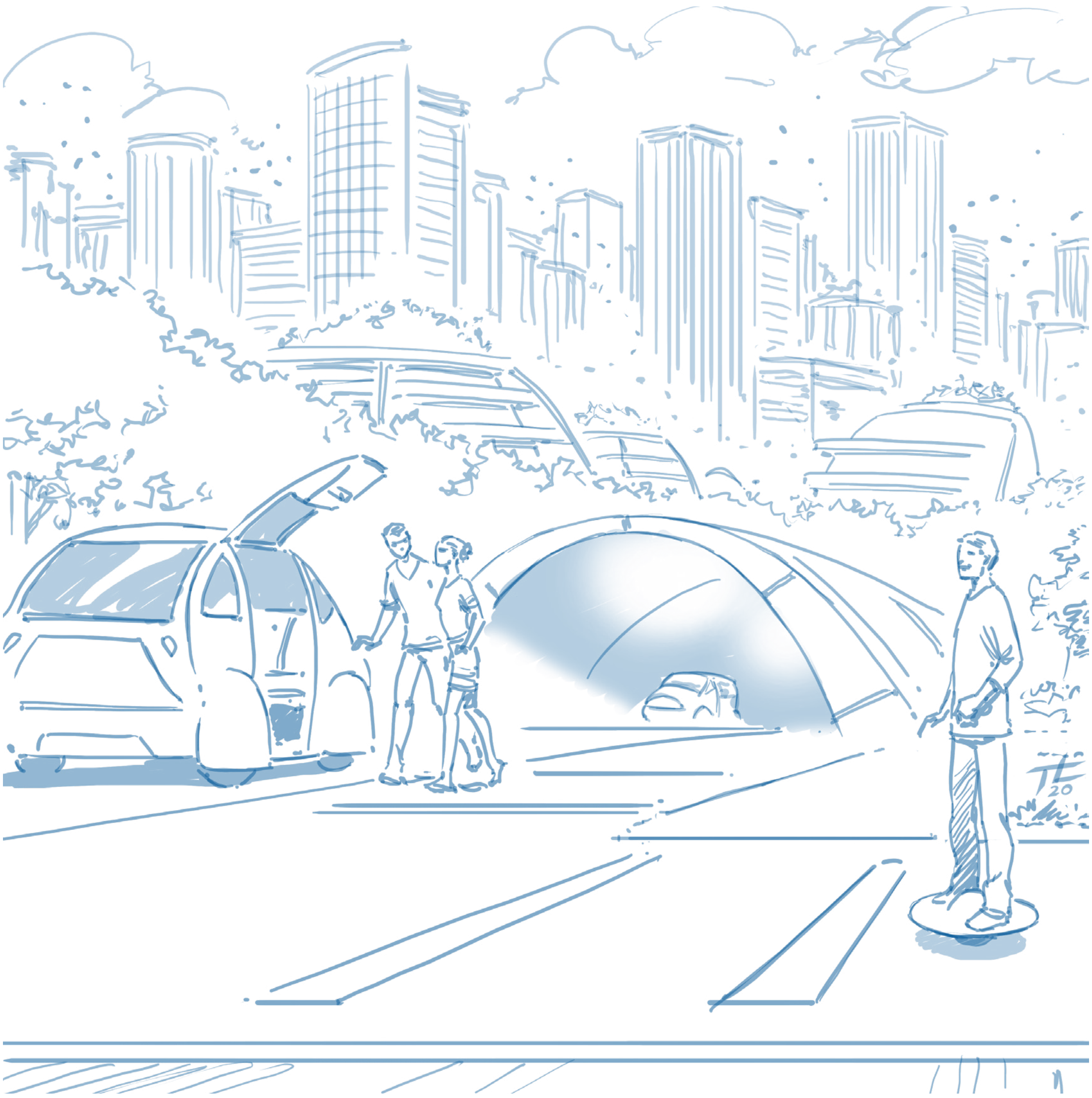
FUTURE OF MOBILITY
ELECTRICITY, HYDROGEN, OR...?

