RUN ON WATER
the hydrogen way

Paul Jenné • Mark Pecqueur

With hydrogen already delivering on its promises to play an active role in both the societal and energy transition, Run on Water is a new publication that gives you every reason to act. Based on a true story of the power of determination and cooperation, it reveals and unfolds how change can be instigated as part of a business culture and what challenges the European automotive industry faces in playing a leading role in achieving the European Green Deal's ambitious objectives. Comparisons with other parts of the world and important aspects of the big debate between batteries and fuel cells are not left out.

The book is based on the author's life-long experience in the bus industry and as a coordinator of two major European fuel cell bus projects. The book contains documented lessons from the projects and insightful contributions from academia on new and exciting future developments in energy, safety, and automation.

The book is supported by Hydrogen Europe, the hydrogen association acting on behalf of its many international industries and research members.

Paul Jenné holds a master's degree in Trade Sciences. During his 45-year career, he held the position of Commercial and Market Development Manager at bus and coach manufacturer Van Hool N.V. in Belgium. From 2012 till 2014, he assumed the role of coordinator for two large European fuel cell bus projects in cooperation with the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

Mark Pecqueur is a Professor and Automotive Research Developer at Thomas More University of Applied Sciences in Mechelen, Belgium. He has 25 years of experience in the research and development of alternative fuel powertrains. He is a well-known keynote speaker at many automotive events.

"Hydrogen presents opportunities in terms of security of energy supply, job creation, technological competitiveness, and environmental protection for Europe. It can contribute to Europe's industrial leadership in clean technologies, stimulate growth and pave the way for a more circular low-carbon economy."

Jorgo Chatzimarkakis Secretary-General of Hydrogen Europe
RUN ON WATER
The Hydrogen Way
Disclaimer:
The purpose of this publication is to provide insights on and to share experiences of the selection and implementation of challenging new zero emission transport technologies. In addition, it aims to foster discussion as well as imminent action, based on the shared opinion of the authors and findings on how the many new developments and policies will impact the way we will live and move around in the future.

In so doing, and despite the search for accuracy, it was impossible to cover the many details of all things hydrogen in transport, or to double-check the endless flow of information and their sources, in times of the internet. As such, the authors do not claim complete impartiality and waive any claim to scientific proof of content.

With the support of Hydrogen Europe (www.hydrogeneurope.eu)
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Preface

JORGO CHATZIMARKAKIS – Secretary-General Hydrogen Europe

I want to congratulate those who contributed to this excellent publication. We finally have a digestible, entertaining and very informative illustration of hydrogen and fuel cell technologies today. It comes at the right time, as hydrogen is becoming one of the main energy carriers of the 21st century. Thanks to its characteristics, hydrogen technology can contribute to achieving the climate objectives set for Europe for 2050 and their translation into economic activities. Indeed, hydrogen is a critical component of the energy system, accelerating the transition to 100% decarbonised systems. Humanity, which thrives on the search for additional renewable energy in large volumes, needs to address the intermittency of renewable energies and how they can be translated into ‘zero-emission’ energy and transport systems. After more than ten years of innovation promoted by the Fuel Cell and Hydrogen Joint Undertaking, the European Commission considers this gaseous energy carrier an important factor in making ‘deep decarbonisation’, reducing up to 95% of CO₂ emissions, an affordable endeavour. It is becoming increasingly clear that an ‘all-electric’ solution would not be physically, politically and financially feasible. That is why decarbonisation through electrons must be complemented by decarbonisation via molecules. That is our commitment, our role.

Additionally, hydrogen presents opportunities in terms of security of energy supply, job creation, technological competitiveness and, as already explained, environmental protection for Europe. It can contribute to Europe’s industrial leadership in clean technologies, stimulate growth and pave the way for a more circular low-carbon economy. Hydrogen-based manufacturing and supply allow a cross-sector approach, also known as ‘sector coupling’ or ‘sector integration’, meaning integrating the energy sector with the transport, industry and heating and cooling sectors with all energy carriers, such as electricity and hydrogen.

As the European Union and its Member States discover the benefits of hydrogen and fuel cell technologies, it becomes important to have a comprehensive and consistent illustration of this rather disturbing paradigm shift. Due to the maturity of the technology - especially in some areas such as bus transport

- an increasing number of policymakers see battery-electric drives as a transition to hydrogen-electric power solutions. We believe there will be market opportunities for all these technologies. However, hydrogen is a promising alternative, as it would allow consumers to maintain their lifestyles with zero-emission technology.

I sincerely thank Paul Jenné for this book. He is one of the first explorers of this technology, especially in the field of mobility. He began to believe in it when many people considered it as science fiction. But believing was not enough. He invested his time and workforce in creating the first bus projects inside Van Hool. Today, we can clearly say that Paul Jenné personally accelerated the pace of introduction of fuel cell buses on a European and global scale. The industry owes him gratitude and respect for the risk he took. This book adds to his achievements. Historically, it marks an essential step for the world of hydrogen and fuel cells. Hydrogen Europe appreciates your work!

Dear Paul, dank u wel, merci.

Jorgo Chatzimarkakis
Preface

BART BIEBUYCK, Executive-Director of the FCH JU (Fuel Cells and Hydrogen Joint Undertaking)

Hydrogen and fuel cells have undergone a long evolution to be where they are today, including many highs and lows. Yet, there have been people and companies who believed in the technologies and pushed them forward. People worldwide and in Flanders are no exception, as some people and companies have made the difference. In Flanders, one of those people is Paul Jenné. He spent his entire professional life with Van Hool N.V., the Belgium-based family bus and coach manufacturer. When Paul asked me to write the preface, I was honoured to do so, and not for a moment have I doubted saying yes to his request.

The “Fuel Cells and Hydrogen Joint Undertaking” (FCH JU) is a public-private partnership between the European Commission on the one hand and private partners from the industry and research institutions on the other hand. One of the FCH JU objectives is to facilitate and accelerate the commercialisation efforts of new hydrogen-related technologies through co-financing research and demonstration projects. Demonstration projects set up by the FCH JU and European companies in the framework of EU calls for proposals, including fuel cell buses, have already shown the potential for market introduction. The FCH JU has financed the cost of the new technology for over 300 buses from five manufacturers located in the EU. New technology is likely to be more expensive initially. However, thanks to the European financial contribution, zero-emission technologies stand a better chance of becoming a daily reality.

Today, the call for regions and cities to buy only zero-emission urban buses and make their city centres emission-free has become loud and clear. These calls are crucial to accelerate the market entrance of this technology and create a volume effect. The demonstration projects have shown its potential, and increased volume will cause the cost to decrease, which will benefit everyone.

The FCH JU’s support has allowed European bus manufacturers to acquire a head start and a better chance of success. Commercialisation still has a way to go, and market penetration is never guaranteed. Further and close cooperation between industry, the researchers, and the public sector is the best way to secure success. Paul and Van Hool had the vision to believe in the technology’s potential and anticipate the development to bring it to market.

For companies such as Van Hool and others, the challenge will be to turn zero-emission bus concepts into a competitive commercial product. The potential market volume for urban buses alone amounts to as many as 20,000 units per year. The European market is ready to offer opportunities to all manufacturers with zero-emission options available. The worldwide competition is working hard to win the unleashed transition race.

I genuinely believe that the knowledge and the passion demonstrated by Van Hool and Paul in applying technological innovation and turning it into products that benefit the environment, and consequently everyone, show the combined strength of entrepreneurship and Europe at their very best. Respect.

Bart Biebuyck
A developed country
Is not where poor people have cars.
It is where rich people use public transport.
Introduction

The idea of writing a book on hydrogen and fuel cells did not cross my mind when, in 2004, these very words caught my professional attention for the first time in the business I have been employed in my entire life.

Now, more than 15 years later, I feel the urge to share a piece of history and tell my story, from idea to vision and from vision to reality, enough to firmly believe that we can collectively change the world, at least a little bit.

This notion of making the world a better place was new to me. I never expected or experienced greater motivation when it came to pursuing sales and business objectives beyond and alongside the call of duty. Now that I have reached a sacred old age, I understand what we want our children and grandchildren to enjoy and share. And suddenly, the opportunity arises, giving me the chance to do something with the authority I received at the end of a long career.

I am acting from my own experience as a market development manager in a Flemish family business with an international scope, Van Hool in Lier. The family bond and the international scope have encouraged me to start and maintain my professional life, leaving no doubt that this long period has impacted my world view. Fortunately, there is nothing wrong with that.

The family context has offered the company the opportunity to maintain its fundamental values. It has allowed us to develop a business vision in line with those values, without necessarily being guided by market analysis, strict business plans or shareholder return policies. The decisions taken were the outcome of a growing awareness that the way forward was the right one, given the challenges of today and the world in which we want future generations to live. This attitude has always been part of the founder’s motive (‘The Way is Ahead’), fuelled by values such as the need for continuous innovation and progress (stagnation is losing ground), the firm belief in our combined abilities and a fair degree of Flemish stubbornness and pride.

We cannot continue to pollute the air and exhaust the land as we have done in recent decades. We can do something about it - right here, right now – on our own territory, in the spirit of the saying, ‘let everyone sweep in front of their own door, and the whole world will be clean’.

Such drivers have proven powerful enough to lead to action, but not without acknowledging that the word ‘new’ has a limited expiration date if it is designed to meet rapidly changing market conditions within an internationally competitive framework. Whether the products relate to all low-floor buses, modern trolleybuses, hybrids or even hydrogen buses, all developments were primarily instigated by the belief that it had to be done.

Even if part of the company’s culture was and always has been to initiate and sustain change, the driving force was a common, undocumented but genuine understanding that we were moulding the future, and in doing so, serving the company as well as its employees. It is safe to say that the implementation of ever-higher levels of technology was built on the company’s financial strength, and largely in a step-by-step process, with both feet firmly on the ground. You must put your money where your mouth is.

Apart from a testimony of the time and place in which these challenges occurred, the book wants to illustrate how this style of management ‘by intuition’ was paramount to pursuing and overcoming them. I sincerely believe that it is exemplary for the generation of family entrepreneurs with whom I had the privilege of working all my life.

On the other hand, and equally challenging, the international business arena requires leaving the cocoon of thinking and acting locally and necessitates going outside of the comfort zone. The pursuit of business projects beyond one’s own culture, language and sensibilities allows access to a broader political and industrial world, a dimension that would otherwise not be explored. It has allowed me to meet and discuss important issues with international leaders, businesses and policymakers, and I am grateful for it.

My findings mainly provide testimony of the 2004-2020 period, when the debate on climate change and its necessary actions had been taken to a higher level. Unfortunately, its translation into commercial products and services has faced many challenges and other delays. However, I am utterly convinced that we are finally getting there. This period, and by extension the next decade, will prove crucial in the history of our planet, as many world leaders and renowned climate specialists consider global warming to be on a dangerous course of no return.

Former U.S. President Barack Obama declared on 4 August 2015, that ‘we are the first generation to feel the impact of climate change and the last generation...
that can do something about it. For this reason, the U.S. is committed to leading the world, because I believe there is something like being late. I, and thankfully most of us, can fully subscribe to the words of the former U.S. President. Unfortunately, his successor, Mr Trump, did not. Fortunately for the world, the US stance towards the Paris Agreement on Climate Change was rapidly changed for the better when President Biden took the oath to become the 46th President of the United States on 20 January 2021. Not only did a new Executive Order undo the withdrawal from the Paris Agreement signed by his predecessor, but he also appointed John Kerry as a Special Climate Envoy. If anyone, Mr. Kerry understands the stakes, as he helped forge the Paris Agreement. At the same time, the US is giving a powerful signal to the world that the US is resuming its leadership role. The closing slide I have used many times in presentations in Europe and overseas was: ‘What are we waiting for? Climate change is not!’ The suggested sense of urgency is well understood by now and is thankfully giving cause to expeditious action.

Finally, the book intends to illustrate the overwhelming wave of innovation in the transport sector. The consequences are hard to grasp, but I do not doubt that they will be implemented in a relatively short time. They will dramatically change the world in which we move through far-reaching digitalisation of new technologies.

If only during the last two years since the publication of the Dutch version of the book, the changes have been dramatic and, for most of them, extremely positive as it relates to the future of hydrogen in transport and elsewhere.

The launch of the European ‘Green Deal’ at the end of 2019 by the EU Commission, headed by President Ursula von der Leyen, is already showing collective action. It has been designed as ‘a roadmap for making the EU’s economy sustainable by turning climate and environmental challenges into opportunities and making the transition just and inclusive for all.’ The objective of making the EU the first carbon neutral continent by 2050 is more than just another set of wishful thinking or window dressing actions, as the main EU institutions, in collaboration with global industrial players, are already giving it tangible shape and form.

Headlines such as ‘green hydrogen is tomorrow’s oil’, a quote from Germany’s Federal Research Minister Anja Karliczek, or ‘Hydrogen is the future of mobility’, or ‘Electricity becomes Gas’ and ‘Hydrogen Valleys’, are just some of the slogans that very important people had not dared to associate with their distinguished names a couple of years ago. Now they do, with pleasure.

States, regions and cities alike seem to be in a global contest as they announce that they will be the first to build a hydrogen economy, unparalleled in history.

The Hydrogen Council, a worldwide initiative of energy, transport and industrial companies, has adjusted its perspective by stating that “by 2050 a total of 400 million hydrogen passenger cars, 20 million trucks and delivery vans and 5 million buses will be running on hydrogen.”

If produced from renewable energies by electrolyzers, the transport world will finally RUN ON WATER.

As public transport is part of the solution to congestion and emissions in crowded city centres, and the sector is mostly run by public entities, it is of the utmost importance that hydrogen buses show success. The basic principle was that, if successful, it will help others in the industry and beyond, to use it in a much broader perspective and in many other applications. Looking back to where it started, and the scale of it, this is exactly what happened, although one would expect to see progress come quicker. Bigger players and manufacturers, all over the world, have developed or are in the process of developing fuel cell versions of trains (Alstom, Siemens), trucks (such as Mercedes, Volvo, Toyota, Hyundai, as well as Nikola and HYZON in cooperation with EU counterparts), boats, drones, motorcycles (Suzuki, Honda), bikes (such as Pragma and Alphabike France) as well as off-road machines such as excavators (Hyundai) and armoured vehicles.

The global interest in hydrogen and its many applications, as well as the concerted efforts to extend the possibilities through so-called sector integration, have made it essential to seek assistance in domains that I have not mastered. The contributions to this book by Professor Mark Pecqueur have proven to be very valuable in framing various interrelated aspects when addressing the bigger picture of hydrogen, including his vision on energy, the developments in China, safety, and autonomous driving. Mark is a Lecturer and Automotive Research Developer at Thomas More University of Applied Sciences. He can draw on 25 years of experience in both research and development of alternative fuel drive trains and is a well-known keynote speaker at many automotive events.

It is safe to say that hydrogen is very much on the agenda, and the products are carving their own application niches in world markets, as a prelude to becoming mainstream between today and 2030.
The persistent waves of step-change innovations over the last decade were the main reason (but not an excuse) why this book was ‘a work in progress’ for a couple of years longer than I had initially anticipated. However, it has now become much clearer how and in what time frame the new developments will unfold, which has allowed me to canvass their outlook. As with so many things in life, an infinite extension is not an option. The Way is Ahead.

Paul Jenné
**1. The Proverbial Spark**

The slogan I chose for the Flemish fuel cell demonstration bus, ‘Water-s-tof’ (Hydrogen), is a play on the Dutch phrase ‘water is tof’ (water is ‘cool’), which shows a visible link to water and gives it a positive connotation.

For me, however, it was not before 2004 that a clear and specific meaning was given to the word hydrogen in a bus application, despite my indirect involvement in earlier initiatives concerning hydrogen drives. Going back as far as the early 1980s, I recall a development initiative for the use of hydrogen in a vehicle, initiated by SCK Mol (Centre for Studies in Nuclear Energies) with a locally based knowledge firm and our company, under the name of Elenco, as a temporary consortium. In the end, however, no equipment was produced. In the ‘90s, the University of Ghent was conducting a test by mixing hydrogen and natural gas consortia. Despite my involvement in earlier initiatives concerning hydrogen in a bus application, despite my indirect involvement, no clear and specific meaning was given to the word hydrogen.

