount as a tax credit.

[68] "*Agevolazioni fiscali per la diffusione dei veicoli alimentati ad energia elettrica,* in *TP: trasporti pubblici",* luglio-agosto 2020, p. 5.

the levels of pollution that have afflicted the main cities of the country for many years; the second, to take advantage of a rapidly growing market. In fact, by 2025, a trend should be consolidated that could bring zero-emission cars on the road to at least 20% of the entire Chinese fleet[69]. These also overshadow the considerable efforts envisaged in this area by California, the results of which, moreover, are still far from what has already been achieved by Norway. An implicit incentive is represented, on a world level, by the very heavy excise duties on petroleum derivatives, imposed in different percentages in the various states but still relevant. In Italy, for example, state revenues from excise duties on motor fuels were in the order of 31.6 billion euros in 2019, 2% of GDP[70]. The question that arises for the future is whether, in the face of a growing substitution in the market of thermally-propelled cars with "electric" ones, individual states will be able to do without resources that are important in their budgets[71]. If, to restore their resources, countries shift the taxation on energy destined for electric traction, this would entail a reassessment of the energy costs borne by the user. As for the advantages currently offered by the different administrations to electric car owners, they also vary from country to country. In Italy, and in most European countries, these can be summarized in the following series of concessions:

- full exemption from property tax;
- discounts of up to 50% on insurance;
- discounts on urban parking;
- free access to the Ztl and Lev areas;
- free access to toll roads;
- free electric charging[72].

It is clear that these types of facilities are a consequence of the incentive policies for the use of "electric" by the various institutions and the current modest number of

[69] Source: OICA, 2021, https://www.oica.net/

[70] Ministero dell'economia e delle fiananze, "*Rapporto annuale 2019",* Roma, 2020.
[71] "*Agevolazioni fiscali per la diffusione dei veicoli alimentati ad energia elettrica",* cit., p. 6.
[72] "*Agevolazioni fiscali per la diffusione dei veicoli alimentati ad energia elettrica",* cit., p. 6.

vehicles in circulation. Therefore, they will tend to be downsized, up to being canceled, as a consequence of the greater diffusion of sustainable mobility[73].

2.3. **Data on the diffusion of electric cars**

2.3.1 **Electric mobility in the world**

The development of the electric car, as we have tried to highlight in the previous pages, has interacted with a phase of profound change in the global automotive sector. Since the new millennium, large producers have had to face a double challenge: on the one hand, the restructuring of production platforms, based on global value chains that operated through assembly plants located in many countries of the world; on the other hand, the entry into the market of new Asian competitors, especially Chinese, characterized by a considerable capacity for innovation and equipped with large structures (in order to serve a huge and rapidly growing domestic market)[74].

The hyper-competition has meant that in the last twenty years the number of cars produced has increased exponentially, going from fifty-eight million in 2000 to almost ninety-eight million in 2017. Moreover, China has conquered the top of the ranking of Car-producing countries, assembling a third of vehicles in 2017 and contributing to the growth of the sector by more than 70%[75]. Contrary to the Asian context, the western productive areas recorded (with the exception of Germany) a tendential contraction in output. In fact, a defensive operational logic prevailed, unable to define an innovative industrial strategy and unable to rethink the production chains according to the new needs of consumers. The evolution of the car market over

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[73] U. Bardi, M. Rossi, L. Celi, "*Ipotesi sulla mobilità del futuro: benefici e criticità sulla possibile transizione verso l'auto elettrica"*, Massa, Lu:Ce, 2020, p. 12.

[74] F. Cassia, M. Ferrazzi, "*L'industria dell'auto: come la globalizzazione cambia la macchina che ha cambiato il mondo"*, Padova, Libreriauniversitaria.it, 2016, p. 22.
[75] Fonte: ANFIA, 2020.

the last twenty years has therefore ended up determining a structure in precarious equilibrium.

Tab. 3: **The 12 car-producing countries**

n.	Country	2000	Country	2008	Country	2017
1	Usa	12.773.714	Japan	11.575.644	China	29.015.434
2	Japan	10.740.796	China	9.299.180	Usa	11.189.985
3	Germany	5.526.615	Usa	8.672.283	Japan	9.693.746
4	France	3.348.361	Germany	6.045.730	Germany	6.070.267
5	South Corea	3.114.998	South Corea	3.826.682	India	4.782.896
6	Spain	3.032.874	Brazil	3.215.976	South Corea	4.114.913
7	Canada	2.963.097	France	2.568.978	Mexico	4.069.389
8	China	2.069.069	Spain	2.541.644	Spain	2.848.335
9	Mexico	1.922.889	India	2.332.328	Brazil	2.699.672
10	UK	1.813.894	Mexico	2.167.944	France	2.278.980
11	*Italy*	1.738.315	Canada	2.082.241	Canada	2.194.003
12	Brazil	1.681.517	UK	1.649.515	Thailand	1.988.823
	Total top 12	***50.126.139***		***55.978.145***		***78.957.620***
	Total Global	***58.336.297***		***70.729.792***		***97.760.356***
	Italy	*1.738.315*		*1.023.774*		*1.142.210*

Source: ANFIA, 2019.

The *e-mobility* revolution was grafted onto this structure with remarkable rapidity, which required a profound rethinking of strategies. The inevitability of this transition, made necessary by the criticality of climate change, by the consequent regulatory interventions for the *automotive* sector and by the growing sensitivity towards environmental issues, all manufacturers have implemented investment strategies to place themselves among the first movers of the transition from thermal to electric traction[76]. Overall, globally, car manufacturers have made commitments for 255 billions in the development of BEV production up to 2023. Two manufacturers in particular, Volkswagen and the Renault-Nissan-Mitsubishi group, have planned investments of one hundred billion dollars in order to accelerate the replacement of the petrol supply with the low environmental impact one. By 2023, Renault-Nissan-Mitsubishi plans to market twelve electric car models, while the BMW and Volkswagen groups have defined BEV-oriented industrial plans, the goal of which is to build forty-seven and eighty new electric models by 2025 respectively. In turn, the Chinese Geely has planned to introduce forty-one new models on the market as early as 2020.

Shifting attention from supply to demand, it can be seen that out of about 1.3 billion cars circulating in the world, only seven million are electric (0.53%). In recent years, however, significant levels of growth have been recorded in China and some European countries, thanks above all to government incentives and programs aimed at strengthening the infrastructure necessary to support and promote vehicle electrification.

The global market for electric traction cars only began to take on a significant dimension starting from 2015. If in that year electric car registrations amounted to just over half a million units, in the following two years the demand recorded a significant growth, reaching 754,000 cars sold in 2016 and 1.2 million in 2017. The market share and unit sales of electric vehicles (battery or plug-in hybrid) therefore increased by about six times between 2013 and 2017, going from a global market share of 0.09% to 0.15%[77].

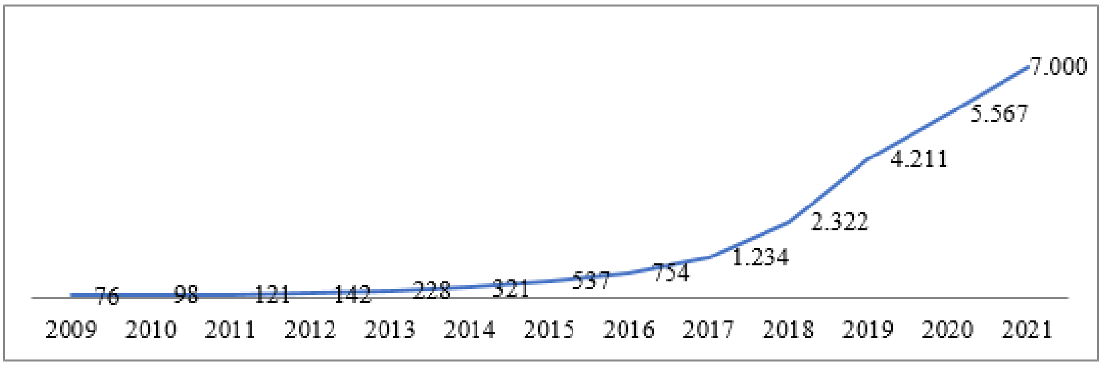
Subsequently, the registrations of electric cars experienced a significant increase, going from more than two million three hundred thousand units in 2018 to four

[76] E. Cassetta, A. Marra, C. Pozzi, P. Antonelli, "*Emerging Technological Trajectories and New Mobility Solutions. A Large-Scale Investigation on Transport-Related Innovative Start- Ups and Implications for Policy"*, in "*Transp. Res. Part A Policy Pract*.", 2017, 106, pp. 1-11.

[77] Source: Rystad Energy, 2021.

million two hundred thousand in 2019, five million five hundred thousand in 2020 and the current seven million[78]. This is 10% of total registrations (equal to 69 million), compared to 5.3% in 2020.

Fig. 4: **Worldwide electric car sales** (in thousands)



Fonte: E-Mobility Report 2021.

In this market, the demand for electric cars covers around 68% of sales, while the remaining 32% for hybrid cars. However, this ratio varies considerably from country to country, depending on the incentive policies initiated by the relevant governments[79]. In recent years, moreover, 85% of sales are concentrated in ten industrialized countries. China is the largest and most dynamic market. Suffice it to say that in 2021 electric car registrations represented 40% of global sales and that the government program envisaged bringing the market for electric motor cars to a share of 20% by 2025 and 40% by 2030[80].

Some manufacturers have long passed the threshold of one hundred thousand units sold per quarter, a value that should lead to half a million electric cars sold per year. Taking 2021 as a reference time frame, the world ranking sees Tesla in first place with 764,000 plug-in cars delivered. After the US manufacturer were BYD with 500,000 units, General Motors-SGMW with 394,000 units. In fourth and fifth place are respectively BMW and SAIC.