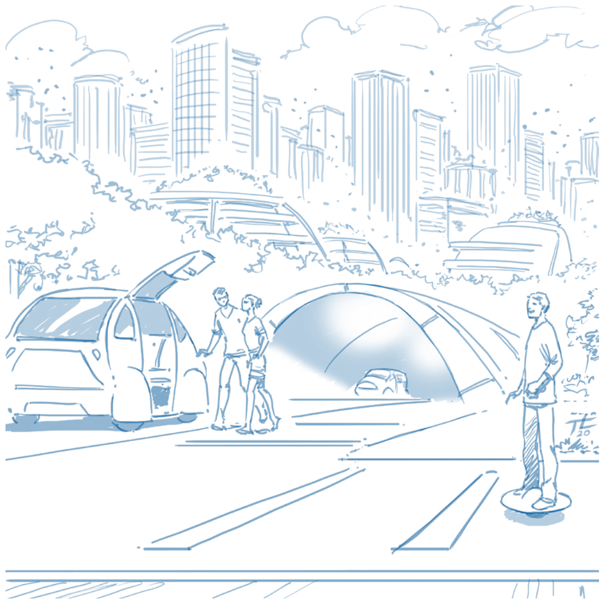


The Futures Literacy Company

Mobility has undergone a profound transformation in recent years, driven by the need to reduce carbon emissions, mitigate climate change and support sustainable transport solutions. As the world grapples with the need to move away from traditional internal combustion engines, two contenders have emerged to take the lead among the green fuels powering the engines of the future: electricity and hydrogen. Although there were many candidates. For years now, vehicles powered by different fuels such as: solar batteries, biofuels and renewable fuels, synthetic fuels, compressed air, nuclear energy, magnesium combined with water or hydrotreated vegetable oil, have been researched and prototyped. However, there is nothing to suggest that any of these options will be able to 'blast electricity or hydrogen out of the saddle' in the next few decades. Going one step further, however, it is worth asking ourselves: what if current experiments with nuclear fusion provide us with an unlimited supply of cheap or even free energy already in the second half of the 21st century, or if research into replacing uranium with thorium brings new prospects for the development of the nuclear fission reactors we know so well? What will happen when, at the same time, science and industry come to grips with the ‚inadequacies' of batteries and provide us with extremely capacious, lightweight, cheap and fast-charging batteries? Will this be the end of hydrogen and other alternative fuels? Given the range of quite significant challenges that the use of hydrogen faces, it seems that the work on hydrogen vehicles has a raison d'être mainly due to the current limitations of batteries. It is therefore possible that hydrogen should be thought of in terms of an interim solution, say for the next 100 years. But let's go back in time, say to 2050, and think about the future of mobility in that time frame. So is it electric vehicles (EVs) or hydrogen fuel cell vehicles (FCVs) that will take the lead in the next era of transport?

Both are vying for a place in the future, but they currently occupy different positions in the market. The electrification of vehicles has gained substantial momentum, with advancements in battery technology, expanding charging infrastructure, and a growing array of electric vehicle models. Decades of work on various technologies such as solid-state and sodium batteries are finally coming to fruition and plenty of chemicals give multiplicate possibilities. Simultaneously, hydrogen fuel cell technology has been steadily progressing, offering a compelling alternative with the promise of faster refuelling times and extended driving ranges.

The debate over which technology will dominate the future of mobility is nuanced, and this report seeks to provide a comprehensive analysis of the key factors influencing the trajectory of both electric and hydrogen-powered vehicles.



HOW QUICKLY AND EFFICIENTLY CAN THE NECESSARY INFRASTRUCTURE FOR EACH TECHNOLOGY BE DEVELOPED AND IMPLEMENTED ON A LARGE SCALE?

WHICH TECHNOLOGY WILL DEMONSTRATE FASTER AND GREATER ADVANCEMENTS IN EFFICIENCY, RANGE, AND PERFORMANCE OVER TIME?

WHAT ARE THE ENVIRONMENTAL IMPLICATIONS AND SUSTAINABILITY OF EACH TECHNOLOGY THROUGHOUT THEIR LIFECYCLE?