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One evening, we were invited by Rick, former general manager of AC Transit, to have dinner in ‘the City’, which was the common name for San Francisco if you lived in the area. The place of action was a rather dark corner of an Italian restaurant. Rick suddenly asked whether we would be prepared to develop a ‘fuel cell bus’ based on the existing diesel bus platform. We knew very well what a ‘fuel cell bus’ was, but how the hell were we supposed to build a ‘fuel cell bus’? To make the request a bit more visual, he started drawing a bus with an open end at the back where the engine usually sits, and some bottles on the roof, which were meant to look like hydrogen tanks. I recently asked him whether the napkin on which the drawing was made is still available and if not, whether he could reproduce it. His answer was a double ‘nay’. This historical document was binned a long time ago, and secondly, his drafting skills were no longer what they used to be. Considering that they were already very basic, I did not insist any more.

Rick was a legendary figure who made the transition from New Jersey to Oakland to use his knowledge and experience in his capacity as General-Manager to take California’s transport agency to the next level. Americans are good at that and are not opposed to relocating across the country, especially to the West Coast. My first contact with him was on 1 May 2001. Rick and his team were looking for low-floor buses, suitable for California, but with European style and finish. He was headed in the right direction. It so happened that we had acquired some experience in developing and producing coaches for the US market since 1987 and knew quite well by then how to meet the technical preferences, as well as the safety standards and import requirements applicable in the US. An agreement with ABC Bus in Minnesota in 1987, which was at the base of the learning curve, had allowed us to export increasing numbers of buses to the US for more than a decade.

Some things never fade away. Clancy Cornell, the founder of ABC Bus Companies, was once a bus driver for Greyhound and by then had taken off his driver cap to sell second-hand coaches. To enter this segment of a highly privatised market – Greyhound was no longer the only carrier - ABC needed to be able to offer new coaches. He warned me in true Midwestern cowboy-style during the negotiation phase, in a bar in Northfield, Minnesota, where Jesse James was arrested after a failed bank robbery in 1876, not to ‘screw him or his two sons’. A good decade later, this very beneficial relationship led to several hundred coaches and a significant share in his company to support the growth scenario.

Nevertheless, the process of convincing management to deliver city buses to AC Transit and California involved great pain and internal struggle. Much of the argument was related to the less desirable characteristics of the American market for city buses. Urban buses are primarily operated by public entities and managed by engineers and public administrators with extensive legal departments. Wild, but mostly genuine, stories circulated about product liability, and it is still practised in the US. It was common knowledge that highly-staffed law firms specialised in defending plaintiffs or defendants in major lawsuits that would pop up when an accident happened. Multi-million-dollar claims would soon emerge when accidents involving death, injury or property damage occurred. The claims system, whether for a single claim or a class action, typically involved all stakeholders, from the operator to the suppliers, being sued. In the absence of a settlement agreement between all parties, it would end up in court. US courts are handled by selectively chosen jurors, generally with a very
unpredictable outcome. In the case of alleged wrongdoings by the supplier, the convictions could amount to millions of dollars.

As such, and to avoid lengthy and burdensome trials, both sides would seek a settlement agreement with the insurance company. The lawyers defending the plaintiffs would be paid an agreed-upon percentage of the settlement amount, which would turn the lawsuit into a commercial commodity product, a concept unknown in Europe.

The knot eventually unravelled in favour of supplying the product to AC Transit. The company did not appear on the list of ‘unwanted’ customers. After local vendors and the EU supplier base had committed to supporting AC Transit on service issues, the red light turned to green. In a format unique to the bus industry, I remember orchestrating the meetings with customers and the local representatives of the technology partners, which led to the final decision to submit a compliant offer for the supply of diesel buses.

Now, many years later and free of any commercial interest, I can safely testify that Rick has dramatically changed the scene in California and across the country. He envisioned that European products would serve the public, starting with his users in Oakland. The large windows and low-floor access for all passengers and the American drivelane’s recognisable components that would not scare away his mechanics were convincing arguments. In doing so, he indirectly forced local bus manufacturers and suppliers to adapt and innovate, from low-floor buses to revolutionary zero-emission technologies, to diesel-hybrid and fuel cell buses. It is a remarkable example of how industries react when the danger of competition looms and the market success of established industries is at risk. It is also an example that should be remembered today, now that Asian companies have discovered new territories for their cheaper products and fair-trade policies, and trade agreements are put to the test even more. Geopolitical tensions are growing between the world’s economic blocs, as either total freedom or total control would be equally devastating to the world.

Mendeleev

I owe it to myself and to the readers to clarify some of the notions used below. First, the word ‘hydrogen’ is derived from the ancient Greek term ‘hydrogenium’, which is comprised of ‘hydro’, or water, and ‘genium’; or gen, the substance for making water. With this simple knowledge, the word hydrogen means ‘water-maker’.

Hydrogen gas is 14 times lighter than air. When hydrogen escapes, it immediately takes off and mixes with the air. In the automotive industry, this is an important property when compared to LPG (liquefied petroleum gas), the latter being heavier than air. Therefore, the leaked hydrogen molecules will seek to escape at the highest point, which may very well be the roof, requiring the workshop to be automatically ventilated to mitigate the risk of ignition.

Hydrogen is the most abundant chemical substance available in the universe.
As most of us will remember - albeit a long time ago - one of the chemistry class lessons revealed that hydrogen was number 1 in the periodic table of chemical elements that the Russian chemist Dmitri Mendeleev released to humanity in 1869. He developed the table showing the elements placed according to their atomic numbers, starting with the lowest: number one, hydrogen.

At atmospheric temperature and pressure, hydrogen is gaseous. To achieve a liquid state of hydrogen (as used in the NASA space programme or in the BMW 7 series early this century), the gas has to be cooled to -253°C and maintain this low temperature at all times. Technically, this is quite possible.

"The compelling argument in favour of hydrogen in modern society is that its conversion to electric energy produces ZERO harmful pollutants. ZERO CO (carbon monoxide), ZERO NO₂ (nitrogen dioxide), ZERO NOx (other nitrogen oxide compounds), ZERO particulate matter (PM). It also produces absolutely ZERO CO₂ and ZERO other GHG (greenhouse gas) emissions at the tailpipe."

The Proverbial Spark

My active involvement in marketing low-emission solutions for urban buses fuelled my interest in the potential of emission-free transport for people. Trolleybuses were already on the menu but had some operational pitfalls, such as flexibility and infrastructure cost, making widespread implementation very doubtful. It was not before 2009 that a new and fierce proverbial spark was effectively ignited.

Curiosity was quickly turned to belief when imagining the many possibilities of using hydrogen for public transport. Soon enough, the belief became a passion for this new technology.

The place of ignition was Vienna, where the UITP (Union Internationale des Transports Publics) held its biannual congress. The keynote speaker for the opening event was Jeremy Rifkin. His visionary ideas on hydrogen were contagious and invited me to explore and discover a whole new world. Rifkin did not hesitate to use terminology such as ‘the third industrial revolution’, after ‘coal/electricity and printing’ in the 19th century and ‘oil/fossil fuels + automation/computers in the 20th century’, although most of us would argue that we are witnessing the fourth industrial revolution, as it describes the disappearance of boundaries between the physical, digital, and biological worlds, particularly through the fusion of advances in artificial intelligence (AI), robotics, the Internet of Things (IoT), 3D printing, genetic engineering, quantum computing and other similar disruptive technologies. While it is probably safe to say that the peaks of each of these revolutions can be related to the respective century, starting from the 19th to the 21st, whether it is called the third or fourth Industrial Revolution is rather irrelevant. But WOW, what a perspective! Humanity can ban and replace oil and other fossil fuels, leaving Mother Earth with everything it has mastered without any interference. By doing so, it would be possible, even plausible, to see the promise of a new world order appear.

According to Rifkin, the economy is governed by the same laws that govern the universe. The first law is the law of conservation: since the Big Bang, all energy remains constant. No energy is lost, and no energy is created. Energy is transformed but only in one direction: from hot to cold, from concentrated to dispersed, from order to disorder, from available to unavailable. Energy systems are open (form and matter), closed (form but no matter) or isolated. The Earth is made up of fixed matter. Extract the fixed matter, transform it, and return it (in one form or another). At each step of the conversion, we must embed energy to transform it and lose energy in the process.

The Aggregate Efficiency (ratio of energy used to the energy received) ranged from 3% in the 19th century, to about 10-20% in the 20th century. With the tools of the second industrial revolution, this will not change. To increase efficiency in the 21st century, we combine all the built-in communication data and use it in an intelligent network to manage energy and move economic life.

The direct engagement of all people in the world on an Internet of Things platform will revolutionise our lives: open, transparent and on a lateral scale. On the negative side, how do we guarantee free, uncontrolled access for other commercial uses and ensure security and privacy? How can we prevent cybercrime within a dark network that is just as strong, and perhaps stronger, than the bright one?

In his book “The Third Industrial Revolution - How Lateral Power is Transforming Energy and Changing the World” (2011), Rifkin is convinced that we are capable of producing our shared energy and together transforming the global economy by using the digital world (Internet of Things or local energy networks). Rifkin was keen to use the word ‘distribution generation’ as the centrepiece of how communication and transportation using an Internet of Things platform will dramatically change our lives.
To tackle the challenges of climate change, it is important to address every producer of greenhouse gas. Transport is number three in the world. It may not be the end of the road, but the business model must change by managing vast transport networks. Logistics is the key, and big data are the tools. Drivers are getting off the wheel and becoming software analysts who handle the data. The budget needs to be reprioritised. Creating smart infrastructure requires both skilled and unskilled employment: from fossil/nuclear fuel, obsolete power grids and transportation systems to renewable energy and smart digital technology. Every building, construction project, and vehicle must be replaced, requiring tonnes of people and paying for itself through massive energy and maintenance savings.

_So spoke Mr. Rifkin._

Although I consider myself moderate, if not conservative, in my ability to judge and put into perspective the impact of new simplified trends and visionary ideas, I must admit that I perceived Rifkin’s speech in Vienna as a revelation. I was very impressed by the potential of his vision of the future world, the possible redistribution of wealth (with Adam Smith’s theory still alive in my mind), and the way it could be achieved. Although I recognised the need for a hierarchy, generally used in relation to power and religion, I was interested in sharing my beliefs and motives in public at the many meetings and presentations I attended in Brussels and elsewhere. I saw them as an opportunity to make people aware of their potential and give testimony when advocating for the suitability of hydrogen for use in bus applications. I did not necessarily discuss the challenges or potential pitfalls of presentation and interest building, in line with generic marketing principles.

Rifkin, who was also an advisor to many European authorities, was firmly convinced that hydrogen was the ultimate way to transform the global economy. Oil, which had been at the heart of the industrial revolution since the mid-19th century, would be replaced by hydrogen. Thanks to the unexploited and unlimited possibilities of producing electrical energy without burning fossil fuels and exhausting the Earth, it would allow all countries to produce and provide their own energy. His creed would apply to all developing nations. Most of them have enough sun and wind to tap into these unlimited sources of abundant new energy. Not only would the large economic blocs have access to the energy carriers and the power and supremacy they acquired through them, but many countries, including the poorest in Africa and Latin America, could produce their energy and even become exporters to neighbouring countries and nations. The birth of the ‘shared economy’ would be a fact. Wow. Wouldn’t that be something?

Today – without challenging Rifkin’s intelligence and foresight - a reality check seems to be in order. Rifkin himself was honest enough to recognise the challenges and described himself as ‘cautiously hopeful’. To think that the benefits of this happy new world will be equally distributed among all people would be both hopeful and naive. Politics and governments - be they European, national, or regional - will invent ways to tax or displace the benefits and orchestrate redistribution as they see fit. It should be remembered that only a quarter of the cost of oil-based energy would be enough to cover the cost of production. The rest of the total cost includes transport, distribution, VAT, and other government taxes. Therefore, it is obvious that future renewable energy bills will be equally manipulated, even if their first and foremost purpose is to save the planet. Political and economic powers go hand in hand.

Despite this reality check, the ‘Wow’ effect has not disappeared. On the contrary, reading about the hydrogen pipeline that could hopefully connect Africa to the European continent has fuelled my belief that hydrogen is about to embark on its global mission.
And, no matter how big the projects are, both industry and policymakers are ready to make them happen, within the increasingly tight time limits. The number of projects is so vast and their impact so dramatic that they are worth covering in a separate chapter.

The geopolitical balance of power could, and probably would, change and create a new, more stable one. Energy independence from the oil and gas producing countries is a dream that Europe has been savouring for quite some time. Controlling energy supply and prices would be a dream come true. It would be a relief to break free from the nightmare that one day Russia might decide to turn the handle on gas and deprive Europe of securing energy supplies or the OPEC (Organization of the Petroleum Exporting Countries) of dumping their oil. Neither of these scenarios is impossible, given the ideological differences between oil-producing countries about their relations with the West and Russia, causing a global crisis that has resulted in armed conflict more than once in history.

The real advantages of hydrogen become overwhelmingly convincing when it is produced from renewable energy sources. The energy produced by the sun in one day is enough to keep the world afloat for 30 years. More than half of it is reflected in the atmosphere or evaporates. Initial tests have shown that it is possible to capture large amounts of solar energy using gigantic parabolic mirrors and convert it into hydrogen.

Arno Evers, the founder of the Hydrogen and Fuel Cells exhibition, argues that green hydrogen can be turned into ‘golden hydrogen’ when we find a way – preferably without billions of subsidies – to locally convert renewable energy (such as solar energy) directly into hydrogen and to produce electricity and fuel for our cars at home. Relatively simple production methods could be used by individual households and regional or small local networks.

In his book ‘The Hydrogen Society – more than just a Vision?’ (2010), Evers reaches a series of similar conclusions. The current electricity production and distribution networks no longer serve their purpose and are a thing of the past. In Germany, the electricity network is 1.78 million kilometres long, enough to cover 45 times the distance from the Earth around the equator and 4.7 times the distance between the Earth and the moon. A total of 566,300 substations and transformers had to be built to bring electricity into homes and businesses. The efficiency losses and costs associated with this large network are extremely high and unacceptable. The electricity grid is old and inefficient. Suppose we continue to produce electricity from coal. In that case, it is reasonable to assume - given the increasing requirements of new economic powers such as Brazil, China, India, and Russia - that more CO₂ will be emitted instead of less. This is what has happened in the first two decades of this century. We all believed that climate change would go away and that the adverse effects were not imminent. Unfortunately, an increasing number of scientists, industrialists and politicians are convinced that the planet Earth, as we know it, is really under threat.

It is also striking that Evers insists on recognising the difference between the ‘Hydrogen Society’ and the ‘Hydrogen Economy’, referring to the social nature of production and distribution, rather than the purely economic component. He is not specific about how this should be done in real life. In any case - and I sympathise with him - we must get rid of the old, worn-out electricity grid, stop building coal-fired power plants, and be cautious about creating gigantic solar panel fields and windmill parks.

The shame that rests on the western world, that we have exhausted the Earth and are not able to feed and dress its population, could finally be extinguished.

You must plant before harvesting

To tell the story of how a Belgian industrial and family company, far away from its incubator, managed to develop a futuristic fuel cell bus for the United States of America, I will have to go back to the place of inception: Oakland, California.

Oakland is located on the shores of the San Francisco Bay and the City of San Francisco. Apart from my early contacts, and as for most Europeans, San Francisco was renowned for the ‘hippie movement’ of the 1960s, the notorious gay community, and of course, the Golden Gate Bridge as its world-famous landmark. Oakland is one of the four cities in the San Francisco Bay Area and has about 400,000 inhabitants, half of whom are African American and Latino. Oakland is particularly associated with its seaport (Port of Oakland) and its container terminals.

That it all started in California is no accident. The state is the third largest and most populous in the United States of America. If California were an independent country, it would have the sixth-largest economy in the world. The film
and entertainment industry, the wine industry (Napa Valley), and the IT industry (Silicon Valley) are the best-known industries. Google, known as the Googleplex campus, has its headquarters in Mountain View, San Francisco (Santa Clara County) and covers 11 hectares. Many of Google's employees are picked up from their homes, or nearby, and transported in a large number of double-deckers with Wi-Fi connection. Their employees' working day starts from the moment the Google staff boards the bus.

At first glance, the weather in California is nothing short of fantastic. The average temperature throughout the year varies between 19°C in winter and 29°C in summer, with a wide range of local variations. For example, Death Valley (about 80 m below sea level and yet mountainous) is the hottest place on Earth, with temperatures nearing 50°C. It was the ideal place to test the engine cooling system, as we learned. I witnessed how an 8-person van lost power for traction and air conditioning due to the air temperature. Carrying enough bottles of drinking water is a must for all tourists visiting the area.