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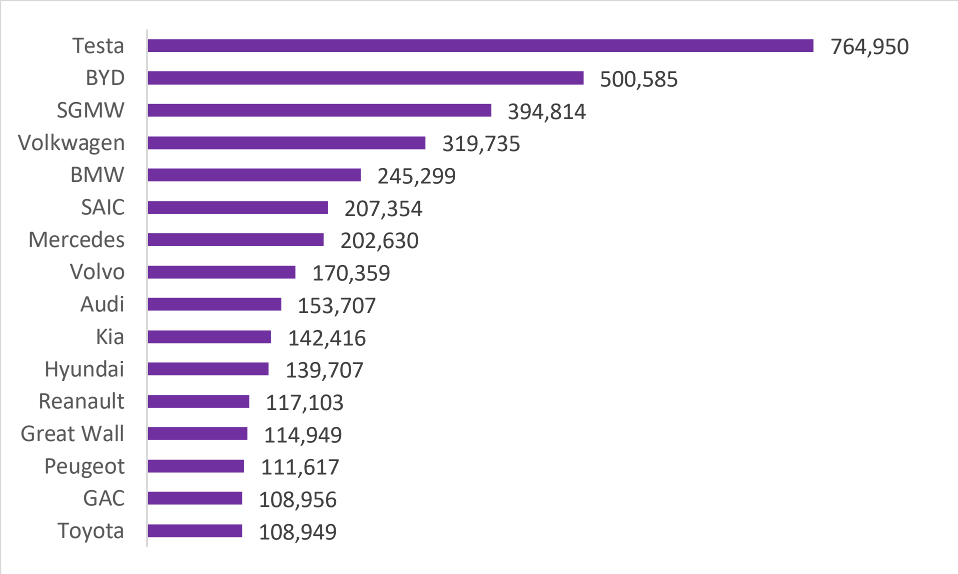
[78] Source: E-Mobility Report 2021

[79] The Dutch government, for example, has geared tax cuts primarily in favor of hybrid cars.

[80] Fonte: E-Mobility Report 2021.

Fig. 5: **Plug-in electric cars sold in 2021**



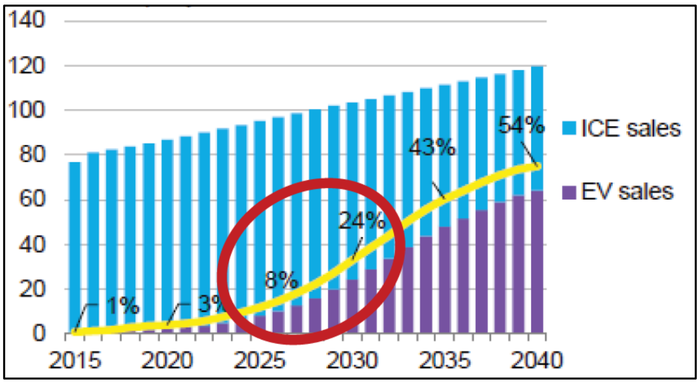
Source: Bloomberg Report 2021.

Tesla's Model 3 was the best-selling car in 2021 (with 550,000 cars delivered). The sales ranking sees the Chinese Mini EV and the Tesla Model Y successively. More contained commercial volumes were recorded by the BYD Han, the Volkswagen ID.4 and the Renault ZOE.

Studies agree on the fact that the next decade will be characterized by a growing diffusion of BEV technology and a progressive contraction of ICE vehicles (which, however, according to estimates, will in any case predominate in the overall vehicle fleet at least until 2050). In its Electric Vehicle Outlook 2020, Bloomberg, examining the structural dynamics of sharply declining battery costs and related orders by automakers, reports that, by 2040, 54% of new car sales and 33 % of the global fleet will be electric. Falling battery prices will drive electric vehicles to highly competitive prices in all major light vehicle market segments before 2030, ushering in a period of strong growth for electric vehicles. According to this hypothesis, therefore, by 2040, half of all new car sales and over a quarter of the world's fleet will be electric BEVs[81].

[81] Bloomberg, "*Electric Vehicle Outlook 2020,* New York", Bloomberg, 2021.

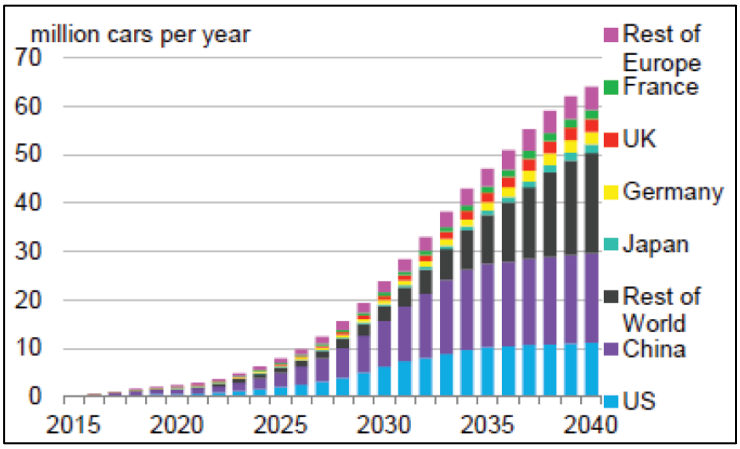
Fig. 6: **Percentages relating to annual registrations of electric cars**



Source: Bloomberg, *Electric Vehicle Outlook 2020*.

The sheer size of these auto markets are the main drivers for high EV sales, assuming continued or even increased regulatory support over the 2021-2025 period. This is a necessary condition to keep purchasing demand high and stable which, in the absence of incentive and support policies, could have great difficulty consolidating. Here, the midsize car segment, which includes big-selling models from Toyota, Ford, Honda and Volkswagen, will account for a large part of this growth, given the current global midsize car market structures and favorable switching costs from ICE vehicles to EVs, starting from the late 1920s, as illustrated in the figure on the next page.

Fig. 8: **Electric car sales forecast by market**



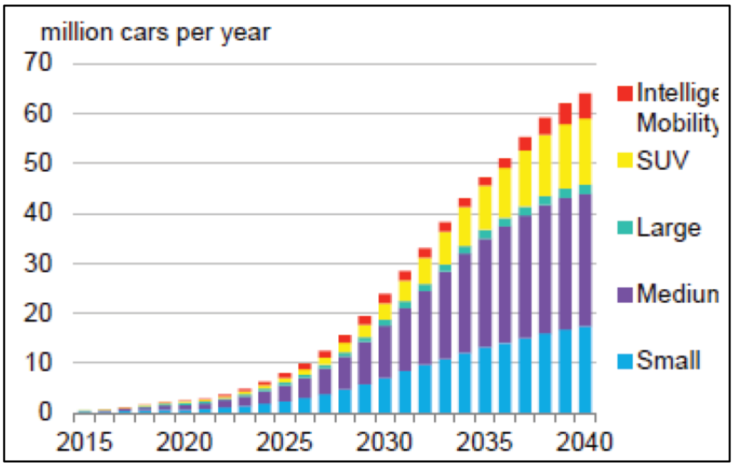
Source: Bloomberg, *Electric Vehicle Outlook 2020*.

The *small* and *medium* segments of electric cars, as shown in the table on the following page, are the ones that, according to Bloomberg forecasts, will drive registrations over the next twenty years.

As discussed in the following page, one of the most critical areas of competition is car charging technology. It should in fact be taken into account that, from a technical/technological point of view, electric vehicles are much simpler than thermal traction for various reasons. The electric motor, in addition to presenting limited room for improvement, requires a much smaller number of components used in the assembly phase compared to ICE vehicles. The electric car also has a low wear rate in relation to the kilometers traveled and, consequently, a comparatively longer useful life[82].

[82] ACEA, "*The Automobile Industry Pocket Guide, 2019-2020"*, Brussels, Belgium, 2021.

Fig. 9: **Electric car sales forecast by segment**



Source: Bloomberg, *Electric Vehicle Outlook 2020*.

The greatest interest of the public, as well as the fulcrum of the competition between the various companies in the sector, therefore lies in the need to find practical, rapid and sustainable solutions regarding the problem of alimentation. Indeed, the diffusion of electric traction depends significantly on the evolution of its main technology, namely the battery, which:

- affects the operational capability of the car;
- represents the cost item with the greatest impact (between 35 and 50 per cent of the total production cost)[83].

As has been said, attention on the damage to the environment and to the community resulting from the use of thermal propulsion engines was initially polarized on individual cars and this because of their significant incidence in the modal split of mobility and the strong impact that they cause to the environment in terms of transported passengers. However, it is evident that the electric revolution also involves the collective vehicle, intending to convert, in the short and medium term, the current diesel fleet with the introduction of electric buses with "BEB" batteries and "PCEB" fuel cell technology[84].

[83] Manufacturers currently have two options for marketing electric cars: the sale of the vehicle equipped with batteries (PSA Peugeot Citroën) or the rental of these through specialized agencies (Mercedes). Only one manufacturer (Renault) provides for both the sale of complete cars and the rental of batteries.
[84] Fonte: E-Mobility Report 2021.

The current situation of collective mobility on the road versus electric is very different from the individual one. While the latter, as has been said several times, is largely equipped with an internal combustion engine, the collective one on the road has, in part and for some time, already been served by vehicles equipped with hybrid or all-electric propulsion[85].

Among the electric road vehicles on road, certainly the most widespread is the traditional trolleybus which had its greatest success between the thirties and fifties of the twentieth century thanks to the combination of some advantages of the bus and those deriving from electric traction, and which has recently returned to some relevance by virtue of its recent technological advances[86]. We should also mention the collective means that only partially exploit the electricity supply, specifically: the bi/tri modal capable of drawing energy both from a heat engine and from an electric one, which can be powered, as well as by a line contact, from a set of batteries.

Furthermore, for years now, innovative wheeled collective vehicles have been in circulation, including the Phileas by Apts (*advanced public transport systems*), characterized by a driving system based on the presence of magnetic tracks, with an electric motor powered by a parallel hybrid consisting of a LPG or diesel motor generator, and the Civis of Irisbus-Siemens, with optical guide, capable of reading a special horizontal signage through a camera, in which the electric energy, captured through a *trolley* from a line aerial or from a combination of batteries and thermal group, powers an electric motor placed in the hub of the wheels.

[85] As far as guided vehicles are concerned, a historical role, which has recently returned to the fore, is played by standard trams. These are characterized by a restricted guide, in promiscuous or reserved location, on steel rails, mostly buried in the road pavement, generally fed in low voltage, 600/700 VDC, supplied by an overhead contact wire on which a gripping pantograph is supported, with return through the rails. Over the years, however, innovative technologies have been developed which have led to the circulation in some cities of trams powered by Aps (alimentation par le sol) soil, in order to eliminate the overhead line, especially in the prestigious areas of the cities. , and others, always powered from the ground, but inductive (Primove by Bombardier); still others, powered by batteries and fuel cells (Yongji motor in China, Feve in Spain), with substantial energy savings and greater available power than traditional vehicles.

[86] It is a semi-constrained guide vehicle due to the fact that the external energy supply source comes from an overhead network, generally low voltage, at 600/700 VDC, through a two-wire contact, one positive and one negative, on the which rests the gripping organ, the trolley, carried by two telescopic rods.