Market Penetration

The adoption of electric vehicles (EVs) has seen significant growth globally, with sales of both battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) reaching 13.6 million units in 2023 (31% annual growth), including 9.5 million BEVs, according to market research firm Rho Motion. It represents a significantly smaller growth rate than the 60% growth that was experienced in 2022. Tesla and Chinese automaker BYD are among the leading sellers of EVs.

In contrast, the market penetration of Hydrogen Fuel Cell Vehicles (FCVs) remains limited compared to EVs, with China being the only Asian country experiencing notable growth in FCV sales (+72%). In total, there were exactly 750 new FCEVs registered in Europe last year, to be fueled by 168 Hydrogen Refuelling Stations (HRSs), compared to about 11,000 FCEVs and 430 HRSs in Asia. In Europe, despite plans for increased hydrogen refuelling stations and EU legislation mandating their expansion, FCV registrations have either declined (Germany by -70%, Switzerland by -50%, the Netherlands by ~ -76%) or remained stagnant across various markets. France stands out with a notable increase in hydrogen vehicle sales (+56%), driven by initiatives such as Stellantis' introduction of hydrogen van models and joint ventures like Teal Mobility. The EU's directive for hydrogen refuelling infrastructure every 200 km as well as in 424 "urban nodes" across Europe by 2030 is expected to further propel FCV adoption. In the UK, which has five HRSs, there were 65 FCEV registrations in 2023 — a 261% increase on the 18 registered in 2022.

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Diversified EV Model Lineup

Automotive manufacturers have been diversifying their electric vehicle lineups, unveiling an array of models tailored to various market segments. This expansion encompasses electric SUVs, crossovers, and luxury vehicles, thereby enhancing consumer options and preferences within the electric vehicle market.

Introduction of Hydrogen Fuel Cell Vehicles

Certain automobile manufacturers have introduced hydrogen fuel cell vehicles to the market, presenting consumers with an alternative to conventional internal combustion engine vehicles and battery electric vehicles. FCVs are deployed only in areas where there is established infrastructure to support hydrogen usage though.

Growing Enthusiasm and Investment in Hydrogen

Interest and investment in hydrogen fuel cell technology were steadily increasing, attracting attention from both established automakers and new players in the industry. Governments, automotive companies, and energy firms alike were unveiling new business ventures and developments within the sector.

Consumer Education and EV Adoption

Consumer awareness and acceptance of electric vehicles are on the rise. This shift is facilitated by educational initiatives, favourable media exposure, and direct experiences with EVs, all of which collectively influence perceptions and promote wider acceptance. Nonetheless, concerns persist regarding future energy costs and the secondary market of EVs.

PROGRESS

Infrastructure Development

The charging infrastructure for electric vehicles has developed significantly, increasing both the number of charging stations and their geographical distribution. Advances in fast charging technologies have led to shorter charging times, offering greater convenience for EV owners. However, without a rapid battery swap system, which none of the major players currently offer or appear to be seriously considering, there is no chance of reducing charging times to a maximum of a few minutes, which is usually sufficient to fully refuel a combustion vehicle. The infrastructure for charging vehicles when they are not in use also remains a challenge, problematic especially for those without their own parking space. In the field of fuel cell vehicles, on the other hand, efforts are being made to expand the hydrogen infrastructure, including setting up hydrogen stations, of which there are still few, and adapting existing stations to distribute hydrogen. The expansion of infrastructure is key to facilitating the development of hydrogen vehicles.

Enhancements in the EV Supply Chain

Initiatives are underway to enhance the supply chain for vital components of electric vehicles, such as batteries and rare-earth metals. Securing a stable and robust supply chain is imperative for sustaining the growth of the electric vehicle industry.

Renewable Hydrogen Generation

Green hydrogen, generated through the utilisation of electricity sourced from renewable sources, garnered increasing interest due to its capability to diminish carbon emissions. However, the overwhelming majority of hydrogen, approximately 98%, is yet derived from natural gas, exacerbating emissions concerns.