Unfortunately, the San Francisco area is also known for earthquakes. One that is still very vivid in our memory is the 1989 Loma Prieta quake, which caused over 150 metres of the Bay Bridge to collapse. The dramatic images of the crumbling coastline and the collapse of the villas and mansions have no time to disappear as their pattern seems repetitive. So are the recurring huge forest fires, even when the root cause is not always the elements’ vicious behaviour. When driving through the area, it hurts to see how a vast and beautiful landscape has been destroyed for many decades, leaving its burnt smell as a silent but penetrating witness.

Due to these destructive whims of the elements and nature that California and its leaders know, more than any other state, it is vital to address them.

The world needs leaders to ensure that appropriate action is taken. California's 38th governor from 2003-2011, not the 'Terminator', wanted to save the world from all evil. His name: Arnold Alois Schwarzenegger. Governor Schwarzenegger firmly believed – and still does – in the potential of alternative energy and wanted California to assume the starring role, in Arnold’s familiar film language. In a video message, shown at the official launch of the fuel cell buses in Emeryville bus depot in March 2006, Governor Schwarzenegger shared his comforting thoughts on the importance of alternative energy and hydrogen in tackling the challenges of climate change. Recently, Arnold shared a tweet in which he repeated his pledge that he is prepared to discuss everything on condition that we all believe that the planet is warming up.'

(E)Mission Control

In the US, environmental issues are handled by the EPA (Environmental Protection Agency) on a federal level, except in California, which has a similar agency known as CARB (California Air Resources Board). Its policies and regulations have traditionally been much more stringent than the measures imposed by the EPA. When it comes to buses and heavy-duty vehicle emissions, California's regulations are the most challenging in the world, and each successive version is more restrictive. The emission standards of their buses were higher than those of the rest of the states, so much so that it was very difficult for diesel engine manufacturers to meet them, mainly because it required software and hardware that had to be designed, tested, and built for rolling stock sold in California. For example, Cummins Engine decided to discontinue its horizontal bus engine due to small volumes versus huge development and compliance costs.

The new administration's derailed climate policy may change all that. Although the federal EPA has been reduced in personnel and budget by almost two-thirds, CARB has managed to survive as a state agency. It is an open secret that the Trump administration would love to incorporate CARB into a smaller federal EPA agency.

Both the EPA and CARB are empowered to issue environmental decrees and penalise offenders in their respective territories.

This was particularly the case for the three big diesel engine manufacturers: Cummins, Detroit Diesel and Caterpillar. Cummins Engine was fined over $2.1 million and was forced to upgrade some 570,000 heavy-duty engines in one of the legendary recalls. The EPA estimated that the breach resulted in 167 additional tonnes of nitrogen oxides (NOx) and CO (carbon monoxide) emissions, as well as 30 metric tonnes of particle matter.

In 1998, CARB submitted two possible options or pathways to the operators of heavy-duty buses (from 15 passengers onwards) due to the adverse health impact of nitrogen oxides (NOx) and fine particles (PM < 2.5µm) on general...
The Proverbial Spark

The operators’ prerogative was to select either of the two options: the first was the so-called ‘diesel pathway’, and the second one identified as an ‘alternative fuel pathway’. The explicit condition in both pathways was to meet the same minimum objectives, i.e., reducing 75% of the harmful emissions by 2010 and 85% by 2020. Operators choosing the alternative fuel path were required to achieve this in 85% of new purchases by 2015. Operators who decided to follow the ‘diesel path’ had to install particle filters (CRT or continuous regeneration trap) in their fleet and start introducing zero or ultra-low emission bus projects. AC Transit selected the diesel path, which explains their keen and genuine interest in zero-emission fuel cell buses in 2004.

The geographical, ecological, and political prerequisites mentioned were the prelude to AC Transit’s expression of interest in the supply of 3 to 5 fuel cell buses.

The Buy America Act

The big difference between a current order for diesel and fuel cell buses was that the latter could only be financed with federal and, therefore, public funds, which in the past were subject to meeting the requirements of the Buy America Act. Unless the US’s end-user received a waiver, they would not be able to purchase the non-compliant product outside the US.

For publicly-funded purchases of rolling stock, the Federal Transit Administration (FTA) could grant a waiver to comply with the Buy America Act in any of the three identified cases: a) the purchase outside of the US is in the public interest; b) the purchase is not available or is of insufficient quality in the US; or c) when purchased in the US, the contract price would be increased by at least 25% for identical products. Compliance with the Buy America Act would have to be declared, and appropriate audits would be conducted to ensure compliance. Since this law, like any other US law, is fully enforceable, the contract would be cancelled, and the products would be lost in the event of non-compliance. No manufacturer in the rolling stock business that delivers products to the US, that I was privileged to know, takes Buy America lightly. Neither did we, and this was not new. Despite the Democratic signature of former US President Barack Obama, the FTA ensured that American public funds would benefit American industries within the FTA regulations’ legislative limits.

This requirement was even extended and strengthened in 2009 by the American Recovery and Reinvestment Act. This act was intended to turn the economy around following the devastating impact of the financial crisis after the fall of the Lehman Brothers and the so-called banking crisis in 2008. This law stipulates that the use of iron, steel, and other goods is not allowed unless they are of American origin. As far as the public sector and the transport industry is concerned, America First was not President Trump’s invention. It has been there since I have been active in the sector. There is little hope that it will disappear, even if the slogan of making America great again has lost traction.

The ‘Buy America Act’ specifies that the obligations are fulfilled as long as 60% of the material’s total cost is of American origin and the final assembly of the finished product is conducted on American soil. Only American manufacturers or foreign manufacturers with assembly plants in the US could meet these requirements.

However, the ‘Buy America Act’ (BAA) does not apply to private corporations. If John Doe is located anywhere in the US, is part of a private, family-owned, or corporate enterprise, and decides to buy a commercial product or service in Belgium without using public funds, this purchase will not be subject to the BAA. Instead, he will only have to pay the import duties in force at the time of the product’s entry into the US.

On 8 August 2008, the FTA published in the Federal Register, the official ledger similar to the Belgian Official Journal (Moniteur Belge), a Notice of Buy America Waiver for the National Fuel Cell Bus Technology Development programme. Quite exceptional was the fact that the waiver was granted for the entire programme, consisting of three consortia and fourteen projects. The arguments justifying a possible waiver are: a) at this stage of the development of the technology, more engineering data is needed to specify a fuel cell accurately for competitive bidding; b) the requirement to comply with the BAA would significantly delay the development effort, be extremely expensive and result in a huge setback in the overall development of fuel cell technology. Allowing the
use of all available technology, regardless of its origin, is the fastest and most robust method of perfecting the technology, ensuring future competition, and accelerating the advent of fuel cell buses in transit. Through the Fuel Cell Bus Programme, successful demonstrations will increase technology awareness and foster a domestic industry by identifying and mitigating barriers and uncertainties in the marketplace. By reducing risk and expanding expertise, the Fuel Cell Bus Programme will improve capital availability for a self-sustaining domestic fuel cell industry.

This allowed us to supply fuel cell buses to the US, as the main component was a fuel cell unit designed, built, and made fully operational in America by UTC Power (United Technology Corporation).

What strikes me most is that the waiver does not hide the reasons behind the final decision. Purchasing products incorporating this new technology on a BAA waiver is more important than ensuring that the components are of American origin in compliance with the act. The FTA considers that a significant delay in applying this new technology would prevent its timely use, make it more expensive, and put more constraints on the domestic industry in terms of risk mitigation and barriers. The words ‘huge setback’, ‘significant delay’, and ‘improving the capital available for self-sustaining domestic industry’ were all well-chosen. It also meant that all those obligations and responsibilities were shifted to the suppliers, whoever they were. And to a large extent, that happened to be us.

Later, in 2010, an appointment was made with one of the biggest lobbying firms in Washington, D.C., to start advocating for the idea that zero-emission public transport was no longer a utopia. It was something very real and, more importantly, needed a lot of continuous support from the government. It is public knowledge that the lobbying firms push the message uphill in Washington, getting it on the agenda and giving it a chance to be translated into a real regulation or law, even with a lot of effort and many years down the road. Through the lobbying firm, we were told that meeting President Obama could be the ultimate chance, at the end of a lengthy process, or that we could leave the message with his administration at a high regulatory level. After all, President Bush had visited AC Transit and California before, under Governor Schwarzenegger. It so happens that we have never met President Obama. However, we did meet with FTA staff and visited Capitol Hill in California in 2015 to discuss the state of affairs in Europe. It was not until 2016 that the acquisition of fuel cell buses was back on the agenda and FTA funds were made available to this purpose, this time without a waiver. The domestic industry had learned the lesson, exactly as the justification for the waiver arguments had targeted.

Are there lessons that European leaders can and should learn? Yes, without any doubt.

**Fuel Cell Buses for America**

Since there were more questions than answers regarding AC Transit’s request, many months passed before a commitment was made. We knew very little about the preconditions, such as the content of the supply, the share of responsibilities during and after the build, the cost, the risks associated with development, validation and homologation tests, the concept of cooperation, intellectual property (IP) ownership, and access to the results, as well as commercial aspects such as delivery time and warranties. The questionnaire was extensive, and the answers were few, terribly vague, or unavailable. Without expressing so many words, the project had many known unknowns.

Only ‘thanks but no thanks’ was not the right answer for an important overseas customer such as AC Transit. The standstill was finally interrupted by a simple reformulation of the request, closer to the language used and understood by the decision-makers on our end. Would we be prepared to build a 40-foot bus, similar to the existing diesel buses, but without the engine, transmission, fuel tank and all corresponding accessories, and with a reinforced roof, pretty similar to the roof structure for a compressed natural gas bus, and able to carry the extra weight of the new tanks and the components? Due to their size, the hydrogen tanks could only be located on the roof. Technical cooperation with ISE, the integrator of the driveline components in San Diego, was considered necessary to answer most of the remaining questions and concerns.

The matter was now more specific, with most of the implications easier to understand. Thanks to the permanent presence of Stuart, the inspector assigned for AC Transit buses, the sky became clearer. Stuart was technically very knowledgeable and equally persuasive when it came to making things happen. As part of his assignment, he was available at the plant on a daily basis and had access to all the technical partners and suppliers who contributed to a successful implementation. At that time, our organisation did not have many secrets left for him in terms of how the family business works, who makes the decisions on what subjects, or whom to talk to at all levels of the project group. He had virtually unlimited access to all decision-making levels, from the management itself to the factory worker.

A draft contract was drawn up with as few modifications as possible to the
existing purchase agreements for diesel buses. Starting over with completely new contracts, involving internal and external law firms on both sides of the ocean, was probably more challenging than building the buses. Therefore, a shortcut was taken by listing the current contract articles that were affected and rewriting them as an amendment to account for the changes. We considered them as diesel buses without the typical driveline components. We included the parties’ responsibilities, with AC Transit acting as the purchaser of the UTC Power fuel cell and of its integration into the bus.

In this way, we learned what a fuel cell module looks like, how it works, why it develops less heat and less noise than a combustion engine, what safety measures needed to be integrated, and a thousand other things. Less heat in the engine means less heat available for the passenger compartment. Dealing with all the new features and their technical implications on the bus structure was nothing less than a professional challenge for many of our engineers, technicians, and IT staff. All parties had to be consulted constantly to understand all the consequences for them. What needed to be modified, and why? Who would be responsible for it? What about the consequences in terms of adding weight and weight distribution, fuel consumption, passenger comfort, life cycle cost? As with many things in a product, modifying one gadget triggers an issue with another.

The founder of our company, who passed away in March 1974, would have repeated the statement he had made on 9 April 1970 on the TV programme hosted by Joos Florquin entitled ‘At the residence of’: “my name is on the bus, and our reputation is at stake. Even if others make mistakes and errors, we must solve them to protect our good name”.

For this reason, and because a bus is built to transport passengers and everything needs to function 16 hours a day and up to 15 years in a row, it is vital to understand, exclude, or mitigate risks as much as possible. Bernard’s statement turned out to be invaluable, as the technology partners are jointly responsible for bringing the project to fruition. Since America is far away and our vision, and their guts to assume such financial and operational risks with the stakes were high. I have always shown my highest respect for AC Transit, their mission, and their guts to assume such financial and operational risks without knowing if the project would be successful.

Jan, the then-acting president of UTC Power, was a Dutch citizen living and working in the US. He offered to loan a fuel cell for two years if we committed ourselves to a demonstration project in Europe. He had worked with other bus manufacturers before, but there was not much moving in his direction at that time. The CUTE project (Clean Urban Transport in Europe), involving 33 fuel cell buses, was about to embark, and the fuel cell bus was reserved Mercedes hunting ground, as they also assumed the role of project coordinator.

A leaflet from UTC Power, developed to support fuel cell buses’ marketing efforts, showed an exterior bus mirror stating ‘this vehicle is more ecological than it looks’. The original phrase
The proverbial spark was meant to warn the driver that mirrors can be misleading when making the right judgment in traffic. So are the external looks of this bus. The historically dirty bus has become a much cleaner one. The metaphor was well understood.

With a follow-up order from AC Transit for a total of 16 fuel cell buses to be designed and built in Belgium with UTC Power fuel cells, the history of fuel cell buses would take a definitive turn. Both UTC Power and the ISE believed that the ISE possessed specific intellectual property rights that were likely infringed upon when the vehicles were manufactured and fully assembled in Belgium. Several lengthy telephone conversations were held with the ISE and its lawyers, to make it very clear that any infringement of their intellectual property would lead to legal action against our company. Considering that the American legal system is equipped, probably like no other in the world, to execute such threats, it was of the utmost importance to be sure that we would not end up in court for the reason mentioned above. My fears about this scenario were fuelled by the fact that we were using the same Siemens electrical drive components and performance software for which the ISE seemed to own the distribution rights in the US. Siemens guaranteed that none of its current agreements in any way excluded Siemens products from being integrated and imported into the US by European bus manufacturers, thus avoiding any conflict with ISE on this issue. A possible violation could only be claimed when the intellectual property protected by ISE was used on its behalf. Therefore, I consulted my engineering colleagues on more than one occasion, who confirmed that they were 100 per cent certain that no intellectual property patented or protected by the ISE was used or infringed upon in the design and construction of the fuel cell buses for the United States.

ISE San Diego would file for Chapter 11 in 2011. However, this unfortunate event had nothing to do with the 16 fuel cell buses built in Belgium. Some of the assets were sold by court order to Blueways USA, a spin-off of the Belgium-based VITO (Flemish Institute for Technological Development). We were unaware of the events that followed until they were made public.

Our own fuel cell bus

Today, more than a decade after its creation, I can safely say that three unwritten motives instigated the decision to build our fuel cell bus. Gathering them today seems easier than collecting them back then.

The first reason to consider building our fuel cell bus was undoubtedly the positive feedback we received about the performance of the buses in California. Positive experiences and confirmation that our efforts are bearing fruit always present a strong business incentive to continue the effort and aim further.

The second reason was a statement by Jaimie, a fuel cell advocate from the first moment we met, which I still vividly remember. He said, ‘Paul, why would you want to throw a Van Gogh painting in the bin?’ This statement was the perfect metaphor. As far as I was concerned, a good enough drive to keep it on the agenda for further discussion with management. The prospect of technology being the dawn of something bigger than us - a means of providing zero-emission at the tailpipe - was exciting enough to take it to the next level. At that point in the history of urban transport, only an electric trolleybus, which requires expensive and sophisticated infrastructure, would meet that same objective. And yet, in cities where trolleybuses were in operation, their service area was limited to a few major central lines with high passenger numbers. Everything else was miles away from offering the same perspective as a fuel cell bus. When compared to the then-current diesel-electric hybrid buses, the potential for reducing CO₂ and harmful emissions (up to 25% at best) was not even close to the potential offered by fuel cell buses. It was time to stir up the flame.

The third, and probably most important, reason for pursuing new goals was that the (diesel) bus model we had redesigned into a fuel cell version for California was not the right bus for Europe. This conclusion was reached because the total weight of buses in the EU was limited and, unlike the US, no exceptions or waivers were granted for city buses. The additional weight of a standard diesel bus’s driveline components was about two metric tonnes, which would reduce the payload accordingly. These components are the fuel cell module, batteries, electric motors, power electronics, eight hydrogen tanks on a separate platform on the roof, double cooling systems, compressors, pumps, and safety equipment.