In a panorama in which urban electric mobility is already partly served by electric vehicles, the revolution represented by electric buses with basic battery technology, BEB and fuel cell, PCEB, is taking place.

Battery-powered buses or BEBs can be defined as means of road transport which, like ICE buses, are free-driving, circulate in mixed or reserved locations, only that the driving force is provided by an electric motor which uses it as an energy source primary chemical energy stored in rechargeable batteries. Battery-powered or supercapacitor electric buses, like electric cars, have been a reality for some time and are based on a technology that does not change the overall structure of the conventional bus. The only change is represented by the fact that the fuel tank, the heat engine and the gearbox-transmission unit are replaced by a battery/supercapacitor pack, an inverter and an electric motor with single ratio transmission[87].

In the face of a higher purchase cost (between 350 and 450 thousand euros), the electric bus allows considerable savings on energy and maintenance costs. In fact, an ICE bus consumes an average of 1.0 liters of diesel every 2.5 km and travels between 30 and 60 thousand km a year, consuming between 12 and 24 thousand liters of fuel with a cost for diesel alone (1.4 €/l•24kl/y) of ~33 thousand €/y. The specific consumption of the electric bus, on the other hand, is ~1.0 kWh/km, while the company cost of the electricity needed to power the fleet is low (0.12 €/kWh), which leads to an annual cost of energy around: 1.0•60 000•0.12 = 7200 €/yr, which can be further reduced by self-producing electricity in fleet depots with renewable energy systems (photovoltaic).

The size of the current vehicle fleet of "all electric" buses is not easy to quantify both due to the poor reliability of the data reported on the dedicated sites, and due to

[87] Even with regards to performance, the reasoning does not differ from that made for electric cars: for example, the standard 12 m buses, with a 220 kW permanent magnet motor, are characterized by a Vmax of around 100 km/h and an average range of about 250/300 km, but their cost of energy supply is much lower than conventional ones, being equal to a quarter/fifth of diesel or hybrid buses. Approximately the recharging times of the high-capacity batteries, generally placed on the floor of the vehicle, if this is done in storage, can be estimated at 5/6 hours; however, in the case of use of superchangers, the times are reduced to 5/10 minutes, as in the case of the 500 kW on-route top loader of the latest generation vehicles.

the not simple distinction between these and the hybrids of different types rapidly evolving in the global market.

The major manufacturers of "all electric" buses are Chinese Yutong with 40,000 buses in 2020, followed by BYD with 25,000 electric buses, within a Chinese market of around 200,000 units[88].

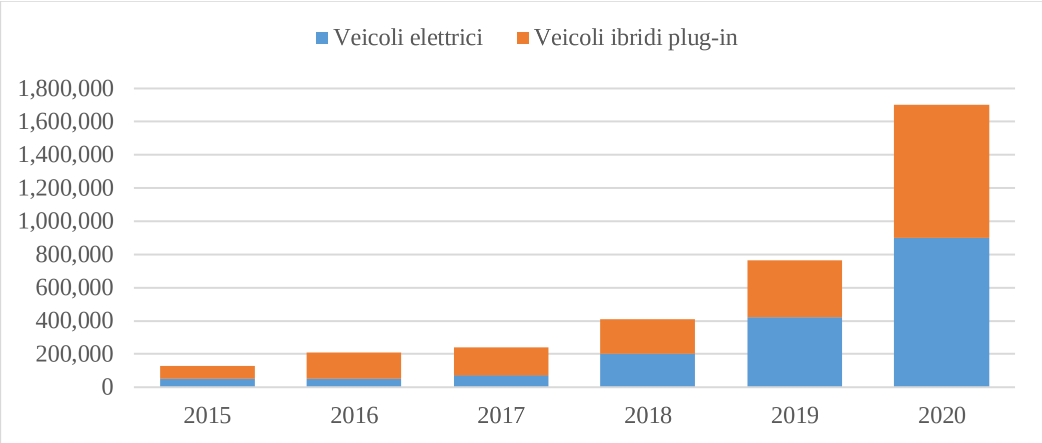
Collective mobility with BEB in China has undergone impressive development: growth stands at values of 35/40% per year, so much so that in 2019 the battery-powered buses in circulation represented 98% of those operating in the world: 170 out of 173 thousand[89]. According to the 2021 Report of the IEA (International Energy Agency) the consistency of the world circulating e-buses (including trolleybuses, hybrids, etc.) reached around fifty thousand units in 2020, with China as the absolute market leader. The smaller North American market, led by US-based Proterra, has a total of a thousand operational e-buses[90].

2.3.2. **Electric mobility in Europe**

Europe represents, together with the United States, one of the markets in which the offer of electric cars has been able, thanks to a growing demand, to record the highest rates of electrification of transport. In 2020, sixteen million cars were sold, of which 511,000 with alternative fuel supply. This was a significant increase compared to previous years, bringing total registrations to 1,753,307, of which 20.8% BEV, 11.3% PHEV and 53.1% HEV.

[88] Cfr. www.cleantechnica.com,
[89] Source: Bloomberg., 2021.
[90] Source: www.transportation.gov.

Fig. 10: **Electric car registrations in Europe, 2015-2020**

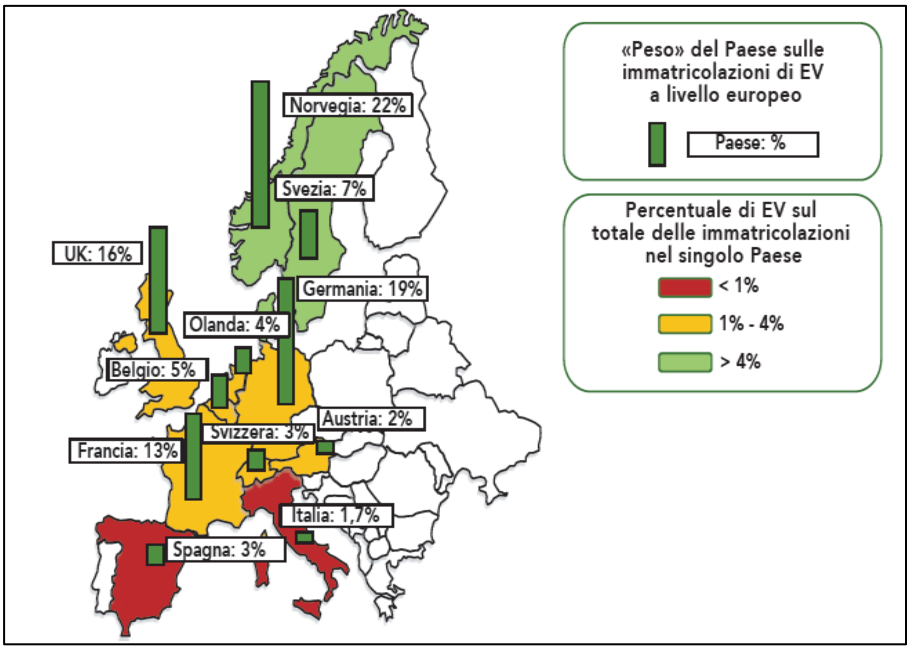


Source: Euromonitor, 2021.

However, national situations have different characteristics. Norway, in particular, currently ranks first for electric vehicles sold, with an electric market share that reached almost 90% of total cars sold in 2021. In terms of sales volume, the most dynamic markets are those of Germany and France, thanks to the state policy of incentives. Significant milestones were also recorded in Sweden (where in 2021 sales of BEVs and PEHVs exceeded those of petrol and diesel cars) and Great Britain (where registrations of electric cars reached 22% of the total). On the contrary, in Spain the share of electric cars in total registrations is struggling to exceed 1%[91]. The figure in the next page illustrates the percentage share of electric cars in relation to the vehicle fleet[92].

[91] E-Mobility Report 2021.
[92] Ibidem.

Fig. 11: **The European electric car market, 2020**



Source: E-Mobility Report 2020.

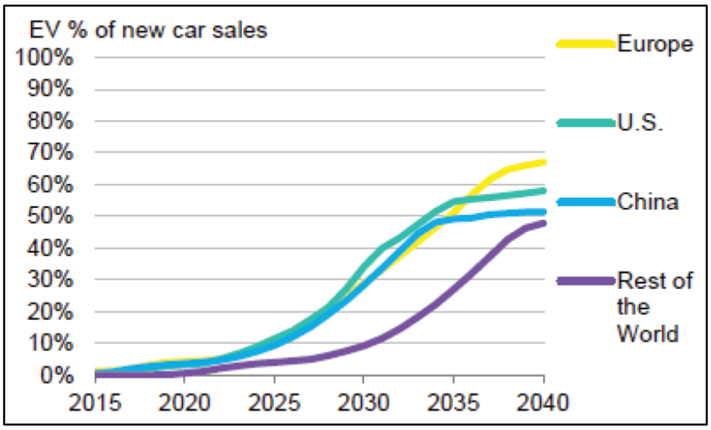
The high expectations of the European market are justified by the fact that the price of electric vehicles is competitive also in relation to the unsubsidized portion (from state contributions). Some segments will take longer, but by 2030 most vehicles will have achieved a market competitiveness equal to, if not greater than, that of ICE vehicles[93]. Only when this condition is consolidated will the maximum penetration capacity in the main vehicular mobility markets begin for EV vehicles. As the figure below illustrates, the maximum penetration of electric cars is expected in Europe by 2040[94].

During this time frame, battery electric BEVs are expected to start to outpace hybrid PHEVs which will continue to drive EV adoption until 2025. After that year, BEVs are expected to take over and will account for most electric vehicle sales[95]. This depends on an effective engineering complexity of the PHEV vehicle platforms, the high cost of which is linked to the presence of power and transmission units that

[93] E-Mobility Report 2021.
[94] E-Mobility Report 2021.
[95] Ibidem.

will contribute to making BEV mobility increasingly attractive, especially in the long term[96].

Fig. 12: **Penetration of EVs in different markets over the long term**



Source: Bloomberg, *Electric Vehicle Outlook 2020*.

In 2021, in Europe, the best-selling car was the Volkswagen ID.3, which preceded the Renault Zoe and the Kia Niro (however, if the French model is down compared to 2021, the Korean car recorded a steady growth). The first five places also include the Skoda Enyaq and the electric Fiat 500.

Tab. 4: **Electric car sales in Europe in the first half of 2021**

Volkswagen ID.3	32.598	Volkswagen ID.4	21.858
Renault Zoe	23.856	Ford Mustang Mach-E	19.884
Kia Niro EV	23.718	Volkswagen e-up!	19.182
Skoda Enyaq	21.894	Hyundai Kona EV	19.044
Fiat 500 elettrica	21.864	Peugeot e-208	15.738

Source: E-Mobility Report 2021.