Anticipated Continued Expansion of EVs

Cox Automotive anticipates that the market share of electric vehicles will escalate to 10% by 2024, propelled by a convergence of increased incentives, inventory, product offerings, and infrastructure enhancements, which collectively bolster the EV market. The International Energy Agency (IEA) projects that the global electric vehicle fleet will reach 180 million by 2030, marking a 22% surge compared to its previous estimations. An interesting factor that could contribute to the growing popularity of electric cars is the popularisation of autonomous vehicles. Such vehicles could drive themselves to a charging station overnight, which would be a major convenience for their owners in densely populated cities.

CO2 Emissions

Electric vehicles boast zero tailpipe emissions, although their overall environmental footprint hinges on the source of electricity used for charging. On the other hand, fuel cell vehicles (FCVs) emit solely water vapour, yet the environmental impact of hydrogen production varies depending on the method employed. Presently, the majority (98%) of green hydrogen is derived from gas.

Advancements in Research and Development

Continual research and development endeavours are directed towards enhancing the efficiency, performance, and longevity of fuel cells. Innovations in materials, catalysts, and system design aim to bolster the overall viability of hydrogen fuel cell technology. Concurrently, advancements in battery technology have led to heightened energy density, extended driving ranges, and enhanced overall performance. The ongoing focus of research and development is to refine battery efficiency, durability, and cost-effectiveness. Moreover, electric vehicles are integrating advanced technologies, including upgraded electric motors, regenerative braking systems, and intelligent connectivity features. Notably, innovations in autonomous driving and vehicle-to-grid (V2G) technologies are also gaining traction.

Policy and Funding Support

Governments around the world are actively promoting the adoption of electric vehicles through incentives such as tax breaks, regulation and funding. In Europe, policymakers have allocated $3.5 billion to the European Battery Innovation project to accelerate the shift away from fossil fuels and advance the development of rare earths. Also, hydrogen technology is being supported, as exemplified by the Biden administration's allocation of $7 billion for hydrogen production centres. In Europe, efforts are being made to enable the use of green hydrogen to decarbonise energy systems. However, its current production is still primarily based on fossil fuels. EU directives aim to integrate hydrogen into national policies, and countries such as Germany and the Netherlands are already offering subsidies and tax breaks. Both in the area of electric and hydrogen vehicles, joint ventures and alliances are emerging, bringing together a broad spectrum of companies to accelerate the transformation of mobility based on hydrogen or green energy respectively.

Heavy-Duty and Commercial Applications

There are already more and more electric trucks, buses and vans on the road. Slowly, hydrogen fuel cell technology is also already attracting the attention of local authorities responsible for urban transport, transport companies and marine ship owners. Here, hydrogen's attributes, such as fast refuelling and extended range, offer a clear advantage over alternatives, including electric vehicles.

CHALLENGES

Availability of metals, pricing, range anxiety, and charging infrastructure are primary barriers to mass EV adoption.

EVs are generally more cost-effective than FCVs due to economies of scale and simpler technology.

Lack of hydrogen refuelling stations is a significant challenge for FCVs, along with varying environmental impacts of hydrogen production.

The popularisation of electric and hydrogen vehicles in cities is hampered by the limited possibilities to charge the vehicles in homes or garages.

High costs of producing hydrogen, transportation, and storage.

Efficient storage and transportation of hydrogen pose technical challenges.

Efficiency losses in hydrogen production and distribution.

Durability and cost-effectiveness of fuel cells remain technological hurdles.

High battery costs hinder EV affordability.

Improving charging speed is essential for enhancing EV convenience.

Too slow development of energy and hydrogen infrastructure.

Battery degradation affects EV performance over time.

CHALLENGES

Sustainable and ethical sourcing of battery materials is crucial.

Recycling and disposal of batteries pose environmental challenges.

Second-hand market concerns impact EV resale value and consumer perception.

Limited availability of „green hydrogen” from renewable sources hinders FCV adoption.

Grid capacity constraints arise with widespread EV adoption.

Building a hydrogen infrastructure requires coordinated efforts among governments, industry, and investors.

Limited consumer awareness about hydrogen and EVs inhibits adoption.

Public concerns about hydrogen safety need addressing for wider acceptance.