The maximum permissible weight for a bus in most EU member states was 18 tonnes. It was evident that reducing passenger capacity would defeat the sales pitch for fuel cell buses. Reducing the payload to less than 70% at an initial cost of four times that of a diesel bus did not sound right. The proposals to the first customers in the market were about to land in the bin, despite Jaimie’s metaphorical comparison with Van Gogh. I convinced the management by suggesting the addition of a third axle to extend the length. A third axle and two additional tires allowed the bus to weigh 26 tonnes and carry 104 passengers, without compromising all the features and comforts of a modern city bus: three wide doors, full low-floor, and 34 seats. Taking into account the overall price of the bus, the addition of a third axle would only be a marginal on-cost to a two-axle...
The overall passenger capacity offered would offset it. The turning radius could remain within the 24-metre limit of the European legislation.

We figured that this relatively minor redesign would be a statement for early adopters who wanted a zero-emission bus, without the burden of planning permits and agonising construction work in the city centre, generally associated with trolleybus systems. If we were to make fuel cell buses a commercial success, our offer would have to match or exceed the operational advantages to a trolleybus network with a reduced overall life cycle cost. With the known cost of the rolling stock, infrastructure, and maintenance of a complete trolleybus network, the odds were kind enough for us to accept the challenge.

A technically necessary detail: adding a third axle does not necessarily mean adding ‘the’ third axle. Instead, we opted for a second middle axle but with steering, similar to the front axle. It would maintain the design from the drive axle to the rear end of the bus while allowing for higher weights and passenger capacity within the maximum permitted turning radius limitations. The steering mechanism on the additional axle allowed for less tire wear. This was the safest way in terms of design changes and limited the additional cost, as there were no orders for such a fuel cell bus on hand, not even in sight.

Since then, the total permissible weight for electric buses has been increased to 19 tonnes, allowing an adequate passenger capacity of up to 75 passengers with a standard two-axle bus. Considering that fuel cell buses, in addition to the environmental benefits, offer more comfort inside, the standing density is generally reduced from six to five or even four passengers per square metre.

With measurements and weights, the European tri-axle fuel cell bus was ready for the drawing board. With 13.15 metres in length, 32 seated passengers and 10 m² standing area, the tri-axle bus was ready to face head-on competition with other zero-emission options in a full low-floor version.

UTC Power was prepared to supply the fuel cell for the Flemish demonstration fuel cell bus as a ‘plug & play’ unit on loan for 24 months of demonstration. After that, they expected the unit to be returned to Hartford, CT, for examination, as large corporations do with field-tested equipment after their ‘maiden voyage’.

A request was made and approved by the Flemish Institute for Scientific and Technological Research (IWT) to help cover this development. Since the technology was completely new, the federal government approved a grant for training. With all the pieces of the puzzle in place, there was no reason for further delays in building our tri-axle fuel cell bus.

After many meetings, inspections, visits, follow-up reports and thousands of hands, the tri-axle fuel cell bus was ready to take to the European roads. Not one day passed without our technical and production management checking and consulting with each other to deal with any issues or questions that might delay the project’s timely completion.

A child is born

Nine months after its conception on the drawing board, the Christmas season was fast approaching, and the new-born needed to show its face. The metaphor could not be more appropriate. The extraordinary coincidence that this promising new technology - made for Flanders, Belgium, Europe, and the world - and the Christmas season arrived hand in hand, inspired me to share the story at the New Year’s reception. The management offered this event in the plant’s showroom in 2007 and welcomed a staff of 400 people. On such an occasion, it is standard practice for our management to talk about our performance over the year and share planned improvements necessary to continue growth and secure our future. About 150 fuel cell buses later, I have reopened the digital box to remember and share those moments.

**Our Christmas Story**

As we approach the end of this calendar year, I would like to share a unique Christmas story called the ‘Flemish fuel cell bus’.

This is my story. No, it is OUR Christmas story. A story of cooperation and peace. It is not 2000 years old, but new and happened during Christmas time in a small corner of the factory, well-hidden in the prototype shop.

The birth of a bus, our baby. A bus made by us for those who believe in a better future, designed and developed in engineers’ brains, made by men and women, and born nine months after its conception. It is already taking its first steps into the world and on its way to maturity and adolescence.
The kings who heard of the child’s existence at the time of its conception came from all over the world, from the East to the West. They all took their most opulent offerings:

The Americans brought a large engine box in which hydrogen, the most abundant matter in the universe, was converted into electricity: a fuel cell.

The Canadians brought eight cylindrical bottles, in which the hydrogen is kept on board at the right pressure: the hydrogen storage tanks.

The Germans brought the power of 170 horsepower, hidden in the electric motors and software to ensure performance: the powertrain.

The Swiss brought extra power to assist the Americans when they needed it: the traction batteries.

But the birth parents came from the area, hesitant at first, unaware of the possibilities of their discoveries. They took the gifts and rushed to the shed so that the public could not see them until today.

The gifts needed to be distributed: the workhorses, close to the wheels; fuel containers on the roof because of their size; auxiliary power in boxes under the floor, left and right; the rest where space permits. Nothing was left to coincidence, and compromise was not an option.

It had three large doors and full low floor for easy boarding and alighting, comfort and connectivity to the outside world. Because it was designed to carry as many people as possible in comfort, more wheels were added so that over a hundred people could enjoy the new-born’s blessings.

Today, we can announce the birth of a new dawn, a new future, and the proof that changes are possible, in our field, as long as we work together.

Zero-emission: the exhaust emits only water vapour, without any harmful pollutant. Our bus is the most environmentally friendly people-mover on the road. It loves to stop and carry more people to their destination. The more stops, the better, as the power will be regenerated until the next stop for more people.

Reduced noise: thanks to the absence of moving parts in the fuel cell, the engine noise is non-existent, and the overall noise is considerably reduced. Passengers will appreciate the silence as it invites them to exchange with other passengers.

Energy-efficient: low consumption and extended range thanks to the use of two power sources and energy regeneration during the braking process. It is perfect. All dimensions fit. The bus radiates power and beauty at the same time.

After a short running-in period, under its parents’ close supervision, the bus will be in actual revenue service. It will carry passengers in Antwerp for six months and be served by other Belgian and European host families. From the first day, it was well-received. It enjoyed much attention and political empathy in Flanders and the Kingdom, overwhelmed by personal care and support.

Our bus’s future is bright, in every respect, even if it will need our continued focus and care, but that is why we are here.

The country’s elite came along to pay their respects, as all of them felt it was the right thing to do. They praised its capacities for all things that need change. We have reached the point of no return. We can leave our children and grandchildren the legacy that we can change and have changed the course of history and have defined a better future for them. We must act NOW to mitigate the threat of climate change caused by human activities, especially in this generation. Fossil fuels are being exhausted, and their cost will skyrocket. Particle matter will damage our health and cause premature death. Our cities will choke.

Let this Christmas story be the beginning of a new era, marked by a generation that has assumed responsibility for tackling the challenges it created. Let this be the first step to a better future. Let this be the message of OUR CHRISTMAS STORY.

Around the Church and beyond

And so it was that, in 2007, the Flemish fuel cell bus entered the European market. It was a product of the future and complied with all existing European regulations and directives.

The film crew of Stijn Meuris, a well-known Belgian media and music producer, filmed a feel-good video in Lier, Antwerp, and Brussels. We were the cast of the day, and we were proud of it. The purpose of the video was to showcase the bus to a broader audience and carry the message that zero-emission was no longer utopia but a real-life option.

Before releasing the video, and putting our name on it, we wanted to check the studio’s product. However, Stijn insisted that the footage and the sequences should not be changed, as a work of art belongs exclusively to its creator.
So, we finally ended up adding the wise words: ‘Global warming, rising sea levels, fine particles in the air, noise pollution in the city. What are we doing? We are working on it’ to end with its fair conclusion: ‘The future. Here. Now.’

Nice.

The bus was unveiled during a ceremony on 17 May 2007 at the factory, in the presence of Flemish politicians of all ranks and parties, including Kathleen van Brempt, Flemish Minister of Mobility; Philippe Muyters, Flemish Minister of Economic Affairs; Marleen Vanderpoorten, Mayor of Lier; and Ingrid Lieten, the General-Manager of De Lijn, the Flemish bus operator. Local know-how, global expertise, and entrepreneurship were acknowledged and praised as essential for Flanders’ industrial future.

Doing the tour around the local church could never have been the goal.

A lease was concluded with De Lijn for an initial period of six months. Fuel supply remained a problem, as OVAM (Flemish Public Waste Agency) would never grant a permit without carrying out a detailed planning review, even if it were temporary. Considering that the cost of a mobile fuelling station was prohibitively high, we opted to refuel from an Air Liquide trailer directly into the bus. With a pressure of about 500 bar in the trailer tanks before the trailer had to be replaced by the next one to allow three buses to be refuelled in less than an hour. The pressure in the tanks would drop considerably with each fill of about 30 kilograms of hydrogen, so emptying the trailer tanks would not be an option unless the bus could stay there for refuelling the entire night.

At the request of De Lijn, the bus was presented in Leuven to the mayor, councillors and management and staff of De Lijn. Mayor Louis Tobback and his councillors loved the drive. They said it would be an ideal solution for complaints from shoppers and businesses on the main shopping street, where diesel buses currently emit a lot of noise, vibrations, and harmful pollutants.

In the first phase, De Lijn decided to have the fuel cell bus with passengers on the regular revenue service, followed by an empty diesel bus. The purpose of this first dual service was to have a replacement bus readily available if there was a defect in the fuel cell bus. It also aimed to have operationally comparable data on consumption, acceleration, and overall performance to meet the service plan. The fuel consumption figures were recorded daily by the driver who picked up the bus from our plant. Fuel consumption is subject to pressure, temperature, battery state of charge, electricity consumption during night-time loading, and tank temperature. Therefore, the figures were collected and rigorously calculated. We quickly discovered that hydrogen consumption varied greatly, and the variations were consistent with the driver and his driving style and habits. I remember that variations ranging from a minimum of 5.9 kg of hydrogen/100 km to a maximum of 9.1 kg of hydrogen/100 km were observed for two identified drivers.

This is not a coincidence. The fuel cell bus is a hybrid bus with regenerative braking energy, and the batteries and fuel cell directly drive the electric motors. Therefore, the driver can make a difference in consumption. If it is fully accelerated (‘pedal to the metal’), consumption will, of course, be very high. Similarly, full or emergency braking would not allow the braking energy to regenerate quickly enough in the batteries (although lithium-titanate oxide is the best technology available for hybrid driving to do so). Progressive acceleration and deceleration have a positive impact on consumption. In a hybrid bus, more than in a diesel bus, the driver is in control of the final number. It is not surprising that transport companies are investing in eco-driving programmes.

All drivers that I interviewed during this time were very enthusiastic about their new experience. In essence, the noise level in the driver’s seat was considerably lower, as it was on the whole bus. The typical jerking effect associated with changing gear in a diesel bus (albeit minor ones with automatic transmissions) had disappeared entirely, as electric motors do not have gears. It was mentioned that both the absence of engine noise and vibrations during gear changes were the two most notable positive differences compared to a diesel bus.

Passengers inside the bus gave high marks for the increased level of comfort. At the same time, those walking outside on the pavement appreciated the absence of noise and vibration from the diesel engines, especially when waiting at and departing from bus stops. While driving it to the UZ (University Medical Centre) in Leuven, a female driver I talked to on the bus praised her new toy, despite the extra length of one metre of the bus compared to her rather small posture behind the steering wheel of this giant machine.

The bus initially leased to De Lijn was then tested under different operational conditions. For instance, during the heat of the Zaragoza International Expo 2008 – Water and Sustainable Development, it transported visitors from the parking areas to the entrance of the exhibition. It was subsequently put in operation in the Leiden area in North Holland to cope with the rather severe winter conditions of -10°C. After the cold test, it was leased for another six months to De Lijn and resumed daily service in the same area, due to the only option of refuelling at our plant.
The Flemish bus has travelled over 120,000 km, including public events and trade shows in Essen, Herten, and Stuttgart. It would serve its purpose again when we decided to use it as an invaluable engineering and testing object, after returning the UTC power fuel cell and preparing the integration of the Ballard Power fuel cell for future sales.

At the end of 2012, De Lijn ordered five of these fuel cell buses as part of the European High V.LO-City fuel cell bus programme. The five buses were delivered at the beginning of 2014 and are still running daily.

The refuelling station was ordered and operated by Solvic (formerly Solvay), in its capacity as a project partner (High V.LO-City), to demonstrate a more valuable use of waste hydrogen from its Chlor-alkali plant in Lillo. Consequently, the buses were put in revenue service in the same area, north of Antwerp.

The acronym I suggested for this programme referred to the abbreviated regions of ‘Vlaanderen (Flanders), Liguria (Italy) and Oslo-Akershus (Norway)’. In addition to creating the pun with ‘high velocity’, it suggested that the programme would accelerate the integration of fuel cell buses in Europe. Unfortunately, as I discovered throughout the programme, it took the cities and regions a very long time to implement. Planning authorisations, co-funding issues, and political preferences seem to impose real and time-consuming challenges. Oslo had to be replaced by the new kid on the block, Aberdeen (Scotland), and Sanremo was partly replaced by Groningen (Netherlands).

PowerPoint Missionaries

The number of workshops, congresses, forums, and events organised by regions, cities, industries, and political entities about or around the subject, was hardly manageable. They all wanted to hear the story or, even better, feature the bus at the exhibition venue and, if possible, experience the ride.

Furthermore, each European project contains an obligation to disseminate the project and its findings and convey it, especially if it is successful. I was told that this is the only visible return on investment that the European institutions are pursuing in these programmes—making the projects known, reaching out to a broader stakeholder forum, and gaining momentum to support the trend that has been set in motion. This message – how else would it work? – is designed to highlight the commitment of all those involved as well as the benefits to the programme parties and to the general public.

It is designed to illustrate that success leads to more success, and leadership must be disclosed and appreciated for all of us to follow its example. In the case of fuel cell buses and hydrogen in mobile applications, the dissemination of the project is a statement that buses and cars are no longer part of the problem. They can be and are becoming part of the solution, proving that technology is no longer a reason for inaction. It is a step forward in cleaning up the world from the enemy that affects all its inhabitants’ environment and health.

The early adopters’ positive reaction was so promising that our name was on the wish list for speakers at the many events related to this topic, in Europe and the United States. This was mainly due to our experience in California and the EU-US cooperation initiatives on the subject. It was paramount that the bus be seen and driven to give testimonial evidence that it works and that its direct benefits were worth pursuing.

A warm heart for the fuel cell bus

Close to home, the fuel cell bus received much praise. Our results were tangible, tested and appreciated. The recognition of our efforts and the fact that Flanders and its industry were acting to meet the challenges of our times were often addressed. Of course, many of the Flemish ministers and senior officials were proud of this achievement. They voiced their support on every occasion, honouring the proverb that ‘success has many fathers, but failure is an orphan’.

From the Flemish bus demonstration unit in 2007 to the delivery of the first five units to De Lijn in 2014, seven years passed. A new generation of politicians was ready to take over in 2014, with an even more urgent agenda to address environmental challenges. Kris Peeters, Minister-President of Flanders, unveiled the first of five buses for De Lijn at Technopolis in Mechelen. Ben Weyts, Flemish Minister of Mobility and Public Works, took over Antwerp’s ribbon-cutting ceremony when the bus began service.

Further from home, I had the opportunity to speak at conferences in San Francisco, Vancouver, Thousand Oaks, San Diego, Sacramento, London, Hamburg, and Berlin. Meetings were held with prominent political representatives on both sides of the ocean. Their goal was to share lessons learned, find ways to introduce this zero-emission technology into urban transportation, and discuss how hydrogen and fuel cells could fulfill their vocational role.
The world famous streetcars in San Francisco and the first of two fuel cell buses for AC Transit. Over one hundred years apart between zero tailpipe emission technologies in San Francisco.

The current AC Transit operation with fuel cell buses on the inside of the bus depot, to be fuelled at 350 bar pressure, and a refuelling dispenser for private fuel cell cars, to be fuelled at 700 bar pressure.

First generation AC Transit fuel cell buses on the Bay Bridge with a spectacular view of the city of San Francisco.

I.h.s.: President George W. Bush and Jaimie Levin, AC Transit, visiting the fuel cell bus.

r.h.s.: Governor Arnold Alois Schwarzenegger, delivering his videotaped address on the occasion of the launch of the fuel cell bus in Emeryville, CA.
The Flanders fuel cell demonstrator bus at De Lijn depot in the city of Leuven, in the presence of Mayor Tobback, Mr. Leopold Van Hool (first line) and invited guests.