Furthermore, Europe is the area of the world where, after China, there has been the greatest diffusion of non-polluting traction buses. It is estimated that the total

[96] Bloomberg, "*Electric Vehicle Outlook 2020*".

number of BEBs in circulation is fifteen thousand units at the end of 2020. European manufacturers are only now timidly entering the field of electric collective transport, but the current growth suggests that the market is leaving the test phase to enter in that of commercial development: it is expected, in fact, to reach 50% of the fleets made up of battery-powered buses in 2030[97]. Currently the most important European markets of BEB are: United Kingdom, France, Germany, Holland and Poland. Italy is starting to experiment with battery-powered buses: Turin (50 Byd), Milan (25 Solaris), Bergamo (20 Solaris) are the first cities where 12 m city buses are being tested in view of a renewal of the fleets. It is clear that the European e-bus market is directed towards BEBs, which already represent 70% of it today.

FC electric buses also represent a response to the request for a clean environment and sustainable development, i.e. a solution to the problems of environmental, chemical and acoustic pollution generated by today's widespread diesel-powered vehicles. *Fuel cell* buses are almost identical to diesels in terms of design, capacity and performance: the difference lies in the presence of several hydrogen tanks in the fuel system, made up of combustion cells, and in the propulsion system, made up of electric motors. FC technology is rapidly evolving: new models such as the Mercedes *Citaro* adopt powerful electric motors, often integrated in the wheel hubs, and use high voltage lithium-ion batteries for energy recovery and storage, a fact which makes them virtually hybrids[98]. Their adoption for public transport in Europe is a consequence of the European Union's growing interest in vehicular transport using hydrogen batteries, which plays a fundamental role in the decarbonisation strategy. This element, even if today it does not yet appear in the energy mix and is used only as a raw material (feedstock) in the chemical industry, is destined to assume critical importance in strategies aimed at obtaining decarbonised energy.

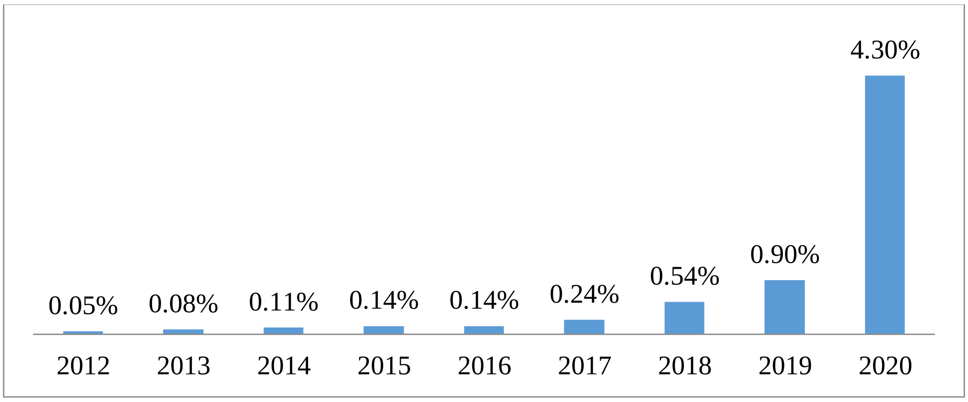
[97] Ibidem.
[98] During braking, the electric motors act as generators, inverting their function by recovering energy which is stored in the batteries and made available in the acceleration or starting-off phases. The fuel, gaseous hydrogen compressed to 35 MPa, is transported in cylinders installed on the roof in conditions of maximum safety. Maximum torque is immediately available and acceleration is progressive.

2.3.3. **Electric mobility in Italy**

Shifting attention to Italy, it is possible to note how in our country, even if the electric car market is characterized by an expansionary trend similar to that underway in Europe, it ranks among the last places in terms of sales volumes. Starting from 2018 (and above all in 2020), however, new registrations have recorded a significant increase: if 17,000 full electric cars were purchased in 2019, in the following year they increased to 60,000, with a market share that it grew from 0.9 to 4.3%[99].

The increase in sales has been accompanied by an expansion (albeit insufficient) of the charging infrastructure. At the end of 2021, electric car owners could use around four thousand public charging points in our country, one eighth of which were *high power*. However, the location of the columns highlights an evident geographical imbalance, since two thirds of them are located in the regions of Northern Italy. Even if these Regions represent the areas with the greatest demand for electric cars, the scarcity of recharging points in Central and Southern Italy makes long-distance journeys problematic and limits the recharging possibilities of buyers in the Southern Regions[100].

Fig. 11: **Share of the automotive market achieved by electric cars in Italy**



Source: ANFIA, 2021.

[99] Source: ANFIA, 2021.
[100] G. Fontanelli, "*Autoshock*", cit., p. 36.

In 2020, compared to a total fleet of 45 million cars, alternative fuel cars totaled almost six hundred thousand. Hybrid cars accounted for 80% of green cars registered in Italy, while *full electric* ones remain a limited option.

Tab. 5: **Car fleet in Italy, 2020**

	Hybrid Petrol-El.	Hybrid Diesel-El.	BEV
Cars	501.868	40.860	53.079
Commercial Vehicles *(CV)*			
- Goods Lorries	1.797	4.022	5.950
- Special Lorries	96	35	672
- Road Tractors	1	1	21
- Buses	8	138	512
Total (*CV*)	1.902	4.196	7.155
Total motor vehicles	503.770	45.056	60.234

Source: ANFIA, 2021.

Shifting attention to the best-selling models, it is possible to note how in 2020 the five cars that rank first are the Renault Zoe, the Smart fortwo, the Tesla Model, the Volkswagen e-UP! and the electric Fiat 500. The following table shows the data relating to units registered during 2020.

Tab. 6: **Electric car sales in 2020 in Italy**

Renault Zoe	5.470	Peugeot e-208	1.733
Smart fortwo	3.770	Hyundai Kona Electric	1.464
Tesla Model 3	3.352	Opel Corsa-e	1.310
Volkswagen e-UP!	2.839	Nissan Leaf	1.251
Fiat 500 elettrica	2.175	Renault Twingo	1.172

Source: E-Mobility Report 2020.

A study carried out by Politico di Milano has identified four different clusters of consumers, classified according to the level of attraction and propensity to use electric cars[101]. Those convinced of the advantages (both economic and environmental) of "green" cars (42% of potential buyers of electric cars) are matched by a cluster of individuals skeptical about the benefits of electric cars (31%). Less numerous are the group including those who appreciate both performance in terms of sustainability and economic savings (14%) and the group of those who are attracted by the service components and innovation (13%).

2.4. **Agreements and *Joint Ventures* in the electric car sector**

The statistics illustrated in the previous pages show how all the main manufacturers are now active in the electric automotive sector. The two strategies implemented consist, on the one hand, according to a widespread approach, in the conversion (or hybridisation) of production to petrol; on the other, to a lesser extent, in the creation of independent brands and product lines. This second option, chosen for example by Renault, involves a greater financial commitment, since it requires the creation of an independent supply chain with respect to traditional establishments.

The operational plans of the major manufacturers are not yet clearly configured. In fact, long-term strategic choices would require a more stable regulatory and competitive framework, as well as a trend in demand less subject to national incentives and periodic decisions to abate emissions[102]. While waiting to be able to outline autonomous industrial plans, the *players* in the sector have created a series of alliances which aim to share research costs and reduce business risk.

A first area of *partnership* consists in the development and supply of accumulators. These alliances are motivated by two sets of reasons: the exploitation of external expertise and the sharing of development costs and risks. After all, electric

[101] Politecnico di Milano, "*E-Mobility Report 2020"*.
[102] G. Fontanelli, "*Autoshock",* cit., p. 6.

cars still have particularly high assembly costs (so much so that on the market the minimum prices are around twenty-five thousand euros) and significant barriers to the internalisation of all modules. The two major barriers consist in the fact that the batteries for *new vehicles* must be acquired from external suppliers and that the small numbers of units produced do not allow for the economies of scale typical of the *automotive* sector to be exploited[103].

These critical issues have prompted manufacturers to implement *joint ventures* both for the procurement of specific modules and for the supply of latest generation batteries[104]. The objective of these alliances is, in the first place, to oversee a research area capable of assigning a significant competitive advantage to the *first mover*, i.e. the manufacturer capable of supplying a vehicle equipped with a powerful, fast-charging battery and ecologically sustainable.

The alternative power supply to batteries, for electric vehicles, is represented by *fuel cells*. These, unlike more traditional batteries, do not constitute an energy storage, storage and conversion element, but only the conversion of energy stored elsewhere[105]. Fuel cells, or FCEV (*fuel cell electric vehicle*) technology, can be powered in various ways, among which, the one that determines zero-emission propulsion, involves the use of hydrogen introduced directly into a tank and stored or in liquid, or in compressed form under high pressure, or in the form of hydrides[106]. Other *fuel cell* power supply methods are still based on the use of hydrogen but with the difference that this energy vector is produced on board through the conversion (*reforming*) of a traditional hydrocarbon or, again, of methanol CH3OH and, in this case, the cells are called Dmfc (*direct methanol fuel cell*). In both, however, the presence of hydrocarbons leads to polluting emissions during the process of transforming chemical energy into kinetic energy[107]. Fuel cells, although still a niche

[103] D. Andre, S.J. Kim, P. Lamp, S.F. Lux, F. Maglia, "*Future generations of cathode materials: an automotive industry perspective",* in "Journal of Materials", 2018, p. 111.
[104] WH Susilo, "*Study on the development the market position company of fully electric vehicles",* E3S Web of Conferences, 2021.
[105] AlixPartners, "*Betting Big in Electrification and Autonomous",* cit., p. 16.
[106] Ivi, p. 18.
[107] Ibidem.

element in the electric mobility market, could in the future represent an alternative to the more conventional battery mode[108].

A second area in which *partnerships* have multiplied is related to the components of electric motors. In this context, moreover, the alliances, motivated by the need to share the risks and costs of innovation, do not concern the supply of modules but the collaboration with the assemblers themselves. Bloomberg has estimated that this strategy of sharing technological *know-how* will be able, in the seven years between 2019 and 2025, to lead to the design and production of around two hundred and eighty electric car models[109]. The same agency highlights, moreover, how mass electricity production, capable of marketing high volumes of deeds, cannot do without creating the conditions for economies of scale also in the electricity sector[110].