Limited availability of hydrogen cars contrasts with the growing variety of EV models.

Consistent government support and policies are vital for industry growth.

TRENDS

Current changes that could positively [↗] or negatively [↘] affect the future of EVs and FCVs.

- ↗ **Continued growth of EVs**, driven by falling battery costs, global governments' regulations and incentives, and expanding charging infrastructure.

- ↗ **Accelerating development of FCVs** as infrastructure challenges are overcome and costs are reduced. This will be helped by technological advances, increasing public and private sector funding.

- ↗ **Rise of hydrogen ecosystems and infrastructure** through initiatives to support the building of the European hydrogen ecosystem, funds to support hydrogen development in the US and the growing involvement of car manufacturers.

- ↗ **Lowering cost and increasing efficiency of hydrogen production** due to technological advancement also in the use of alternative production methods and/or producing hydrogen from new base materials. Besides utilising renewable energy sources, such as solar or wind power, to produce hydrogen through electrolysis, there are ongoing investigations on other innovative methods, involving:
  - amending the process with steam instead of water and non-ceramic materials that work at lower temperatures,
  - ammonia cracking,
  - bio-hydrogen,
  - sewer gas, also known as hydrogen sulphide, found at sewers and landfills or a byproduct of oil refineries,
  - using seawater instead of freshwater for hydrogen production,
  - advancements in electrolysis techniques, such as high-temperature electrolysis or photoelectrochemical processes,
  - novel catalysts and materials, including metal-organic frameworks (MOFs) and nanomaterials.

- ↗ **Improving battery technology** thanks to decades of research which start coming to fruition, the commitment to growth of a sustainable and competitive battery industry in Europe and Asian initiatives and ambitions to become a thriving hub for EV manufacturing driving research and development.

- ↘ **Rising geopolitical conflicts**. The transition to EVs and FCVs faces challenges, as nations vie for control over critical resources like lithium and rare earth metals essential for manufacturing EV and FCV components.

- ↘ **Growing competition for raw materials** amplifies pressures on the production of EVs and FCVs, prompting stakeholders to seek sustainable solutions and diversify sourcing strategies.

- ↘ **Progressing climate change**. The urgency of combating climate change catalyzes the rapid expansion of EVs and FCVs production, driving technological innovation and investment in renewable energy solutions to decarbonize the transportation sector. At the same time it could hinder the green energy and EVs and FCVs production due to high temperatures, changing winds, natural disasters and/or water scarcity.

- ↘ **The rise of cyber threats** is highlighting the critical need for robust cybersecurity measures to safeguard increasingly interconnected automotive systems and production processes.

- ↗ **The massification of extremely fast electric vehicle chargers**. Researchers in China have developed a way to charge a lithium-ion battery to 60 per cent capacity in less than six minutes and 80 per cent in just over 11 minutes by improving the performance of battery anodes - optimising the distribution of graphite particles to increase capacity. However, more research is needed before this technology can replace the fastest chargers currently on the market. Research is also underway to address the problems associated with rapid temperature rise during fast charging.

- ↗ **Fast progress towards commercialisation of solid-state batteries.** They promise to improve safety, increase energy density and longevity compared to traditional lithium-ion batteries.

TRENDS

Current changes that could positively [↗] or negatively [↘] affect the future of EVs and FCVs.

- **Growing second-life applications of batteries and their recycling**. As the EV market continues to expand, the importance of sustainable battery management will only increase, making these efforts critical for the long-term viability of electric transportation.
- **Growing applications of wireless inductive vehicle charging**. There are ongoing tests of electrified roadways that can wirelessly charge EVs as they drive over them. The electrified roads work by embedding electric coils in the roadway, which wirelessly transmit energy to receiver pads mounted underneath vehicles. The technology works for all types of EVs, including delivery vans and trucks. Inductive charging on a large scale could eliminate heavy battery packs as well as downtime spent at charging stations.
- **Increase in the efficiency and profitability of electrolysers** used to produce green hydrogen through a more competitive and scalable process.
- **Accelerating integration of renewable energy in the hydrogen production** process. Green hydrogen production through electrolysis using renewable energy is a key driver for the environmental sustainability of hydrogen fuel cell vehicles.
- **Returning importance of other energy sources** (fission and/or nuclear fusion).
- **Rising popularity of battery swapping.** China's Nio already has more than 2,000 such stations and has pledged to build 1,000 new stations by 2024. The company is seeking to expand into Europe. The battery swap could solve the problems of when and where to charge electric car batteries, potentially reducing the advantages of hydrogen cars.