Visit of President Emmanuel Macron of France to the Fébus bus for Pau.

Official inauguration and ribbon cutting ceremony of the first of five fuel cell buses for De Lijn in Antwerp by Mr. Ben Weyts, Minister of Transport of Flanders.

Key handover ceremony of the first of thirty-five fuel cell 12m buses to RVK Cologne (Jens Conrad, Project Manager) by Jan Van Hool (Director Van Hool N.V.)
The proverbial spark

Before reaping the harvest, you must plant the seeds.

Mr. Mark Rutte, Minister-president of the Netherlands, visiting QBuzz’ Director of Marketing Michel van der Mark, operator of the fuel cell buses in Groningen/Drenthe.

Jorgo Chatzimarkakis, Secretary-general of Hydrogen Europe in the Sanremo fuel cell bus.

The hydrogen musketeers (from left to right): Daljit Bawa, Ballard Power Systems; Bert De Colvenaer, Executive-director FCH JU; Carlos Navas, Project Manager at FCH JU; Paul Jenné, Van Hool N.V.
The Proverbial Spark

We are the first generation to feel the impact of Climate Change. We are the last generation that can do something about it. We only get one planet. There is no plan B.

(President Barack Obama, 2015)

A life H2 structure was shown at Busworld in 2011 to make visitors aware of the possibilities of hydrogen buses as well as to share video testimonies from the project in California.

Award winning new products:

Left: first hydrogen powered articulated bus rapid transit bus.

Right: Ecology Label Award at Busworld 2013 for 3-axle fuel cell bus with Ballard fuel cell (Courtesy Van Hool)
2. Hydrogen and Fuel Cells

Energy - The Big Picture

From my first contacts with the European institutions, I was convinced that the degree of attention paid to the application of hydrogen in urban transport was related to another magic word: ENERGY.

One of the reasons for my early suspicion about the esteemed attention to buses was that this industry, whether ecologically or economically, was too small on its own. At first, the general thought process was that the energy transition would occur first, and the automotive sector would follow suit. The question was whether the demand side (the transport sector, starting with the most apparent markets first) would meet the supply side (the new energy world). That supposed order has changed over time. Less than three years ago, I was convinced that the order of precedence would be quite the opposite. Today, I believe the energy and the mobility transition are set to converge, and that is probably the best thing to happen.

That said, it found it nevertheless flattering then to see and feel so much focus on the ‘bus’ at such a high level.

In order to understand how valuable the energy sector is for the European Union, it is necessary to look at the bigger picture.

The IEA (International Energy Agency) estimated, in a business-as-usual scenario, that energy needs will increase from 373 EJ (exa-joules) in 2013 to 640+ EJ in 2050. In other words, our energy needs will rise in that time period by a staggering 72%. Annual energy consumption in the EU will reach about 1,800 GWh (gigawatt-hour). This is an enormous quantity of energy and a gargantuan amount of CO$_2$ emissions.

No matter what, recent studies have shown that – under some pre-set conditions – green hydrogen will be able to provide up to one-third of the energy in the EU, which is a major contribution to lowering greenhouse gas emissions. According to IRENA, the International Renewable Energy Agency, the world will need 19 EJ of green hydrogen in the energy system in 2050, which converts to around 150 million tonnes of green hydrogen per year. However, the warning is out that ‘there is an elephant in the room’. Producing the vast quantities of green hydrogen that the world will need would require an absolutely massive amount of renewable energy. The current distribution is 23.4 GW of offshore wind, 480 GW of solar, and 397 GW of nuclear energy. Virtually all of this capacity is being used to generate electricity, not green hydrogen. The conclusion of the IRENA report was obvious: the share of renewables in the world’s total energy consumption will have to increase six times faster than its current pace in order to meet the agreed climate goals.

The role of hydrogen is also described in the multiannual SET-Plan (Strategy Energy Technology Plan). This plan unequivocally states that the energy sector must ‘decarbonise’ even if that means taking drastic measures. After many years of scepticism, hesitation, and negotiation, it has become clear that the world needs to find ways to put an end to the burning of fossil fuels, which causes global warming and climate change. Studies have calculated that an effective action plan would cost 1% of the GDP (Gross Domestic Product) of the EU28, but if no action is taken, between 5% and 20% of the same GDP would be lost.

The four measures considered most necessary to meet energy and CO$_2$ emission reduction targets through the energy transition:

- Improvement of energy efficiency
- Carbon capture and sequestration (CCS) and Carbon capture and utilisation (CCU) of CO$_2$
- Transition to zero-emission energy carriers such as electricity and hydrogen
- Use of renewable energy to replace fossil fuels

The importance of the SET-Plan defining the technology objectives cannot be overestimated, as it seeks to ‘develop technologies and create the conditions for the industry to develop and commercialise hydrogen vehicles’. At the same time, it calls for new developments to enable battery technology to foster electric mobility, reducing GHG emissions to the needed levels. With the aim of being climate neutral by 2050, GHG emissions from transport must be reduced by 90% by 2030 and 100% by 2050. ‘Where have I heard this before?’ is, without any doubt, the immediate and spontaneous reaction. However, this time it is more serious than ever. The new Climate Law developed by the EU under the New Green Deal does not leave much choice as to the outcome in 2050. The path to achieving the goal is, of course, dependent on all of us, producers and consumers alike. Measures will be mandatory in their implementation, intermediate accountability will be an absolute necessity, and the pressure will be on as we move forward with the plans.

Today, hydrogen is being called ‘the new oil’, and for good reasons. This statement, of course, implies that the ‘old oil’, after being gradually replaced, will need to be phased out completely one day.
Despite the apparent growing interest of ‘Big Oil’ in emerging zero-emission technologies, including hydrogen, and despite the presence of huge windmill parks in many areas, the end of ‘old oil’ does not seem to be near. A recent study by Natixis, a French bank, sees four barriers to change for Big Oil:

- The destruction of jobs in vital economic sectors, such as fossil fuel producers and distributors and automotive manufacturers.
- The hundreds of millions of euros in tax revenue levied on the use of (fossil-related) fuels.
- The destruction of accumulated capital in stranded or obsolete assets in connection with a major change in the industrial tissue.
- The growing dependency on Asia in general, and China in particular, due to the region’s supremacy in feedstock and rare earth, which are necessary for the new technologies.

Electricity represents less than a quarter of energy use in Europe. Around half of the total energy use is for heating, which is mainly covered by natural gas. The other big part is transport, which represents about a third of the total and is mainly covered by liquid fuels.

But things are rapidly changing as mandates become more binding and enforceable.

California announced that it is aiming to achieve 100% green electricity on its network by 2045. Europe will reach 50% by 2030. The current level of renewable energy use in Europe is 7.1% in transport and 19.1% in heating.

**The Energy Problem**

(researched and narrated by M. Pecqueur)

There is no energy problem. We just have to dare to make the right choice.

As a child, I could romp for hours with my friends in the great outdoors. We enjoyed a vast landscape full of fauna and flora. Our green playground seemed endless. Today, the reality is different. Urbanisation has led to fewer and fewer people living in rural areas. We started organising ourselves in cities. And children who grow up there spend their free time in city gardens or landscaped parks and squares, not in the great outdoors, like me.

Urbanisation in our society is increasing. And that is not surprising. The world population is growing year after year. In the 1950s, there were about 2.5 billion people on our blue planet. Today the counter stands at about 7.8 billion. I sometimes read in the media that there are too many people to give everyone a good quality of life. I tend to disagree. There is plenty of room. Urbanisation allows us to live well with many people on a limited surface.

Manhattan seems to be the paradise of urbanisation. Apparently, everyone wants to live there. With 27,000 inhabitants per km², it is one of the most densely populated areas on earth. Rents are sky-high, and apartments are only available on the rental market for a limited time. If everyone wants to live in Manhattan, I suggest building a Manhattan in one of the smallest countries in the world. Then we can all live together there, and the rest of the planet is free to develop.

Modern man has two basic needs: food and energy. A good quality of life is impossible if those needs are not met. I am not a nutrition expert, but if I can believe the authorities in that area - and I do - there is enough food to fill all stomachs. Unfortunately, due to waste, logistical challenges, and the pursuit of profit, people are starving.

Energy means wealth. Countries need sufficient and affordable energy to develop. And it is available. The total power we can generate worldwide is 15 terawatts. To give you an idea, that is the power of 15,000 nuclear power plants. But our energy needs will continue to rise in the coming years. So, we will have to look for new energy sources because the story of nuclear energy is winding down, and fossil fuels are not endless.

Energy consumption varies widely from country to country. In Europe, consumption - expressed in equivalent litres of diesel or petrol - is between 15 and 20 litres per person per day. Qatar sits at over 70 litres per person per day. The most ecologically responsible people on this planet live in Bangladesh. There, a person consumes less than 1 litre per day, though that is not a conscious choice but rather a consequence of the dire poverty in that country.

Our energy consumption is enormous. And that is easy to explain because we all use more and more energy in our daily lives. A few years ago, people who had a sauna or air conditioner at home were an exception. Nowadays, relaxing in your sauna at home or enjoying the refreshing coolness of your air conditioning is increasingly the norm. We order products online and worldwide. Globalisation has created a huge logistics chain in which products in containers travel around the world to end up in our letterbox as a package. And that, of course, also involves a lot of energy consumption.
I would like to note that transport over water is much more ecologically friendly than transport overland. Large container ships move 21,000 containers at 40 kilometres per hour. They use 16,000 litres of fuel per hour. That seems like a lot, but it is actually very little because, when converted, it means consumption of fewer than 2 litres per 100 km. For comparison: a truck consumes 25 to 30 litres per 100 km.

Our travel behaviour also contributes to our great energy needs. We fly around the world. We are going on a weekend trip to Barcelona, on a city trip to New York, or on a business trip to Shanghai. Aeroplanes such as the Airbus A380 consume 16,000 litres of fuel per hour. Is that very much? With 800 passengers on board, consumption is 3 to 4 litres per person per 100 km. In comparison with a car, that seems like very little because it corresponds to a car that uses 20 litre per 100 km. A car drives - so far - much less quickly.

So, it is clear that we are using more and more energy. And with rising prosperity and a growing world population, there is only one solution: we must look for new forms of energy that have no impact on our planet. The challenge? The new forms must be able to generate at least 15 terawatts of power in a renewable manner and without emissions or the use of rare materials. This is the only way we can meet the increasing demand without evolving from an energy problem to a scarcity of rare materials.

The million-dollar question: What can those alternatives be?

The answer to that question quickly leads you to the usual suspects. Biofuels, hydropower, geothermal energy, wind energy, hydrogen, and solar energy are the most obvious alternatives.

But can they also offer the solution?

Biofuels such as biodiesel or ethanol (as an alternative to petrol) are extracted from crops that are specially cultivated for this purpose. Rapeseed is the most widely used crop for biodiesel, while sugar cane and corn are important for the production of ethanol. The yields per hectare strongly depend on the crop and the year. One hectare of rapeseed yields 4 to 6 tonnes, corn about 45 tonnes and sugar cane up to 100 tonnes.

Biofuels can be extracted anywhere in the world where agricultural land is available. In Europe, biofuels have often been a handy currency. When Poland -
Hydrogen and Fuel Cells

To put that number into perspective. You need 100 mega turbines at sea to re

The real big boys are in

geothermal energy offers us a solution for the energy issue.

In recent years, more and more governments have invested in wind energy. Large wind turbines are emerging off our coasts and along our highways. Wind energy is one of the oldest forms of energy supply. Just think of the windmills that ground grain in the Middle Ages. In these modern times, wind turbines have become a kind of symbol for renewable energy. The real big boys are in the sea. They can generate up to 10 megawatts. That’s a lot, but you also have to put that number into perspective. You need 100 mega turbines at sea to replace a nuclear power plant. The good news? With a potential of 72 terawatts, the entire world can easily switch to 100 percent wind energy.

Biofuels, hydropower, geothermal energy, and wind energy are interesting avenues, but actually, we are looking for a much larger energy source. A source that can supply the world with energy without any kind of rare material. A source that can provide everyone on our planet with enough energy to live a pleasant life. And that source exists. Her name? The sun.

The sun provides 85,000 terawatts of power. That means we have enough energy to do everything we do now if we capture 1 percent of the sun’s energy with a 2 percent return. Figures we can easily reach. So, there is no energy shortage or energy problem. Thanks to the sun, we can use as much energy as we want.

The sun literally and figuratively gives energy. With the heat, you can generate steam, just like geothermal energy, which you can convert into electricity via a steam turbine and generator.

Morocco is a country that is fully committed to solar thermal energy in its transition to zero emissions. Ghassate has the largest thermal solar power station in the world. With a capacity of 510 megawatts, this solar power plant delivers the power of half a nuclear power plant without emitting even one gram of carbon dioxide. The United States and Spain also score well in the field of thermal solar energy. Both countries have different power stations with a capacity between 150 and 400 megawatts.

Thermal solar energy is good for the planet, although it also has some drawbacks. You need sun and a lot of space to install the brine systems. So, not everyone in the world can use it. In addition, solar energy is converted into electricity. And that is an energy form that is difficult to store. Batteries have their limitations in terms of capacity and durability. Fortunately, it is very easy to transport electricity, even over thousands of kilometres. With a high DC voltage line of 1 million volts, you can transport electricity with a limited loss of 3 percent per 1000 km. Do you want to transport electricity from North Africa to Brussels? You will barely lose 10 percent of the power.

Not everything runs on electricity. And that will also be the case in the future. Electricity is a building block for many alternative energy sources. Think back to the experiments during physics class in secondary school. You discovered what electrolysis is – decomposing substances into single substances under the influence of electricity – by putting two plates in a salt solution and then chasing electricity through those plates. Under the influence of electricity, water splits into hydrogen and oxygen.

Hydrogen has many applications. The European Stratofly project is a good example. The aim of this project? Develop hypersonic aircrafts powered by liquid hydrogen that can take passengers to the other side of the world at speeds of up to 9500 kilometres per hour. Hydrogen applications are also gaining more and more power in the automotive, construction and petrochemical industries.

Hydrogen is not just an end product. It can be the building block for other energy carriers, such as methanol. Renewable methanol is a combination of carbon dioxide from the air and renewable hydrogen. Methanol has one major advantage over hydrogen: it is a liquid. And that’s easier to store and transport than a gas. Methanol from renewable hydrogen is an interesting new energy source, especially in the maritime world.

Solar thermal energy - and by extension hydrogen and methanol - therefore seems to be the right choice. But is it also a cost-effective alternative? Making hydrogen to use in the production of methanol is not efficient, is it? It is evident that the direct use of electricity is the most efficient option. The question of the return is actually superfluous. The sun is an inexhaustible source of energy. The return, therefore, plays no role whatsoever.

We must focus on developing cost-effective and efficient ways to store that energy. That requires a significant investment, but we will live in a more predictable world. Fuel costs are now a variable factor. You buy a house that you need to heat without knowing how the fuel price will evolve over time. By converting those variable costs into investment costs, you know from the first day what those costs will be. We just have to dare to make the choice.
Hydrogen

This table shows the properties of hydrogen. I also include the properties of methane (as the main constituent of natural gas) and gasoline for comparison.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hydrogen</th>
<th>Methane</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (27 °C (300 K), 1 atm)</td>
<td>0,090 kg/m³</td>
<td>0,78 kg/m³</td>
<td>5,11 kg/m³</td>
</tr>
<tr>
<td>Boiling point (1 atm)</td>
<td>-253 °C (20 K)</td>
<td>-161 °C (112 K)</td>
<td>25-215 °C (298-488 K)</td>
</tr>
<tr>
<td>Energy content (LHV)</td>
<td>119,7 MJ/kg</td>
<td>50 MJ/kg</td>
<td>42,7 MJ/kg</td>
</tr>
<tr>
<td>Flammability Limits in Air (25 °C, 1 atm)</td>
<td>4–75 % vol</td>
<td>5,3–15,0 % vol</td>
<td>1,2-6 % vol</td>
</tr>
<tr>
<td>Auto-ignition temperature (°C)</td>
<td>585 (858 K)</td>
<td>540 (813 K)</td>
<td>~220-500 (~493-773 K)</td>
</tr>
<tr>
<td>Ignition energy (MJ)</td>
<td>0,02</td>
<td>0,28</td>
<td>0,25</td>
</tr>
<tr>
<td>Squeezing distance (mm)</td>
<td>0,64</td>
<td>2,03</td>
<td>~2,0</td>
</tr>
<tr>
<td>Adiabatic flame temperature (°C)</td>
<td>2045 (2318 K)</td>
<td>1917 (2190 K)</td>
<td>~2197 (~2470 K)</td>
</tr>
<tr>
<td>Laminar flame speed (m/s)</td>
<td>1,90</td>
<td>0,38</td>
<td>0,37-0,43</td>
</tr>
<tr>
<td>Stoichiometric composition in air (volume percent)</td>
<td>29,53</td>
<td>9,48</td>
<td>1,65</td>
</tr>
<tr>
<td>Mass-based stoichiometric fuel-air mixture</td>
<td>0,029</td>
<td>0,058</td>
<td>0,0664</td>
</tr>
</tbody>
</table>

The properties of hydrogen not only play an important role in the elaboration of procedures and protocols. They also determine - just as with systems for petrol, diesel, natural gas, or LPG - the points of attention in the design of a hydrogen system and the conditions with which such a system must comply. In this part, I zoom in on the unique properties of hydrogen and point out the points of attention.