Furthermore, as regards the aspect relating to sources, it is not possible to force the introduction of electricity on a global scale, without first solving the problem of how to produce energy from clean and renewable sources. If we were to rely on traditional ones that exploit fossil fuels, the risk could be that of shifting emissions from cars to the primary processing plant. This would lead to an improvement in the livability level of cities but would not change, in a global vision, the terms of the problem. This danger is only partially avoidable by the ever-increasing levels of efficiency that thermal power plants are reaching, which produce more electricity with less fuel, and by their emission abatement systems, much more efficient than any technology that can be implemented on thermal vehicles[111].

The radical solution to the problem lies, however, in the use of renewable sources, wind, solar, hydroelectric, etc., which, although growing exponentially all over the world, still require huge investments to be able to transform all the energy needed to electric mobility. While some countries, such as Norway, Sweden, France,

[108] Proof is given by the fact that, since the end of 2014, the Toyota Mirai, the most successful FC car, is available for sale in Japan, California, United Kingdom, Denmark, Norway, Germany and Belgium.
[109] Bloomberg, "*Electric Vehicle Outlook 2020*".
[110] U. Bardi, M. Rossi, L. Celi, "*Ipotesi sulla mobilità del futuro: benefici e criticità sulla possibile transizione verso l'auto elettrica*", cit., p. 42.
[111] G. Fontanelli, "*Autoshock: viaggio nella rivoluzione dell'auto elettrica*", cit., p. 79.

Germany, Japan, China and the United States, are at the forefront, other geographical areas are lagging behind in their large-scale introduction[112].

Another aspect concerns the problem of the absorption of electricity at peak times, a criticality that can lead to the unsustainability of the production of clean energy from exclusively renewable sources. On the one hand, in fact, primary renewable sources are typically discontinuous, unlike fossil fuels and nuclear power, on the other hand, the recharging times for electric vehicle batteries are characterized by critical peak periods[113]. Enedis, a French energy distribution company, states that, in France, the recharging of electric vehicles absorbs 30% of the country's entire availability during peak evening hours, when users return home. The data provided by Enedis also show that already in 2019 the sum of the powers installed in the 122,000 recharging stations corresponded to 739 MW, equal to the entire production of the 240 wind farms present in the country. Moreover, if France has nuclear energy available, which in 2018 represented 72.3% of the electricity produced in total and made available in the country, in other contexts, such as Italy for example, the cost of recharging and the possibility of having a surplus of energy in the moments of greatest absorption will be a crucial problem[114].

From a technological point of view, one solution is represented by the role that electric cars can play in *smart grids*, electrical distribution networks managed in an efficient and rational way that minimize overloads and voltage variations. In other words, *smart grids* enable a series of strategically important services and functions such as storage, i.e. the accumulation of energy produced by renewable plants in vehicle batteries. The future goal entrusted to *smart grids* is to ensure that all the recharging points of electric cars, both individual and collective, are connected to them in order to allow energy storage in the production peaks of renewable generation

[112] P. Ferrari, "*Il processo di diffusione dell'auto elettrica*", cit., p. 503.
[113] AlixPartners, "*Betting Big in Electrification and Autonomous*", cit., p. 15.
[114] Ivi, p. 15.

sources in accumulators of the cars to then make sure that they can make it available on the net at times of maximum demand[115].

2.5. **Advantages and disadvantagesof the electric car**

The road towards the electric car currently seems to be traced at the level of government policy and industrial plans. The growth of the BEV market is also facing some significant critical issues, capable of slowing down its development. In the first analysis these concern, in addition to the economic and energy macro-problems, the appeal of the electric car to the user[116]. Above all, one wonders how the obstacles that make it less accessible to large segments of the population can be overcome and, on the other, how decisive some current strengths that today seem to favor its market penetration will still be[117].

As regards the former, three aspects are more important in curbing the attractiveness of the electric vehicle compared to the ICE one: the cost of the vehicles, their autonomy and the problems of refueling.

The modest propensity of users to purchase the BEV vehicle derives, first of all, from its high cost, largely due to that of the batteries, which, for the same performance, make it less economical than the ICE car[118].

To this initial handicap must be added the strong loss in value of the second-hand product resulting from the reduction over time of the performance of the batteries themselves, which determines a contraction of its value by 50% in a few years. As

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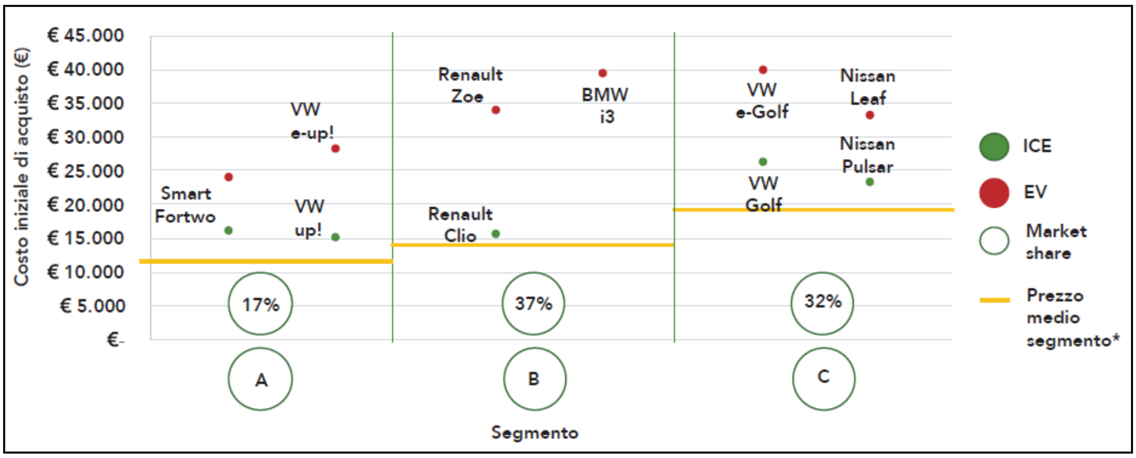
[115] U. Bardi, M. Rossi, L. Celi, "*Ipotesi sulla mobilità del futuro: benefici e criticità sulla possibile transizione verso l'auto elettrica",* cit., p. 46.
[116] P. Ferrari, *Il processo di diffusione dell'auto elettrica*, in *Ingegneria ferroviaria*, 2021, 6. p. 496.
[117] U. Bardi, M. Rossi, L. Celi, *Ipotesi sulla mobilità del futuro: benefici e criticità sulla possibile transizione verso l'auto elettrica,* cit., p. 34.
[118] The cheapest BEV on the market today is the Smart ED which costs around 24,000 euros.

for the fuel cell car, however, its technological complexity puts it on the market at a price that is inaccessible to the vast majority of potential buyers[119].

A research conducted by the Amsterdam Roundtable Foundation has estimated that, from a comparison relating to the *total cost of ownership* of an ICE and BEV car, the latter enters the "frontier of convenience" if it is used for at least four years and traveled fifteen thousand kilometers per year. In turn, the E-mobility Report found that this frontier operates once it reaches twenty thousand kilometers a year (fifty-five a day). It should also be noted that the *total cost of ownership* varies considerably from car to car.

Fig. 13: **The total cost of ownership**



Source: E-Mobility Report 2020.

In recent years, the progressive (relative) reduction in the price has led to greater attractiveness for both electric technologies. It is evident, therefore, how the economies linked to their production on an industrial scale and product innovations will lead to a reduction in purchase costs[120].

[119] The Toyota Mirai is sold for 66,000 euros, while the Hyundai ix35FC, one of the first mass-produced with this technology at the Ulsan plant in South Korea, equipped with a drive similar to that of BEV cars and with a range not far from that of petrol or diesel cars is placed on the market at a price of 68,000 euros

[120] U. Bardi, M. Rossi, L. Celi, *Ipotesi sulla mobilità del futuro: benefici e criticità sulla possibile transizione verso l'auto elettrica,* cit., p. 36.

Then there is the aspect concerning the reduced autonomy of BEV vehicles, which is also central in the decision-making process of choice. For both technologies, the range depends on the energy available on board, which is in turn linked to the energy density of the battery or of the compressed hydrogen in the tank. While the latest generation BEV cars, belonging to the upper class such as Tesla's *Model S*, have a range of around five hundred kilometres, compatible with the needs of a significant portion of users, those of the small-medium class, much more numerous and contestable due to the lower price, they have, on the other hand, an autonomy that on average does not exceed 150/200 kilometres. This limit, certified by the US government agency EPA (*Environmental protection agency*) and estimated with favorable driving conditions, determines a strong impediment to the purchase, especially for the portion of mobility that travels great distances or makes intensive use of the car[121]. Moreover, the modest autonomy constitutes a problem, often decisive in the choice, even for users who make daily trips of shorter lengths and less than the distance allowed by the autonomy of the vehicle. These, which constitute the absolute majority of all mobility[122], are in fact also conditioned by problems of autonomy. To explain this phenomenon, the literature refers to the so-called *range anxiety*, i.e. the concern of not being able to have enough energy to make one's journey even if this is presumably less than the vehicle's range.

Conversely, *fuel cell* cars generally have a large average range, around six hundred kilometres. This datum is also surpassed (basis to think that the Hyundai FE-FC guarantees movements of at least eight hundred kilometres), marking a substantial equality with respect to internal combustion engine cars. This leads to the conclusion that, although they are undergoing rapid technological evolution, BEV technology cars and FCEV technology cars will be able to coexist on the market: the first is more suitable for private cars and medium and small city buses, while the second it is

[121] P. Ferrari, *Il processo di diffusione dell'auto elettrica*, in *Ingegneria ferroviaria*, 2021, 6. p. 499.
[122] As certified by the statistics which, for example, say that in Italy 68% of daily car journeys are less than 10 km. See Isfort, 2016.

designed for individual high-performance vehicles, for standard urban and extra-urban buses and for trucks[123].

A further element of little satisfaction with electric cars concerns the difficulty involved in refueling them in relation to recharging times. BEVs can, theoretically, recharge anywhere, at home, in car parks, shopping centres, service areas. but with long recharging times and often not compatible with the needs of the owners. A 3 kW home battery charger, for example, needs at least six hours of recharging to ensure a range of 100 km. Charging times are not always the same, but depend on the rated power of the battery chargers and this can vary considerably, especially in public facilities. These systems, numerically insufficient in most countries, can be sized for fast recharges, with powers ranging from 50 up to 350 kW and more, the latter capable, for example, of carrying out a "full tank" valid for 400 km in ten minutes[124].