DISRUPTIONS

Potential future developments that may abruptly change the course of current trends in a way that can be either beneficial [↗] or detrimental [↘] to the development of EVs and FCVs.

- **A shortage and high prices of minerals** used for the production of batteries
- **Interruption of a supply chain** due to a geopolitical conflict or turmoil in the country mining the minerals or producing key components for EVs and/or FCVs
- **Breakthroughs in battery and/or fuel cells technology**: longer range, faster charging, lower cost
- **Efficient and affordable green hydrogen production** and distribution networks
- Surge of **ammonia-powered engines**
- **Cyberattacks on energy or hydrogen production and transport infrastructure** (power grids, wind farms, photovoltaic installations, hydrogen installations and transport facilities)
- **Impediments to the production of green energy** (hydrogen / electricity) caused by climate change
- **Shortages of energy** resulting from increased electricity consumption, slow energy transition, poor energy infrastructure modernization and development, climate change or armed conflicts
- **Policy measures and incentives** affecting one or both technologies
- **Consumer shift in preferences** and willingness to pay for sustainable mobility solutions
- **EVs winning the race with FCVs** due to additional energy sources ("come back" of nuclear fission and/or breakthrough in nuclear fusion)
- **Halting market penetration of electric and hydrogen cars** due to too slow growth of infrastructure

CONCLUSIONS

Electricity and hydrogen are viable options for cleaner transport in the future. Both technologies offer a number of advantages bringing us closer to zero-emission driving and face a number of obstacles, such as high costs, shortcomings in the relevant technology or lack of infrastructure. BEVs currently dominate, but a single solution may not be enough to eliminate CO2 emissions in transport as much as possible. Overcoming technical and economic challenges, coupled with increased consumer acceptance and sustainability efforts, will be key to determining the eventual winner in the race for dominance in 'clean' transport.

The development of BEVs and FCVs will be significantly influenced in the first instance by the final shape of the energy transition, the growing demand for electricity and the availability of water. The challenges of moving away from traditional energy sources will drive the development of each of the available options. The winners will be those that deliver environmental and economic efficiency in production. It is likely that it will not be one type of energy, but a mix of them, so both electric and hydrogen-powered vehicles will compete in the market in the future. Although the tide is currently tipping towards EVs, due to the maturity and availability of the technology, the future availability of green hydrogen and the infrastructure to refuel it could reverse this trend.

Currently, performance issues such as vehicle weight and range are challenging for electric-powered vehicles, Economic and technical challenges related to network capacity and charging infrastructure further complicate their mass use. Hydrogen vehicles, although currently more expensive and without refuelling infrastructure, offer greater environmental advantages. Regulatory incentives and industry initiatives could play a key role in shaping the trajectory of sustainable transport in the future. Consumer preferences, particularly as dictated by price, safety, durability and the ability to dispose of particular vehicle types on the secondary market, will also be important.

All that could change if current fusion research brings us an unlimited supply of energy that will be available cheaply or even for free as early as the second half of the 21st century. In addition, advances in science and industry could solve the problems associated with battery inadequacies by providing us with extremely capacious, lightweight, inexpensive and fast-charging batteries. All of this could spell the end of the era of hydrogen and other alternative energy sources. However, such a revolution may not occur until the second half of the 21st century at the earliest.

In case of further interest in hydrogen we encourage you to also look at our whitepaper "Polish Hydrogen. Will we make it in time?" and final report of our project executed on behalf of the Pomeranian Marshal Office "Pomorskie na lekkim gazie – kierunki i scenariusze rozwoju gospodarki wodorowej do 2030 z perspektywą do 2040" (in Polish).

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