Its low density is perhaps the most important property that makes hydrogen a safe substance with many applications. At atmospheric pressure, hydrogen weighs 90 grams per cubic meter. This makes it by far the lightest gas on our planet. This low density ensures that hydrogen spreads very easily and rises quickly when it is released into the air. Just think of a weather balloon filled with hydrogen. It rises at a speed of 5.8 meters per second.

The ability to rise rapidly causes released hydrogen to quickly dip below its flammability limit when released into the free atmosphere. In order to ignite hydrogen in the free atmosphere, at least 4 percent of the substance must be present in the air. This means that there is very little to no risk of ignition or explosion if hydrogen is released into the free atmosphere.

The fast-rising nature of hydrogen gas is also the reason why hydrogen will always be injected into the bottom of the fuel cell or engine. This prevents avoidance in the air. I would like to note that there is also a disadvantage to this low density: it does not make the method for storage of hydrogen obvious because it has to be done under high pressure. But I’ll tell you more about that later.

Its wide flammability limit is another important property of hydrogen. You can ignite hydrogen with a volume percentage between 4 and 75 percent. This means that you can ignite hydrogen with air in various mixing ratios. In the free atmosphere, however, hydrogen escapes so quickly that it is very difficult to rise above the lower flammability limit. That is a point of attention if you want to use hydrogen to drive engines because that is only possible with the correct mixing ratio.

Hydrogen also has a very low ignition energy, 10 to 15 times lower than natural gas or petrol. And that is interesting in view of applications in engines because the ignition candle must only provide minimal energy. In the free atmosphere, a very small spark is sufficient within the ignition limits to ignite a mixture of hydrogen and air.

A direct consequence of this low ignition energy is that hydrogen has a very small squeezing distance. That is the smallest possible diameter of a flame. As an experiment, try to make the smallest possible flame with a lighter. You will see that your flame always goes out at a diameter of about 2 mm. The reason? A flame with a diameter of 2 mm contains just enough energy to ignite the new butane gas that flows from the lighter. If your lighter is filled with hydrogen, the diameter of your flame would be much smaller, because the ignition energy of hydrogen is much lower than that of butane gas. This property makes hydrogen an interesting source of energy. The return is high because, if you ignite hydrogen, the amount will burn out almost completely.

Hydrogen is the energy carrier of the future. It can be produced from electricity generated by renewable energies, such as wind and solar, allowing for local emission-free use in many applications and completely free of any harmful pollutants or greenhouse gases from tank to wheel when produced on site.
About 70 million tonnes of hydrogen is currently being produced worldwide for many applications, as shown in the illustration. Contrary to fossil fuels, such as coal, natural gas, or crude oil, hydrogen cannot be mined. About 71% of the world’s hydrogen is currently being produced using steam methane reforming (SMR) processes. This means that it comes mainly from natural gas. It is commonly called ‘grey’ hydrogen because GHG emissions are set free during the steam reforming process.

It is possible to produce hydrogen from methanol (CH₄O) or other carbon-rich compounds, such as biogas. However, as long as fossil fuels or compounds are being used, CO₂ and other GHG emissions will be inevitable. Surely, there may be a trajectory towards zero CO₂ emissions rather than a one-off change to green hydrogen produced by renewable energies. No doubt, a number of countries will seek to meet climate goals while using existing industry texture and available infrastructure. This trajectory from current to green hydrogen will define the chosen colour path from brown, to grey, to blue, to green (some add ‘gold’ hydrogen when produced and consumed locally, i.e. by individual companies or households in a closed ecosystem). The future of the brown and blue hydrogen technologies seems to be the carbon capture and storage of emissions (CCS) and the carbon capture and utilisation of CO₂ emissions (CCU). Brown hydrogen refers to production by means of coal or lignite gasification. Only about 2% of the total production is currently green, but the world is catching up very rapidly.

It makes perfect sense to pursue other ways of producing hydrogen at an acceptable cost when it serves the purpose of greening the economy and at the same time helping the so-called sector coupling by extending its applications, thereby making it more accessible and reaching cost parity with fossil fuels more quickly. Today, the parity turning point is assumed to be reached at a hydrogen price per kilo of less than 2 eurocents per kWh, whereas it is currently still 7 eurocents per kWh. With hydrogen containing 33.33 kWh of usable energy, the production cost of hydrogen would need to go down to 0.6 euro per kilo. Whether or not this would mean price competitiveness in any application remains to be seen, as other cost and efficiency factors would have an impact on the outcome. One of the ways to help realise this ambitious goal is to completely stop the subsidies for fossil fuels. Geopolitically, the shift to hydrogen could very well help Europe retain leadership in hydrogen technologies and, as such, counter China’s supremacy in low-cost manufacturing and control of much of the earth’s feedstock, including rare earths. Power-to-X and sector coupling may very well turn out to be magical words in the future.

Wherever suitable, transport of hydrogen takes place via pipelines. The industrialised triangle – Antwerp (BE), Rotterdam (NL), Lille (FR) – is connected through Air Liquide pipelines. The Air Liquide Northern pipeline network covers about 3,000 kilometres, of which 870 km consists of hydrogen pipelines in three countries.

Fuel Cells

The combustion engine can be replaced by a fuel cell, converting hydrogen into electricity with pure water vapour and heat as the sole, clean emissions. As such, hydrogen holds the promise of being key to a zero-emission future, especially when it comes to heavy-duty transportation. The car freaks among us will miss the typical engine noise when hitting the throttle. Other than that, there are a lot of points in favour of an electric drive, including the performance (an electric motor offers greater and quicker torque to the wheels), the sound of your stereo, and the smoothness of the drive. All the good aspects of a petrol car, when it comes to operating range, fuelling, parking, and maintenance, are kept intact without compromise.

In the fuel cell module, an electro-chemical process takes place that produces electricity from hydrogen and oxygen. The electricity is used to drive the electric motor, which in turn will provide traction to the wheels and power the accessories, such as compressors, pumps, cooling systems, etc. When the bus is leaving the (numerous) stops, the batteries will provide traction until
the fuel cell takes over. The electric energy delivered by the fuel cell will flow directly to the electric motor and provide traction to the wheels. According to the engineering strategy, the electricity generated by the fuel cell can be used to (re)charge the batteries en route, which will provide traction to the electric motor. The efficiency losses of the batteries are minimal. Still again, thanks to the fuel cell, the battery capacity can be much lower, so why not provide the electric power from the fuel cell directly to the motor? It is true that hydrogen produced from electricity is now converted again into electricity in the fuel cell and into mechanical energy to turn the wheels. It is an eternal argument for the opponents of hydrogen that the efficiency is reduced, but they completely ignore the many pros as well as the fact that hydrogen offers much more energy than any other liquid fossil fuels.

A fuel cell is much quieter than an internal combustion engine, thanks to the absence of mechanical parts producing friction, which is, of course, a great advantage of electrical vehicles in general, not just fuel cell ones. An audible noise reduction inside the bus of 3 to 5 dB(A) is quite realistic. Given that any noise reduction of 3 dB(A) is equivalent to halving of the level of noise perceived by human ears, the result is remarkable. The improvement of the noise levels, both inside and outside the vehicle, is so dramatic that a safety issue can arise when bystanders do not receive the typical (noise) warning of an approaching bus. We could not think of a better way to deal with it than by installing a horn, producing the sound of (yes) a tram bell, a measure that was approved almost unanimously by all the operators buying fuel cell buses. Noise emissions in inner cities have become quite an important issue in cases of heavy traffic conditions. Even more worrisome in the case of buses are the vibrations. It is not uncommon for diesel bus fleets with a short headway to continuously vibrate the windows on the ground and first floors in shopping areas.

It shows that fuel cell vehicles deserve a place in transportation, when it comes to avoiding emissions and drastically reducing noise emissions and vibrations, especially in city centres and public areas, where the quality of life is increasingly challenged.

In mobility applications, the industry is almost exclusively using so-called PEM (Proton Exchange Membrane) fuel cell technology. The functionality of the fuel cell, converting hydrogen into electricity to provide electrical power to the vehicle, is comparable to a battery. However, in a fuel cell, the process can be repeated on board the vehicle thanks to a continuous supply of hydrogen gas from the storage tank and oxygen from the air, as opposed to a closed battery system.

Current and future generations of fuel cell buses have been developed on the basis of a hybrid drive system. However, that used to be different in the beginning. In order to provide proof of concept, the first 33 Mercedes/Evobus buses in the CUTE (Clean Urban Transport in Europe) programme had the diesel engine replaced by a fuel cell, which was the sole source of traction. The hydrogen consumption, which is already more expensive than diesel, was so high that the buses needed to be refuelled at midday. Since then, all bus models from the current fuel cell bus manufacturers have offered a hybrid driveline.

The hybrid concept entails that two sources work together to provide power to the wheels and ensure that all the accessories can be driven electrically. The fuel cell and traction battery system is managed and optimised electronically per the strategy defined by the manufacturer concerning the various regulatory and legal requirements for safety and operation. If the traction battery has reached its established lower state of charge, the fuel cell will always take over and refill the batteries to ensure the performance of the vehicle. Considering that the braking energy during the stopping process is regenerated in the batteries, I do not recall that it has ever been a problem for the bus to depart from its stop with the batteries. On the contrary, when the batteries are already full before braking takes place, the energy is stored in brake resistors for later reuse (i.e. to heat the passenger compartment). Any additional excess energy when the brake resistors are full is dissipated in the air. This action allows for more efficient use, thus optimising the flow of energy. It also allows the energy management system to be tailored to the specific needs of the application. Climate zones, stop-and-go profiles, topography, average speed, or average loads, can now be taken into account in the software strategy, depending on the performance and the desired longevity of the batteries.

This energy optimisation process is precisely what the hybrid driveline is about, including increased operating range (less consumption equals more kilometres) and fast refuelling times to achieve the daily service target. The latter may be very demanding for a typical city bus duty cycle: 18 hours a day in harsh operational conditions, including stop-and-go traffic and low commercial speeds, with no opportunity for en-route refuelling. No one said a bus life would be easy. Thanks to the energy conversion (from hydrogen to electricity) on board, the capacity and size of the battery can remain very limited, mostly only 24 kWh, compared to about 10 or more times this capacity to ensure the same performance of a battery-electric bus.
Fuel Cell (PEM) Working Principle

Each fuel cell has an anode and a cathode side and an electrolyte membrane. Hydrogen (at the anode) and oxygen (at the cathode) are inserted on each side. A catalytic reaction splits the hydrogen into positively charged H+ ions (protons) and negatively charged ions (electrons). The electrons are sent to the cathode, thus building an electric current.

The unused protons and electrons come together at the cathode and react with oxygen (O) to produce water (steam) and heat, none of which is harmful.

In the case of a bus, a cell typically produces approximately 0.7 volts, resulting in the need to put cells in packages. One of these packages is called a ‘stack’, and several stacks are packaged into one module, defining the total power output capacity required. For a heavy-duty bus, the total power output of the fuel cell was 150 kW initially and has been reduced in the meantime to between 85 and 75 kW for a 12-metre bus in current bus applications. The efficiency of the fuel cell may be rounded 50%. However, energy regeneration (i.e. when braking) and reuse (i.e. to heat the passenger compartment), will improve the overall efficiency of the system.

Production of Green Hydrogen

Will the CO₂ emission problem be gone completely when we all drive battery-electric or hydrogen-electric cars?

Unfortunately, it is not that easy. The CO₂ footprint from well-to-wheel, i.e. from the cradle to the grave, meaning the production and the distribution throughout the entire lifetime, will depend on how hydrogen is produced and distributed.

Electrolysis: The most common way to produce green hydrogen is from water by electrolysis. Electrolysis is the process of splitting water (H₂O) into hydrogen (H₂) and oxygen (O). The concept is far from new. It was discovered in the late 18th century and used by Zénobe Gramme in his ‘machine’ that split water into hydrogen and oxygen. A method of industrial synthesis of hydrogen and oxygen through electrolysis was developed by Dmitry Lachinov in 1888. The main reason for clean hydrogen produced through electrolysis failure to become mainstream is that a lot of electricity is needed in the process, and the electricity does not come cheap. Even today, with the cost of renewables rapidly falling, the kilo price for green hydrogen should not exceed 1.5 to 2 USD/kg in order to compete with steam methane reforming (SMR) hydrogen. The on-cost for green hydrogen should therefore be less than the cost to deal with the CO₂ emitted through SMR techniques. This can be achieved through decreased cost of electricity from renewables or by increasing the carbon prices which would need to be increased 40 USD/tonne to make green hydrogen attractive from an economic perspective. Today, the CO₂ EEA (European Emission Allowance) is still at 25 USD/tonne.

The ETS, or Emissions Trading System, allows emission producers to ‘cap and trade’ emissions to stimulate the use of clean technologies from the moment it becomes cheaper to invest rather than to pay for the emissions.

The same goes for the cost of CCS (carbon capture and sequester). Given the high CO₂ output of big power plants running on (brown) coal or natural gas, it is technically possible to capture the CO₂ emissions and bury them deep under the soil where they can stay trapped for a very long period of time.

Hence the conclusion that, when electricity is provided from sources other than fossil fuels (coal or gas), the overall CO₂ footprint of hydrogen may not be or may hardly be better than diesel, as shown in the illustration.

However, when using redundant electricity from renewable sources of energy, such as solar or wind, the energy is clean and comes at a marginal production cost when converted and stored in hydrogen.

Well-to-Wheel CO₂ Footprint for Hydrogen (kg/100 km) produced by means of electrolysis, based on the 2015 energy mix, compared to diesel fuel.

<table>
<thead>
<tr>
<th>Source</th>
<th>Diesel</th>
<th>Hydrogen:</th>
<th>H₂ grid electricity - methane reforming</th>
<th>H₂ grid electricity mix in DE</th>
<th>H₂ grid electricity mix in UK</th>
<th>H₂ grid electricity mix in NL</th>
<th>H₂ grid electricity mix in FR</th>
<th>H₂ grid electricity mix in NO</th>
<th>H₂ Electrolysis RES (Renewables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>122</td>
<td>H₂ grid</td>
<td>106</td>
<td>225</td>
<td>201</td>
<td>180</td>
<td>31</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Since electrolysis of water requires power, it is highly recommended – if not a MUST – to use electricity from (redundant) wind and solar renewable energy sources. This energy is truly ‘green’. 5.6 kWh of energy and approx. 9 litres of water are needed to produce 1 kilogram of hydrogen through electrolysis. The kilo of hydrogen contains 33 kWh of energy. Once converted in the fuel cell, it will provide 18 kWh of power, which translates to 55% efficiency. Therefore, the total cost equation will depend mainly on the cost of electricity, unless priority is given to other factors instead, such as the societal value of ZERO well-to-wheel emission and/or the certainty and independence of energy supply. With things becoming increasingly clear, I thought it would be interesting to share the current situation and outlook of considering the total cost of ownership in another chapter of the book.

With the cost of wind and solar energy falling rapidly, it is only a matter of time before green hydrogen will be produced competitively. The question is no longer if but when, and the time pressure is on. Because of the many promising projects that are going on worldwide, not least in the EU, in any event, the ONLY way forward is without any doubt the use and storage of hydrogen produced with electricity from renewables.