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[123] R Bohnsack, J Pinkse, *Value propositions for disruptive technologies: Reconfiguration tactics in the case of electric vehicles,* in *California Management Review*, 2017, 2, p. 15.
[124] P. Ferrari, *Il processo di diffusione dell'auto elettrica*, cit., p. 501.

Chapter third

The future history of the electric car

3.1. Types of electric cars

The current electric motor road vehicles on the market are powered in two ways: by rechargeable batteries or by hydrogen through a fuel cell (*fuel cell*) which supplies electricity to the engine. Both power supply methods allow, in the operating phase, the elimination of pollutants (PM10, nitrogen and carbon oxides, unburned hydrocarbons, etc.), connoting themselves as zero emissions means or ZEV[125].

The two systems can be combined to create a hybrid vehicle with *fuel cell* and battery: at low speeds, for example in the city, cars work like all electric vehicles, i.e. exploiting the energy accumulated in the battery, which is recharged when the car slows down or brakes as the engine turns into a generator. Outside the city, when the car is traveling at higher speeds, the electric motor is powered only by the hydrogen cell; if more power is required, e.g. in the event of a sudden acceleration, the battery returns to function to support the system by adding itself to the cell.

BEV vehicles use as primary energy source the chemical energy stored in an energy tank consisting of one or more rechargeable batteries and made available by these to the engine in the form of electric energy. Significant progress has been made in the last two decades with the discovery and development of innovative batteries such as lithium-ion and lithium-polymer batteries[126].

An intermediate path between the ICE internal combustion engine vehicle and the "all electric" FEV, is the so-called HEV (*hybrid electric vehicle*), in which a petrol/diesel-powered heat engine and a battery-powered electric motor coexist. The

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[125] O. Baccelli, R. Galdi, G. Grea, "*L'e-mobility. Mercati e policies per un'evoluzione silenziosa",* cit., p. 47.

[126] M. Traub, A. Maier, K.L. Barbehön, "*Future automotive architecture and the impact of IT trends",* - IEEE Software, 2020, p. 3.

batteries are recharged by the combustion engine and have a limited autonomy[127]. Depending on the speed, one of the two types of drive takes over or both.

In "series hybrids" the internal combustion engine is not connected to the wheels, but has the task of generating the current to power an electric generator and the electric motor which transforms it into motion. Superfluous energy, on the other hand, is used to recharge the batteries. Because electric motors are capable of operating over a wide RPM range, this architecture removes or reduces the need for a complex drive train. Series hybrids are considered the most appropriate and efficient for motor vehicles that require continuous braking and restarting, such as urban vehicles, buses and taxis, which use battery-powered electric travel.

A second architecture that is widely used in hybrid cars is the parallel hybrid. It is characterized by a mechanical power coupling node, whereby both motors (electric and thermal) supply torque to the wheels simultaneously. The battery pack is smaller than the series one. Generally the Ice engine is dominant while the electric one has the function of providing greater power in times of need (starting off, accelerating, etc.). The advantage lies in the elimination of low gears (which consume more fuel) and consumption with the wheels stationary or at low speed.

In the series-parallel hybrid, the heat engine transmits power directly to the wheels but can be disconnected. A mechanical node (Psd, *power split device*) divides the power between the two engines and realizes the mechanical coupling between the heat engine, the two electric machines (generator and engine) and the final transmission shaft through the combination of a gear train planetary gear and a reduction gear[128].

A sophisticated system of over forty control units monitors the consumption of the batteries in relation to the use of the electric propulsion and commands the ignition or pause of the internal combustion engine. The electric motor is always active (but not in motion, it is active only when the vehicle is moved by it or when it has to act

[127] The pure hybrid HEV does not require connection to the power grid.

[128] A. Emadi, Y.J. Lee, K. Rajashekara, "*Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles",* in "IEEE Transactions on industrial electronics", 2008, 55 (6), pp. 2237-2245.

as an acceleration support, or as a brake), reducing to a minimum the energy waste typical of standing starts, forwarding in low gears, acceleration, braking and stopping[129].

Finally, PHEV hybrids are vehicles with batteries that can be connected to the power grid called PHEV (*plug-in hybrid electric vehicle).* These cars use batteries with a longer range than traditional hybrids. The battery is charged by the heat engine but can also be recharged by connecting it to the network. *Plug-in* hybrids represent the latest frontier in the evolution of hybrid cars. The internal combustion engine is no longer indispensable for the locomotion of the vehicle and is used as an aid to motion and to extend the autonomy of the car which uses the battery for movement[130].

The greatest advantages of hybrid vehicles are found in driving at low speeds typical of runoff in urban areas. In fact, at those revs, only the battery-operated electric motor comes into operation with consumption drastically lower than that of the internal combustion engine, also because the low gears (those that consume more fuel) are eliminated; emissions of chemical pollutants are eliminated in electric driving and noise emissions are reduced; moreover, with stationary wheels, consumption is zero because the *stop & start* device comes into operation. The disadvantages, however, are not negligible: the price is high, about 40% more than the equivalent of fossil fuel; the vehicles are heavier than the ICEs due to the presence of the large battery pack and the electric and thermal engines: repairs are expensive also due to the complex technologies used and the use of electronics.

Nonetheless, the hybrid car market is growing rapidly. This segment, according to analysts, is destined to grow at a rate of 16%/year for the period 2020/25, characterizing itself as the solution identified to renew a very old vehicle fleet. More generally, the goal of decarbonisation, set for 2050, is pushing manufacturers to gradually expand their offer of electric cars. In 2021, these cars, with seven million

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[129] A. Emadi, Y.J. Lee, K. Rajashekara, "*Power electronics and motor drives in electric",* cit., p. 2242.

[130] There are two basic configurations of plug-in hybrids: the Phev series, also called EREV, in which only the electric motor drives the wheels and the internal combustion engine supplies electricity to recharge the battery when it is nearly flat; they can go electric for short distances; the parallel Phev, in which both the electric and thermal motors give torque to the wheels and move the vehicle in all driving conditions; driving in electric only takes place at low speeds.

registrations, covered 9% of the world market (reaching moreover 44% for the bus segment). According to Bloomberg[131], in 2025 the electric car market will reach twenty-one million cars sold (ie 23% of the market). The two areas characterized by the greatest growth will be China and Europe (each with 39% of the market), with some countries (Germany, United Kingdom, France) which will register a share of registrations close to 50%.

The same report estimates that, in the light of the *phase-out* imposed by the European Union, in 2040 registrations will be close to forty million cars, approaching 90% of the market.

Tab. 7: **The evolution of the electric car market**

Anno	*Registrations*	*Market share*	*Total Fleet*
2021	6,6 millions	9%	16,7 millions
2025	20,6 millions	23%	77 millions
2040	70 millions	90%	700 millions

Source: Bloomberg, *Electric Vehicle Outlook 2021.*

3.2. **Hydrogen as a new frontier: technological progress**

International documents underline some characteristics of hydrogen capable of making it the energy carrier which, according to the most recent estimates, will tend to prevail in the industrial, transport and residential sectors[132]. In the first place it is a clean solution, as it is produced from renewable energies and has a zero emission factor in its final uses. Seondly, hydrogen is the most widespread element int the globe and would guarantee an almost unlimited availability (contrary to current petroleum-derived fuels). Furthermore, hydrogen makes it possible to use existing

[131] Bloomberg, *Electric Vehicle Outlook 2021.*
[132] M. Della Pietra, S. McPhail, L. Turchetti, G. Monteleone, "*I 'colori' dell'idrogeno nella transizione energetica",* 2020, in https://www.eai.enea.it/archivio/energia-e-green-new-deal-sommario/i-colori-dell-idrogeno-nella-transizione-energetica.html

infrastructures and therefore allows for the implementation of coupling strategies with the gas and electricity industries[133].

A third feature is to improve, on the one hand, the level of stability and flexibility of the integrated electricity network and, on the other, the contribution of renewable energies thanks to the storage capacity[134]. The diffusion of hydrogen as a storage of decarbonised energy is closely linked to the increase in the percentage of penetration of these sources in the energy mix. With the increase expected for the next few years, the share of intermittent and non-programmable energy sources (solar and wind) will increase significantly with a consequent imbalance between production and demand. In this context, the need for short and long-term storage systems is essential and hydrogen is considered an energy carrier for long-term storage[135].

Massive electrification of the transport sector through battery electric and fuel cell vehicles has become a necessity. Many projects in recent years have involved the creation of pilot fleets of hydrogen vehicles, such as city buses or *car sharing* services. Among the various initiatives it is possible to mention the H2ME, which aims to introduce hydrogen-powered cars, commercial vans and trucks in Europe, with related refueling infrastructures[136].

Hydrogen-powered cars usually use on-board fuel cells to produce electricity: they are therefore electric cars to all intents and purposes, but internally they produce the electricity necessary for traction, through an electrochemical reaction. Compared to battery-powered electric cars, they have the advantages of high autonomy and rapid refueling times, but currently have a higher overall cost than other propulsion systems[137]. Germany is the country that has invested the most globally and expects 1,800,000 hydrogen cars to be in circulation on its territory by 2030.

A hydrogen vehicle is a vehicle that uses hydrogen as a fuel or energy carrier: this expression can refer to both a car and any other means of hydrogen transport, road, rail, naval or air. In these vehicles, the chemical energy of hydrogen, through

[133] Ivi, p. 3.
[134] ENI, "*Idrogeno e transizioni energetica",* Milano, Eni, 2020.
[135] G. Glenk, S. Reichelstein, "*Economics of converting renewable power to hydrogen"*, in "Nat. Energy", 2019, 4, pp. 216–222.
[136] Confindustria, "*Piano d'azione per l'idrogeno",* Milano, Confindustria, 2020, p. 7.
[137] Mobilità H2, "*La tecnologia della mobilità elettrica a idrogeno",* 2020, in https://www.mobilitah2.it/tecnologia.

the reaction with oxygen in a fuel cell, is converted into direct electric current which feeds, suitably managed via chopper/inverter, an electric traction motor.

Only in the first decade of the 2000s did some car manufacturers (the German Daimler and Mercedes, the Japanese Honda and Toyota and the South Korean Hyundai) begin to develop hydrogen and *fuel cell* cars[138]. These cars have zero emissions: compared to BEVs; they have the advantage of a great autonomy with a full tank of hydrogen (500/600 km), the speed of the refueling operation which takes about three minutes, comparable with that of ICE vehicles and the performance, independent of the quantity of H2 on board. Among the many problems remains that of the diffusion of charging stations which, at present, are still very few and located only in the most advanced markets (United States, China, Europe, Japan) and the cost of the vehicles themselves, still high, given the modest production volumes[139].