A full breakthrough is likely to occur when green hydrogen is being produced, stored, and used on the production site, which may very well be by companies, hospitals, bus depots, and why not, households in a well-balanced local ecosystem. Pilot ecosystems are being developed in regions, such as Groningen/Drenthe in the Netherlands, that aim to be hydrogen hubs.

The Japanese company Enapter’s founder and CEO claims that the latest electrolyser generation will be able to produce hydrogen for 1.5 euro/kg by 2030, whereas they are still facing a market price of 7 euro/kg today. He continues to state that ‘the units will be considerably smaller than the current ones and be fit for small on-site systems allowing the deployment of relatively small ecosystems’.

Other renowned electrolyser players are Hydrogenics, a Canadian company with manufacturing facilities in Belgium recently acquired by Cummins Engine Company, ITM in Sheffield, UK, and NEL in Norway, who are extending their electrolyser offering to storage solutions and hydrogen refuelling stations.

This explains to a certain extent why some countries, such as Norway and, more recently, France are keen on developing a hydrogen economy, and others are not. The reason why some countries are keen on hydrogen despite their apparent lack of green grid electricity, such as Japan, Germany, and the Netherlands, is that they are in the process of developing major plans to switch to renewables or want to secure the energy supply, as is the case for Japan.

The opposite is also true. As long as electricity is being produced from fossil fuels, the grid will not be green. Consequently, batteries will not offer well-to-wheel elimination of GHG emissions in the near future. Except for a very few countries, such as Norway, the grid electricity is mixed with other sources, such as coal and gas, and as such, will only be “greening” the grid over a long(er) period of time.

This argument does not seem to hold in the eyes of the public. Electric cars run on electricity, do not pollute on the road, and therefore get a green sticker when entering the city. They may not be CO₂ neutral, some not even by a long shot, but nobody cares, nor are vehicle manufacturers requested to certify well-to-wheel emissions or publish their overall real CO₂ footprint. Europe and the world will realise this is a major mistake and that consumers are at risk of being fooled once again.

Hydrogen produced by electrolysis with electricity from renewables, on the contrary, offers the prospect of being fully and entirely green from day one, as shown in the illustration. The preconditions to achieve this ultimate goal are a) the production of hydrogen through electrolysis using renewable energy and b) store and use the hydrogen at the production site (or very close by). This may sound theoretical, but it is not: in the case of bus fleets, the bus operator may have its own on-site electrolyser and the refuelling infrastructure in the bus depot. Already now, small electrolyser systems are being economical from bus fleets of 20 units. Hydrogen would then be the only fuel that is completely and fully carbon-free from day one.

Admittedly, the above preconditions would face some practical issues when it
comes to producing home-made hydrogen, in a way that refuelling private cars can be done in each and every home. Even without home-made hydrogen, the overall well-to-wheel CO₂ footprint would be considerably less than batteries, but not entirely zero.

Decarbonising the economy and in particular transport is a MUST (given the importance and the sense of urgency), but also a WORK IN PROGRESS (given the complexity of the issues).

Considering that many intermediate solutions will emerge, both in time and in technology, before projects, tests, and early market adopters will lead to full market acceptance, it would make sense to categorise and differentiate them based on the greening levels reached, ranging from carbon-rich to carbon-free.

To do just that, a scheme has been developed in the European-funded CertifHy project, as shown. The definitions are generally related to the current base line emission level of hydrogen, i.e. hydrogen produced from natural gas through the most commonly used Steam Methane Reforming or SMR process. The benchmark SMR value is 61 grams per MJ H₂.

- High H₂ level: between 91 and 36.4 gram per MJ H₂.
- CertifHy Low H₂ level from non-renewable sources: less than 36.4 gram per MJ H₂.
- CertifHy Green H₂ level from renewable sources: less than 36.4 gram per MJ H₂.
- CertifHy Ultra-low or Zero CO₂ from renewable sources (renewable green hydrogen): zero grams CO₂.

This scheme can be used perfectly well to inform markets about the level of decarbonisation and certify each individual supply accordingly. There is no reason why battery-electric products should escape from certifying their overall CO₂ footprint.

Green hydrogen, as an energy carrier or an energy storage option, can be valorised in the energy sector in different ways, in the so-called Power-to-X, including:

- Power-to-Power (P2P): electricity used in a fuel cell;
- Power-to-Gas (P2G): hydrogen directly injected into the natural gas infrastructure or converted to bio-methane (using CO₂ in the process);
- Power-to-Mobility (P2M): for direct use in cars, buses, trucks, trains, drones, etc. or blended with traditional fuels to produce bio-methanol, bio-methane or to lower the carbon footprint in traditional refinery processes;
- Power-to-Chemicals (P2C): used in the production of ammonia, in the petrochemical industry and the food industry, to decarbonise the chemical sector. Power-to-ammonia seems to be the most promising. Here, e-ammonia (NH₃) is synthesised from green hydrogen and nitrogen. E-ammonia can be used as feedstock for fertilisers (urea, ammonia phosphates) and other chemicals.

The multiple uses of green hydrogen, whether directly as a fuel or indirectly, will help build the business case for generalised use, while at the same time, greening traditional industries and creating the momentum and the critical mass for a significant green energy transition. Power-to-X is the key to unlocking the potential of this so-called sector coupling. Sector coupling is nothing more (nor less) than bringing renewable energy from the power sector into other sectors to thereby decarbonise the entire energy system, according to Dr. Pflug from Siemens.

For the ones among the optimists who dare to dream even bigger, some inroads into other methods of green hydrogen production have been made.

“Only when ALL electric products are required to state their footprint will manufacturers be forced to meet the goals on CO₂ reduction targets, and will the public be able to appreciate their respective climate change impact. This applies not in the least for electric vehicles. Certifying the content of GHG emissions in all products in order to document their greening level, will be a major step in the right direction.”
They include:

**Photo-Electrochemical Hydrogen**
In photo-electrochemical (PEC) water splitting, hydrogen is produced from water using sunlight and specialised semiconductors, which use light energy to directly dissociate water molecules into hydrogen and oxygen. The challenges appear to be improving efficiency through better absorption of sunlight, as well as the durability and lifetime of the materials used.
In a recent article, Professor Claudia Turro from Ohio State University is quoted, saying that we can use a cell in the form of a molecule (rhodium), which harnesses 50% more energy than current cells and is able to absorb the visible sunlight (photons) and act as a catalyst to store 2 electrons to turn it into hydrogen.

**Biological Photosynthetic Hydrogen**
This method uses certain micro-algae as well as photo-synthetic bacteria to produce hydrogen instead of sugar and oxygen.

**Conversion of Biomass and Waste**
Through thermochemical conversion (pyrolysis) or fermentation, biomass and waste can be converted into hydrogen, even without the addition of energy (so-called dark fermentation).

**Solar-thermal Water Splitting**
Water will typically be dissolved into hydrogen and oxygen at a temperature of 2,500°C. These temperatures are possible with concentrated sunlight.

Photocatalytic water splitting has the simplicity of using a catalyst and sunlight to produce hydrogen from water.

The sun emits about 3.86 x 10^26 watts of energy at any given time, of which about 174 followed by 24 zeros at the end of that number hits the face of the earth, enough energy for 1 kilowatt for every square metre of the planet. To make it even more concrete, that is nearly ten times what a standard household uses in a day. Capturing some of that energy to produce and store hydrogen for use whenever required would be more than a dream come true.

**E-fuels**
Sometimes designated as ‘Power-to-Liquid (P2L)’, e-fuels are fuels that are synthetically produced with renewable energy. The hydrogen produced by electrolysis by means of renewable electricity is combined with CO₂, yielding synthetic fuel, including kerosene, petrol, and fuel for heating. In some cases, pilot projects have reported a reduction of 80% of CO₂ emissions in the process.

It is noteworthy that the new fuels have a need for CO₂, which in turn could trigger a renaissance of carbon capture and utilisation (CCU), making CO₂ a new commodity at real market prices.

The revised Renewable Energy Directive (so-called RED II) already stipulates that renewable fuels of non-biological origins (which include e-fuels but also ‘green’ hydrogen) should represent 14% of the market share of transport fuels in 2030.

E-fuels also offer the possibility of being produced in the same area as their consumption, which is another plus when reducing the GHG emissions.

The Jülich Forschungszentrum in Germany has investigated a biological process for the production of methane from CO₂ in a purpose-built plant. It involves the use of bacteria that can process CO₂ and hydrogen into methane under anaerobic conditions. This could possibly lead to methane gas based on green hydrogen and CO₂, replacing natural gas.

Although the road to heaven is always paved with good intentions and an equal amount of hurdles, the technology is not so far off. The comment that the technology is much less of a hurdle than the business considerations applies to most of the recent developments. Most of them are very much technically feasible but need to be prioritised to attract and aggregate the huge investments that are necessary, based on their expected impact, both in time and in cost.

It will not surprise you when I add that these production methods are in the early stages of development and testing. Given the need as well as the outlook that relatively low quantities of energy are required to produce green hydrogen, all technical means are being exhausted to achieve such a breakthrough.

**By-product Hydrogen**
During the production of chlorine-alkali, hydrogen is released as a by-product. This is the case at the Solvic plant (formerly Solvay) in Lillo, near Antwerp. Considering that the hydrogen pipeline is only a couple of hundred metres away from the plant, a connection has been made for the hydrogen by-product to be discharged in the pipe. Similarly, the Chemiepark in Hürt, Germany, burns off about 6,000 kilograms of hydrogen per day coming out of the production plants, failing to find a more economical way to use this excess hydrogen.
Among others, this was a good reason for RVK (Regionalverkehr Köln), the intercity bus service agency for the Cologne area, to test four fuel cell buses. The hydrogen had to be transported by trailer to the refuelling station, where it had to be compressed and stored in buffer tanks for subsequent unloading at 350 bar into the buses.

Worldwide, about 150 plants produce hydrogen as a by-product of their regular production and either vent or burn it on the spot. With about 400,000 tonnes of hydrogen per year being wasted in the air, approximately 1.8 million cars could be running on waste hydrogen. Additionally, about 40,000 bio-waste plants could produce hydrogen so that the total by-product hydrogen could add up to 100,000 MW of energy per year.

**Mega(watt) Electrolyser Plants**

Megawatt Electrolyser plants are a prerequisite for the production of green hydrogen that can be used in the applications and sector coupling areas stated before.

Wood MacKinzie reported in March 2020 that the electrolyser capacity has nearly tripled in the previous five months, to reach 8.2 GW. A big leap has been noted in the number of projects with a capacity of 100 MW or higher. 17 projects are now under construction around the world, including in Europe, the US, South America, and Australia.

Engie and RWE have plans to build a 100 MW electrolyser plant, and the goal for 2030 is to have their first 1 GW unit.

**Transport of Green Hydrogen**

*(narrated by Jorgo Chatzimarkakis, Secretary-general of Hydrogen Europe)*

Clean hydrogen can substantially contribute to the decarbonisation of a number of strategic European industries usually grouped into industrial clusters, e.g. refining, petrochemicals, steel, and cement-to-gas facilities can be directly connected to offshore renewable power installations to produce clean hydrogen. Offshore gas pipelines can be utilised to transport it to demand hubs far away from production. Hydrogen transport via pipeline is also a cost-effective solution for transporting energy over large distances. Offshore platforms can also be used as hydrogen hubs at sea to supply hydrogen to ships in transit.

But is this feasible? A group of 11 European gas infrastructure companies (Enagás, Energinet, Fluxys, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas and Teréga) have developed the prospect of a European Hydrogen Backbone. The network could cover 23,000 km of pipelines by 2040 based on 75% repurposed existing pipelines and 25% new pipelines. The network can be created in a cost-effective way with levelized cost of hydrogen transport estimated to be between €0.09 and €0.17 per kg of hydrogen for transport over a distance of 1,000 km.

Yet, in order to implement this endeavour, we need to introduce a holistic approach to Ten-Year Network Development Planning (TENDP process) between electricity, gases, and clean hydrogen to optimise investment efforts required for the transformation of the energy system. We need to simplify the PCI (Projects of Common Interest) selection processes that reflect the ambitions of the EU Green Deal and incorporate a sustainability dimension in the PCI selection based on GHG emissions reduction potential, to be applied in a non-discriminatory manner.

Most importantly, we need to introduce ‘clean hydrogen networks’ as a new thematic area under the TEN-E Regulation. New infrastructure projects, as well as hydrogen transport (including pipelines, maritime, road, and other) solutions, intermediate storage, and associated infrastructure projects, should be encompassed in the framework of TEN-E. This should also include new innovative projects, such as power-to-gas, offshore wind combined with electrolyser and hydrogen pipelines, large-scale hydrogen storage, and decarbonisation of ports and LNG terminals to import clean hydrogen and its derivatives.

The first step, and so to say, the low hanging fruit, would be to support the interlinking of hydrogen clusters, particularly projects of cross border nature, paving the way for the development of an EU hydrogen backbone. We, therefore, should consider a revision of the regional TEN-E Groups to include clusters of Member States ready to form regional hydrogen backbones. This also includes the introduction of provisions that favour the repurposing of existing gas infrastructure (incl. LNG & storage facilities) to transport and store pure hydrogen as well as the development of new dedicated hydrogen infrastructure and support for the retrofitting of gas infrastructure to accommodate blends.

When it comes to the updated regulation ‘hydrogen’ needs to be integrated as a new energy infrastructure category alongside electricity, gas, oil, and carbon dioxide. The new regulation should include, among others, dedicated hydrogen pipelines and repurposed natural gas pipelines for the transportation of pure hydrogen. At the same time, reception, storage, and regasification (when applicable) or decompression facilities for liquid hydrogen or dehydrogenation...
of hydrogen carriers or hydrogen-based fuels should be added in order to support the import of hydrogen into the EU.

We should also think of conversion parks and required infrastructure in ports where electrolyzers convert renewable energy into green hydrogen for the supply of industrial plants and facilities to use the ‘waste streams’ as well as heat and oxygen power-to-gas facilities for the conversion of electricity to hydrogen and, if applicable, further to synthetic gas in so far as they perform network-related functions.

**Storage of Hydrogen**

A major advantage of hydrogen is that, once produced, it can be stored for later use at any time and in any place. The storage of hydrogen is not limited to huge cylinder-like containers but can also take place in salt caverns. Storing fuel in caverns is not new. The world’s largest storage facility for 1,000 megawatts (MW) of clean power is in Utah, but the concept is quickly gaining momentum in Europe. While California alone has the potential to create up to 100 caverns, Europe aims to invest 55 billion euro in storage by 2030 to build a capacity of 3 million tonnes of green hydrogen.

**State of Play**

**European Union – European Green Deal and Climate Law**

The European Climate Law (EU 2018/1999), the European Green Deal, and the COVID-19 Recovery Plan are all interlinked. As already approved by the European Parliament, the Member States will be using one third of the funding from the COVID-19 Recovery Plan to foster and support green initiatives. Hydrogen is one of the cornerstones. On 8 July 2020, the European Commission issued a communication entitled ‘A hydrogen strategy for a climate-neutral Europe’. Although it includes both grey and blue hydrogen to meet the 55% CO₂ reduction targets in the next decade, the absolute priority has been given to ‘green’ or ‘clean’ hydrogen, i.e. produced from renewables. Considering its anticipated impact on the transport sector at large, more details about the Hydrogen Strategy and its impact on the final breakthrough of hydrogen are given in the Run on Water section in Chapter 4.

The European Green Deal has set out a new growth strategy, envisaging a future where ‘there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use’. The Intergovernmental Panel on Climate Change (IPCC) Special Report on the impacts of global warming of 1.5°C above pre-industrial levels confirms that greenhouse gas emissions urgently need to be reduced further in order to meet this objective, particularly in light of the likelihood of extreme weather events. In plain English, it means that, if the achievements at the end of 2018 showing a reduction of GHG emissions by 23% while the economy grew by 61% result in a business-as-usual scenario, we cannot expect the reduction to be more than 60% by 2050. That is far from the climate neutrality goal set in the new EU regulation, known as the Climate Law.

Its main clauses can be summarised as follows:

- Net zero GHG emissions by 2050
- EU institutions and Member States shall take the necessary measures to enable this collective achievement.
- By September 2020, the Commission shall make a review and explore options for a new target of 50-55% reduction by 2030. In the meantime, the 55% reduction objective has been cast in stone.
- By September 2023, and every five years thereafter, the Commission shall assess the collective progress and the national measures taken by each member state and review the consistency of the measures taken and the targets achieved.