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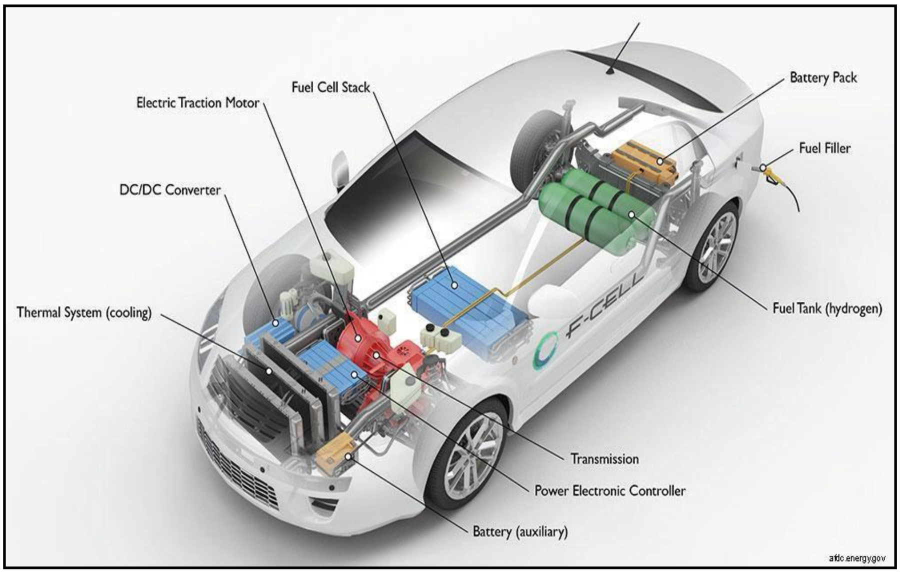
[138] M. Gurz, E. Baltacioglu, Y. Hames, "*The meeting of hydrogen and automotive: a review",* in "Kaya - International journal of hydrogen", 2017, 1.

[139] The technology for moving a hydrogen car requires one or more tanks of compressed H2, capable of containing about 5/6 kg of H2, a Pem membrane fuel cell powered by hydrogen and air blown into the cell by a special compressor, a DC/DC chopper at the fuel cell outlet with the task of increasing the voltage generated by the cell pack up to the correct voltage for the operation of the electric motor, a DC/AC inverter, a direct motor-wheel transmission. Furthermore, the presence of an auxiliary battery allows the recovery energy to be conserved during braking and to transfer it to meet energy requests during acceleration: it is necessary because fuel cells have a non-immediate response, i.e. they are unable to follow sudden accelerations requests while driving.

Fig. 15: **Components of a *fuel cell* car**



Source: www.afdc.energy.gov

Hydrogen-powered fuel cell buses represent a solution to the problems of environmental, chemical and noise pollution generated by today's diesel-powered vehicles. Hydrogen technology combined with electric motors is a possible response to the request for a clean and sustainable environment. FC buses are almost identical to diesels in terms of structure, capacity and performance: the most marked difference is the operating noise which in these electric motor vehicles is limited to the rolling of the tyres. Being silent and non-polluting (only water in the drain), hydrogen buses are very comfortable and appreciated by public transport users.

3.3. **The potential and criticalities of the different propulsion systems: a comparison**

One of the key aspects for the development of electric vehicles concerns the energy efficiency of the two competing systems: batteries and hydrogen and fuel cells.

From a structural point of view, the battery electric vehicle is simpler in terms of components. However, to move a road vehicle a considerable amount of energy must be stored on board and the battery, even if perfected and miniaturized, is still far from accumulating energy per kilogram of mass of a value comparable to that of fossil fuels or hydrogen. In fact, the best batteries on the market, lithium-ion, contain 0.2 kWh/kg while the fossil fuel, petrol, is around 13.3 kWh/kg[140]. Therefore, hydrogen was looked at as an alternative as it contains 33.3 kWh of energy per kilogram, almost three times the fossil fuel and 166 times the specific energy of an advanced battery. Furthermore, hydrogen is the most abundant element in the universe, being present in water for 11.19% and in all organic compounds and living organisms. Unfortunately, the production of hydrogen by electrolysis of water according to a process that involves the generation of electricity from renewable sources is an energy-intensive and expensive method, but it promises to become convenient if the production process is improved[141].

The parameters chosen in the literature to compare BEV and FCEV are very different. Some researchers compare the total cost of ownership (TCO) of the two systems, which shows the convenience of the BEV up to a range of ~300 km[142]. Others compare the efficiency of two cars with the same engine power and range[143]. This comparison shows that the energy needed by the two systems to get the wheels to 60 kWh which would allow cars to travel about 480 km with a Nedc cycle. These studies show that the BEV converts 60/87.6 = 68% of the electricity produced into energy at the wheels; on the other hand, the FCEV vehicle uses 60/168.7 = 35.5% of the electricity produced on site from renewable sources at the wheels. Therefore, for

[140] J.M. Desantes, S. Molina, R. Novella, M. Lopez-Juarez, "*Comparative global warming impact and NOX emissions of conventional and hydrogen automotive propulsion systems",* in "Energy Conversion and Management", 2020, 11.

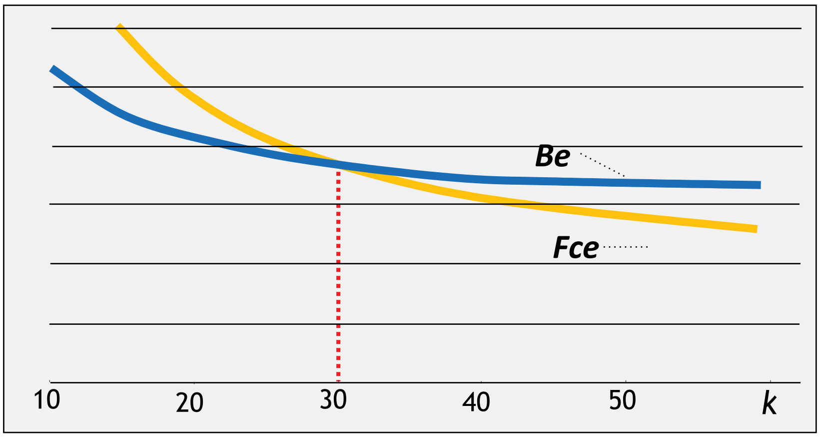
[141] Currently, the best water-splitting electrolysers produce 1 kg of H2 by expending 45-50 kWh of energy with an efficiency of 70% (alkaline) or 80% (Pem electrolyser). However, a new Iccom-Cnr process is able to obtain 1 kg of gaseous H2 from alcoholic solutions using only 18.5 kWh of renewable energy.

[142] A. Le Duigou, Y. Guan, Y. Amalric, "*On the competitiveness of electric driving in France: impact of driving patterns*", in "Renewable and sustainable energy reviews, 2014, 37, pp. 348–359.

[143] J.M. Desantes, S. Molina, R. Novella, M. Lopez-Juarez, "*Comparative global warming impact",* cit., p. 22.

the same amount of energy available to the wheels, a *fuel cell* car would require about twice as much energy as a BEV vehicle.

Fig. 16: **Tco trend as the range of vehicles varies**



Source: A. Le Duigou, Y. Guan, Y. Amalric, "*On the competitiveness of electric driving in France,* cit., p. 352.

However, this comparison does not take into account the mass of the battery pack to be transported on board the BEV which, to allow 480 km of autonomy (Epa), should be around 600 kg, instead of the 450 kg of the FCEV. This means that the masses of all the components of the vehicle must be increased, starting from the braking system and ending with the dimensions of the engine. The mass of the battery pack influences the entire architecture of the vehicle, consumption, manoeuvrability, space on board, performance and, last but not least, cost. However, the advantage in energy efficiency of the two electric vehicles compared to an internal combustion engine car is enormous: in fact, the energy that reaches the wheels of the ICE vehicle is a variable share between 16 and 20% of that contained in the petrol stored on board and only 12% of the energy available at the source.

A study by Notter and colleagues[144] compared three cars: petrol, battery-electric and hydrogen. The thermal vehicle has a very high autonomy, comparable only to that of the hydrogen vehicle, but it is also the one with the highest specific energy consumption: 59.5 kWh/100km.

[144] D.A. Notter, K. Kouravelou, T. Karachalios, M.K. Daletouc, "*Life cycle assessment of Pem FC applications: electric mobility and μ-CHP*", in "Energy Environm. Sci.", 2015, 8, pp. 1969-1985.

Tab. 7: **Energy comparison between ICE-BEV-FCEV vehicles**

Parameters	*ICE*	*BEV*	*FCEV*
Fuel Consumption Nedc	Gasoline 6,1 l/100km 59,5 kWh/100-km	Electricity 17,0 kWh/100km	Hydrogen 0,85 kgH2/100km 28,3 kWh/100km
Fuel on board	50 l	34 kWh (B 300 kg)	5,1 kgH2 @70 MPa + 2,3 kWh (B 20kg)
Autonomy	820 km	200 km	600 km
Engine Power	55 kW	55 kW	55 kW
Fuel cell Max Power	–	–	90 kW
Emissions	Euro 5	0	0

Source: D.A. Notter, K. Kouravelou, T. Karachalios, M.K. Daletouc, "*Life cycle assessment of Pem FC applications: electric mobility and μ-CHP*", cit., p. 1977.

The battery-powered vehicle, on the other hand, is the one with the lowest energy consumption (17 kWh/100km) but with a range limited to just 200 km, while the consumption of the FCEV is much higher than that of pure electric. This reflects the double electricity-hydrogen-electricity conversion, for which it loses compared to the BEV in the energy balance, but only if we limit ourselves to evaluating the energy expended to have a range of 200 km. However, it must be considered that if one wanted to bring the autonomy of the BEV to values comparable to those of the FCEV (600 km), the volume and mass of the batteries would double, which would lead to an increase in the mass of all vehicle components, including the engine and, therefore, the energy consumption of the BEV would reach the same order of magnitude as that of the vehicle FCEV if not higher.

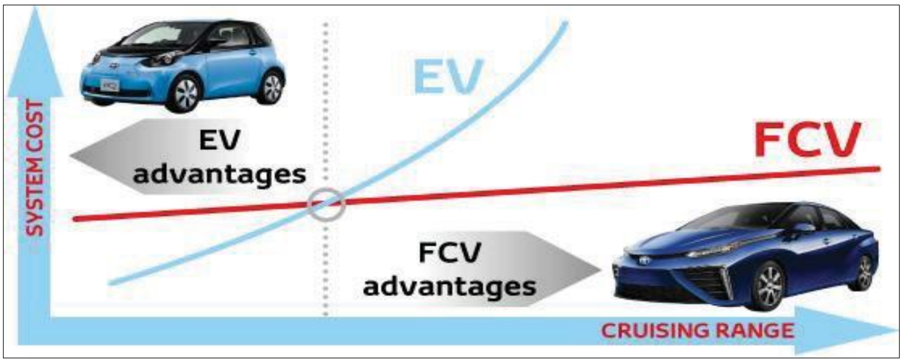
It can be concluded that the fuel cell electric vehicle, when large *ranges* are required, "can provide the adequate range, passenger and trunk space and, most importantly, the refueling times required by motorists"[145].

In fact, it has been found that most drivers would not accept more than ten to fifteen minutes of waiting for recharging on long-distance journeys with BEVs, while FCEVs can be refueled with hydrogen in the three minutes users expect. Hence, battery electric vehicles are expected to find applications as city cars and *limited-range* commuter cars. These considerations are illustrated in the following figure,

[145] G. Sdanghia, G. Maranzana, A. Celzarda, V. Fierro, "*Review of the current technologies and performances of hydrogen compression for stationary and automotive applications",* in "Renewable and Sustainable Energy Reviews", 2019, pp. 150-170.,

taken from a Toyota study, in which the costs of cars powered by the two alternative systems are compared as the required *range* varies[146].

Fig. 17: **Convenience range of Bev and FCev cars to 2030**



Source: Toyota's website.

The trend in the cost of the vehicles of the two systems shows the convenience of the BEV vehicle in terms of cost for ranges up to ~250 km. For higher values, the fuel cell vehicle prevails, given the low-gradient linear increase of its cost with autonomy. Battery-powered and hydrogen-powered vehicles do not compete with each other: they serve different market segments and meet different mobility needs[147].

3.4. **The evolutionary paths of automotive mobility**

Wanting to summarize the elements of advantage of the various technologies, capable of favoring their future development, it is possible to note that the range and recharging times represent the real limits that currently oppose the widespread diffusion of battery-powered vehicles.

Hydrogen-powered cars can in theory guarantee a much greater range than battery-powered ones: from 12 to 4 times for the same volume of the energy storage

[146] Mobilità H2, "*La tecnologia della mobilità elettrica a idrogeno*", 2020, in https://www.mobilitah2.it/tecnologia.

[147] G. Sdanghia, G. Maranzana, A. Celzarda, V. Fierro, "*Review of the current technologies and performances of hydrogen compression*", cit., p. 165.

system. In practice, however, the *fuel cell* efficiency is good but not very high, as the TTW transfer efficiency (H2–FC-booster-inverter-motor-wheels tank) is ~50%, while in the BEV case the TTW efficiency (battery-inverter-motor-wheels) is around 75%. Instead, the TTW efficiency of a diesel ICE vehicle is only 25%[148].

It must also be considered that hydrogen cars are penalized by the presence of various secondary but indispensable equipment (auxiliary battery, booster, air and H2 compressor, cooling system, etc.) which reduce efficiency and the available internal space. The shape and positioning constraints of the tanks and other parts also contribute to limiting the effective range of hydrogen cars. On the contrary, the latest generation battery-powered cars of the small-medium class already allow a range, with one recharge, of around 200 km in a real driving cycle and, shortly, high-end BeV cars will reach the 800km. The BEVs intended for predominantly urban or suburban use, on the other hand, will maintain batteries suitable for a *range* contained in just 150/200 km, ensuring reduced costs and mass. It follows that, as regards small-medium sized cars, the greater autonomy offered by FCEV technology, but at high costs, does not seem so relevant compared to that of BEV technology.

As far as energy efficiency is concerned, a BEV electric car is much cheaper than a hydrogen FCEV. After all, a good part of hydrogen will still be produced for decades from fossil sources by *reforming* methane or other hydrocarbons, accepting a certain production of greenhouse gases.

Shifting the focus to refueling, BEV electric cars can be charged everywhere: at home, in car parks, shopping centres, service areas, etc.: in this case we are talking about distributed recharging. This simple and economical way of refueling is exclusive to battery-powered cars, including *plug-in* hybrids. Instead, as far as hydrogen cars are concerned, the only possibility of refueling is to go to public H2 distributors (still few) exactly as you do with petrol and refuel during a stop of a few minutes.

148 P. Ferrari, *Il processo di diffusione dell'auto elettrica*, cit., p. 504.

From a technological point of view, as has been said, the development of *smart grids*, enabling a series of services and functionalities of strategic importance, such as for example storage, i.e. the accumulation of energy produced from renewable sources in vehicle batteries during of low demand, it can open up new perspectives[149]. For hydrogen cars, on the other hand, recharging times are immediate, less than three minutes on average, but with a significant handicap, consisting of the fact that there are still very few public H2 distributors. In Europe, for example, there are around two thousand, mostly located in Germany, while around thirty Italian systems are reserved only for certain categories of users. However, looking to the future, it must be said that the infrastructures planned in Europe are already in the order of ten thousand. While these data are encouraging on the one hand, it should be emphasized that they are still insufficient. In fact, it has been calculated that, for the generalized diffusion of hydrogen road vehicles, a minimum network would be needed that includes at least one refueling station every two hundred kilometers[150].

For many users, high-power electric recharging may be occasional: in this case, a thirty-minute stop to carry out a partial recharge, only when needed, is considered acceptable as long as the number of recharging stations is adequate to minimize the risk of tails. But if the user wanted to resort mainly or exclusively to rapid refueling as in the case of petrol or diesel, hydrogen would have a clear advantage. However, many Bev drivers, with a little programming, only charge in fast mode, such as during a lunch break. These methods of refueling the vehicle will probably constitute the main difference in use between the two types of fuel supply.

Shifting the focus to operating cost, *fuel-cell* car makers are promising similar or lower operating cost per kilometer than current fossil-fuel cars. Even the BEV electric car, already today, allows considerable savings on the cost per kilometer: half or even less than a fossil fuel car. However, it should be noted that the greatest savings are achieved with private charging, which is mostly slow. In the case of public top-up the cost is higher, even if the top-up is fast. Therefore, at present, the energy operating

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[149] G. Fontanelli, "*Autoshock",* cit., p. 72.
[150] P. Ferrari, *Il processo di diffusione dell'auto elettrica*, cit., p. 502.

costs of the two electric vehicles compared are of the same order of magnitude (even if the domestic supply of the BEV is very cheap), and absolutely comparable with those of endothermic cars.

On the other hand, it is complex to compare the cost of cars, given that we are only at the beginning of a technological revolution that will still lead to cost reductions for both technologies. The price of BEV and *fuel cell* cars should gradually get closer, but it should be considered that the hydrogen car is more complex than a battery one and therefore, in the long run, will probably remain a little more expensive[151].

It is certain, however, that from the point of view of local impact, battery-powered and hydrogen-powered cars are equivalent. Both are locally emission-free. The hydrogen car has only a small emission of water. Emissions of hydrocarbons (HC), nitrogen oxides (NOx) and sulfur dioxide (SO2) are therefore completely eliminated, and those of PM10 and lower particulates are almost eliminated (a small emission of fine particles from wear remains, however minimal thanks to regenerative braking)[152].

Research and experiments are currently underway in all areas of the hydrogen supply chain, in the awareness that this energy source can constitute a truly effective solution for environmental protection and the fight against climate change. Investments and industrial policy actions are essential to ensure that technologies and infrastructures reach levels of maturity such as to allow widespread penetration of hydrogen in the various sectors.

[151] D.A. Notter, K. Kouravelou, T. Karachalios, M.K. Daletouc, "*Life cycle assessment of Pem FC applications",* cit., p. 1982 .
[152] P. Ferrari, *Il processo di diffusione dell'auto elettrica*, cit., p. 506.

Conclusions

The two technologies BEV and FCEV have their advantages and disadvantages, and are therefore complementary. Both are still under development (but the BEV started many years earlier) and destined to replace current internal combustion cars in a few decades.

In recent years, hydrogen technology has experienced a slight decline in interest. However, even if attention has shifted towards batteries, hydrogen technology for vehicles has not been abandoned, especially by oriental manufacturers. At the same time, the attention for BEV electric cars has grown, above all for the remarkable technical development of the batteries. In reality, FCEV and BEV can coexist on the market, as for decades they have coexisted for the same car model with different types of fuel (petrol, diesel, methane); the choice is up to the end user based on his needs (urban journeys, long distances, energy saving, etc.).

The analysis conducted during the work showed that, in principle, battery technology is more suitable for small-medium cars and for city buses when fast charging is required. Hydrogen technology, on the other hand, seems more suitable for larger vehicles, suburban buses, heavy trucks, construction vehicles. The two segments, however, have no clear boundaries and can overlap. The supporters of the FCEVs themselves do not propose hydrogen as opposed to the battery-powered car, but as a complement for uses for which batteries are not very suitable.

Currently the manufacturer that promotes hydrogen the most is Toyota, which mass-produces a FC car. According to the Japanese industry, "pure battery-powered vehicles will be the smallest cars, intended for short distances in urban and suburban areas, while hydrogen-powered vehicles will be cars for long distances and heavy vehicles". The vast middle segment is seen by Toyota as still populated by hybrid and fossil fuel technology, excluding both pure electric and fuel cell and hydrogen electrics. In particular, it is expected that in the coming years all the major car manufacturers will market various models of purely electric vehicles in all market segments and the FCEV variants will also appear (although concentrated above all in the higher segments). Regardless of the segment, it can be hypothesized that battery-powered cars will be preferred by those who prefer recharging while the vehicle is parked and, above all, by those who want to minimize running costs as much as possible.

The four-year period from 2022 to 2025 will be decisive for the introduction of FCEV private cars. Its diffusion will only be possible if a minimum network of refueling stations is installed. The major interested parties on this front are the large energy groups and service stations. These operators have an interest in setting up a distribution network, since it represents the necessary condition for maintaining their business and maintaining the already existing traditional fuel stations.

Compared to the diffusion of BEV and FCEV technologies, the role of the dynamics of urbanization or the departure from the cities of ever greater shares of the population should not be underestimated either, two phenomena capable of influencing the changes underway. The circumstance that the great majority of km/car is done in urban areas makes it possible even in the immediate future, i.e. in the absence of an electrical infrastructure for long distances, the ownership of a BEV for a growing number of households, possibly integrated with the rental of an ICE car for longer distance journeys. Conversely, housing choices outside cities tend to slow down the transition to the electric car and favor FCEV mobility options.

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