If inconsistent, the Commission will make the necessary recommendations. All Member States are required to comply with the recommendations.

Europe wants ‘to act more firmly in response to the climate and environmental-related challenges, as one million of the eight million species on the planet are at risk of being extinguished, and forest and oceans are being polluted and destroyed.’ At the same time, the Green Deal aims at putting Europe on a new path of sustainable growth, by drafting the roadmap of the key policies and measures needed. Given that the production and use of energy across economic sectors accounts for more than 75% of all GHG emissions, energy efficiency and supply must be prioritised.

The Green Deal also wants to deflect two other serious threats: the risk of transfer of production by EU companies to other countries outside the Union that have lower ambitions for emission reduction and the risk of replacing EU products with more carbon-intensive imports. If that happens, under the solidarity principle of the Green Deal, the Commission will propose a carbon border adjustment mechanism – read import duty or tax – to reduce this risk, such that the final price reflects the respective carbon content.
Transport accounts for a quarter of the EU’s greenhouse gas emissions, and this number continues to grow. To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050. The plan includes the following guidelines and objectives:

- Multimodal transport needs a strong boost: a shift from inland freight by road to rail and inland waterways and a new start for a true Single European Sky to achieve significant reductions of aviation emissions.
- Automated and connected multimodal mobility: smart traffic management systems enabled by digitalisation to support new sustainable mobility services in urban areas. Mobility as a Service solutions will be funded by available EU sources.
- Price of transport should reflect the impact it has on the environment and on health. In other words: subsidies to fossil fuels should end, and alternatives for the Eurovignette should be back on the table.
- Ramp-up the production and deployment of sustainable alternative transport fuels: by 2025, about 1 million public recharging and refuelling stations will be needed for the 13 million zero and low-emission vehicles expected on European roads. In accordance with the Smart Mobility Strategy, the hydrogen refuelling station (HRS) targets are: 500 by the end of 2025 and 1000 by the end of 2030.

The very first tangible joint European initiative was taken in March 2020, only days before – in some cases coinciding with - the lockdown measures taken by most Member States following the outbreak of the COVID-19 virus. This European Clean Hydrogen Alliance initiative calls for an EU-wide partnership to develop clean hydrogen fuel technologies, in an attempt to push forward the carbon neutrality strategy in Europe. The Alliance follows the precedent set by the European battery alliance, which received 3.2 billion euros in overall public support. It is designed to provide the necessary tools, including trade, competition, and procurement policies. It will most probably clear the way for state aid, not in the least to step changers, such as Air Liquide, Alstom, and Michelin in France and Bosch and Siemens in Germany.

The Green Deal advocates for imposing a carbon tax on entry of all imported products, including on so-called environmentally-friendly products, from outside the Union when their foreign manufacturers are not able to provide proper certification of the net GHG emission content, in accordance with international standards. The Green Deal includes further legislation and guidance on green public purchasing, such that ‘green claims’ should be substantiated against a standard methodology to assess their impact on the environment.

The European Commission’s President Ursula von der Leyen, backed by German Chancellor Angela Merkel, made it clear the European Green Deal was to be situated at the centre of the EU recovery plan, pledging a trillion-euro fund to restart the economy. In her public address in January 2021, President von der Leyen made it very clear that hydrogen was an intrinsic part of the recovery and resilience plan. Hydrogen is definitely back on the agenda after, and despite (perhaps thanks to), COVID-19.

The role hydrogen should be playing in the energy transition and towards decarbonising society has been given a tremendous boost with Communication 301 of the European Commission, published on 8 July 2020 and entitled ‘A hydrogen strategy for a climate-neutral Europe’. After decades of struggling to define what its place should be, it has now become obvious that the door is finally open for the following reasons, clearly stated in the document: ‘in the past, hydrogen did not take off despite peaks of interest. Today, the rapid cost decline of renewable energy, technological developments and the urgency to drastically reduce greenhouse emissions, are opening up new possibilities. The share of hydrogen in Europe’s energy mix is projected to grow from the current less than 2% to 14% or more by 2050’.

Interestingly, the document seems to understand and address the various challenging aspects of getting there, as it realises that neither the private sector nor Member States alone can successfully address the issues. Driving hydrogen past the tipping point needs critical mass in investment, an enabling regulatory framework, new lead markets, sustained research and innovation, new market concepts, a large-scale infrastructure network that only the EU as a single market can offer, and cooperation with third-party country partners.

Because of the many different and important aspects of the final goal of building ‘a dynamic hydrogen ecosystem in Europe’, other chapters of this publication will elaborate and comment on the content.

Oddly, but not before their time, the European competition rules and the intellectual property plan (ITP plan) are very much on the agenda as part of the new industrial strategy. The intellectual property plan intends to uphold technological sovereignty, promote a global level playing field, better fight against IT theft, and adapt the legal framework to green and digital transitions. The competition rules will include the ongoing evaluation of merger control and fitness checks of state aid guidelines and ensure that the rules are fit for purpose, considering that the economy is quickly changing to one that is digital, green, and circular. Those tasked with ensuring fair competition at home and abroad...
will adopt the white paper to address distortive effects caused by foreign subsidies in the market and tackle foreign access to EU public procurement and funding. At the same time, a legal instrument to address the lack of reciprocal access for public procurement in third countries at the World Trade Organisation will be put in place.

**United States of America – A roadmap to the hydrogen economy**

Fifty years ago, the US put the first man on the moon. The Apollo 11 mission relied on a hydrogen-powered fuel cell system, which supplied electricity and water for the mission and liquid hydrogen as fuel to propel the rockets. These are the introductory words of a recent document entitled ‘Roadmap to a US hydrogen economy’, from which I have borrowed most of the future outlook views.

Understanding that each country, let alone each economic bloc, has its own reasons for pursuing policy measures, it strikes me that most of them seem to concur with those pursued in Europe. Given the geopolitical position in which both the US and the EU are working, this is nothing less than remarkable. Or is it not? Let’s see:

- The energy system in the US is evolving: decarbonisation, preservation of natural resources, aging infrastructure, the growing need for energy storage, new customer demands, a less resilient and reliable energy system.
- Hydrogen is the key to overcoming some of the challenges. A vibrant hydrogen industry would maintain US energy leadership and security, create jobs, significantly reduce carbon emissions, and support economic growth.
- The time to boost support for hydrogen is now. Department of Energy (DOE) is funding hydrogen and fuel cells with an average of 150 million USD per year, a fraction of the subsidies in Japan and China.
- Investment is needed to lay the groundwork: capital, incentives, removal of regulatory barriers, development of codes and standards.
- Hydrogen is critical for a lower-carbon energy mix and has the potential to meet 14% of the energy demand in the US by 2050. In the more ambitious scenario, hydrogen demand potential across all applications in the US is expected to reach 17 million tonnes by 2030 and 63 million tonnes by 2050.
- Hydrogen could drive growth by 150 billion USD per year in revenue by 2030 and 750 billion USD by 2050 and add a cumulative 3.4 million jobs.
- Hydrogen could help preserve national energy security by utilising domestic energy resources, by using abundant renewable resources, natural gas, and carbon storage, and by enabling the nuclear industry.

In transport, hydrogen vehicles are particularly suited to be used as heavy duty vehicles, refuel quickly, drive long distances, carry heavy loads, and have high uptime. The total cost of ownership (TCO) is calculated to break even with the TCO of internal combustion engines between 2025 and 2030. Already now, in fuel cell forklifts and vehicles with applications needing high uptime and fast fuelling, their cost of ownership is less than battery-electric counterparts.

The hydrogen application roadmap shows the development stages of four different applications in an equal number of time frames:

- **2020-2022: immediate next steps** – early commercially viable applications in early adopter markets – 7,600 vehicles
- **2023-2025: early scale-up** – electrolysis from renewables, gas reforming using natural gas from renewables, carbon capture and sequestration – blending of hydrogen with natural gas for heating – up to 50,000 vehicles (light-medium, heavy-duty)
- **2025-2030: diversification** – meaningful sector coupling, long-haul trucking, unlocking full market – 200,000 vehicles on the road.
- **Beyond 2031: broad rollout** – cost parity with fossil fuels for most applications – large-scale production facilities across the US – distribution pipeline network – large fuelling station infrastructure network – 5.3 million vehicles.

In a separate document, the US transit bus industry laid out the goals for commercial sustainability of fuel cell buses. They include performance and availability goals, range, and capital cost requirements as well as fuelling infrastructure and maintenance budgets. Most strikingly are the capital costs for the bus to reach cost parity with a diesel-hybrid bus and for fuel costs not to exceed 5 USD/kg hydrogen. The plan includes requirements for purchasing zero-emission buses, starting in 2023 with a minimum 25% of yearly fleet replacement, increasing to 50% in 2026 and 100% from 2029 onwards, for the larger fleets.

Having said that, there are (only) 8,285 fuel cell cars and 42 buses in America, almost all of them in California, where the California Fuel Cell Partnership is actively pursuing all applications. It is a tiny percentage of the 270 million gasoline-powered vehicles found in the US today. The chicken-and-egg controversy about who’s first, fuelling stations or cars and buses, is only one of the reasons, and the fuel cell stations are catching up quickly. Another 200 stations, most of them running on renewable hydrogen generation, are planned before 2025. The purchase cost per unit is another issue, although in all fairness, it is compensated by health cost reduction when limiting pollution levels in the city and savings in maintenance. Fuel cost per mile is still not at parity but is probably very realistic when low-cost production of renewable hydrogen hits the 1.5-2 USD/kg mark.
Asia
(researched and narrated by M. Pecqueur)
China’s position as by far the largest car market in the world can also act as a catalyst for other car brands.

Asia is without doubt the pioneer of hydrogen as a fuel. Nowhere in the world are hydrogen vehicles more present in the streets than in Asia. Japan has more than 100 hydrogen refuelling stations and more than 3,000 hydrogen trucks driving around. The Japanese government made it a point of honour to organise all transport during the Olympic Games of 2021 without local emissions. Under the impulse of car manufacturer Hyundai, South Korea is going full steam ahead on hydrogen. The country already has 86 hydrogen filling stations and has the ambition to increase that number to at least 1200 by 2040.

Hydrogen as a fuel is also gaining popularity in China. In June 2019, Wan Gang - one of the fathers of the Electric Revolution and former Science and Technology Minister (2002-2007) - announced that the era of hydrogen had arrived in China. Wan’s announcement should come as no surprise. The electrical market in China is very highly developed, and a shift in focus to hydrogen is therefore evident. According to Wan, hydrogen is the best fuel for long-distance journeys. The incentives for electric cars are disappearing, and the country has chosen a number of specific regions to develop the hydrogen market. This development includes the installation of filling stations and storage facilities, the roll-out of transport systems, and the construction of hydrogen vehicles.

China’s ambition is not entirely new. In 2016, the Chinese government launched the Hydrogen Fuel Cell Vehicle Technology Roadmap as part of its 2025 vision plan. Under this plan, there should be more than 300 hydrogen refuelling stations in the country by 2025. In addition, at least 40,000 hydrogen vehicles with a cost of less than 26,000 euros and 10,000 commercial vehicles with a cost of less than 130,000 euros must drive on hydrogen.

China is without a doubt the most important player in the electric car market. These are not yet massively present on the European market, but this will undoubtedly change soon. The challenge for China to be a leader in the hydrogen car market is also great. In this respect, the country is technologically lagging behind Europe, America, Japan, and South Korea. But China has started to catch up, with only one goal: to become the biggest. The fact that a superpower such as China is betting on hydrogen proves that the country believes in a strong future for hydrogen as a fuel. China will make every effort to achieve the goal it set for itself, regardless of the efforts it has to make to achieve it.

And a nation that succeeded in building a hospital in just a few days during the COVID-19 crisis will certainly succeed in its goal of quickly becoming the global hydrogen player.

In China, just about everything is top down. The policies on hydrogen are not any different. The country has realised that the challenges are great, and the Chinese government is therefore investing heavily. At the end of 2019, the counter was at 14 billion USD. With a view to the 2022 Winter Olympics, China wants to show not only a sporting spirit but also a hydrogen aspect. In April 2020, China’s Hebei Province announced a support program of 8.75 billion yuan (1.1 billion euros) to develop the hydrogen economy, so that during the winter games, China can demonstrate that it has also become an authority in hydrogen. By 2021, the Zhangjiakou region will produce 21,000 tonnes of hydrogen per year, a figure that will further boost the region to 50,000 tonnes in 2035.

Meanwhile, the hydrogen economy in China is starting to take shape. In March 2020, Haima launched the 7X, a fuel cell-powered car with 7.25 kilograms of hydrogen on board – a quantity with which you can drive 800 kilometres, according to the manufacturer. Grove previously launched two hydrogen models at the 2019 Shanghai Motor Show and revealed its ambition to be the largest producer of hydrogen cars in the world within a few years. Grove is a Chinese company with an R&D department in Barcelona and opts for a total approach. In the region where the company will be responsible for the rollout of hydrogen vehicles, it will not only sell hydrogen vehicles but also build a network of service stations. This way, customers can always fill up close to their home. If the project proves successful, it will be rolled out across China. With 240 vehicles for 1.4 billion inhabitants, there is still a lot of potential. The roll-out across the rest of the world will follow from 2022. The plan may be delayed due to the COVID-19 crisis, but Grove’s ambition will certainly remain intact.

China’s position as by far the largest car market in the world can also act as a catalyst for other car brands. Volkswagen is now the largest player in the Chinese market but has no immediate interest in the development of hydrogen vehicles. The question is whether the German brand should not change that attitude if it wants to maintain its position in the Chinese market. The pressure to enter the hydrogen market will be great.

China is also taking the lead in the field of hydrogen filling stations. In June 2019, the world’s largest hydrogen refuelling station opened in Shanghai. Capacity: 2 tonnes per day. The equivalent of filling sixty buses a day. That’s a lot, but to meet future demand, that capacity will have to increase!
China is not the only Asian country where hydrogen has a firm foothold. Japan and South Korea also believe in hydrogen as a future fuel. Japan is aiming for 900 service stations and 800,000 hydrogen cars by 2030. Those targets are not surprising with strong Japanese brands such as Honda and Toyota. The latter brand sold more than 10,000 copies of the Mirai model, the group’s hydrogen car, worldwide. The second generation of the model hit the market in 2020, and Toyota strongly believes in successful sales. Proof? The car manufacturer plans an annual production of 30,000 vehicles. Toyota’s hydrogen technology is not only finding its way into passenger cars. Buses and trucks are also equipped with their fuel cell technology through partnerships. In Europe, Toyota has a partnership with BMW, which can fulfil its hydrogen ambitions on the basis of the Toyota fuel cell. To induce you to buy a Mirai, Toyota will give customers in the US a card to buy hydrogen for free for a period of three years.

South Korea is competing with Japan when it comes to hydrogen. With Hyundai as its flagship, the production and sales of hydrogen-powered vehicles are growing strongly. With the Nexo, Hyundai has, after the Santa Fe FC and the Ix35, its third generation of hydrogen cars on the market. Hyundai anticipates production of 40,000 cars by 2022 and even 700,000 by 2030. Like its Japanese competitor, Toyota, Hyundai is not limited to the passenger car market. As a large industrial group, it also markets buses. And recently, the H2 Xcient Fuel-Cell truck was held above the baptismal font. This makes Hyundai the only global player to offer the full spectrum of hydrogen vehicles.

Another strong statement comes from the, Craig Knight, the Australian Managing Director, CEO, and cofounder of Horizon Fuel Cells and their automotive subsidiary brand, named HYZON. He is confident that the push for electric heavy-duty vehicles, both trucks and buses, and the general global desire to decarbonise will be instrumental in achieving commercial success based on smart marketing. Following the Plug Power concept in the forklift market in the US, HYZON intends to lease the buses and trucks, taking away the technology concerns as well as the investment barrier.
3. The End of the Diesel Era

CO₂ – To Be or Not to Be

Global warming and climate change are consequential phenomena caused by the excess presence of greenhouse gases (GHG) in the lower levels of the atmosphere, triggering an increase in the average overall temperature on Earth, thereby making sea levels rise, threatening ecosystems, and affecting and ultimately destroying life on the planet as we know it.

Because the excess of GHG emissions has been created by mankind, overwhelmingly due to power generation from fossil fuels, it is IMPERATIVE and URGENT that ALL fossil fuels be replaced by carbon-free fuels.

I vividly remember a visit to British Airways (BA) in 2006, on their invitation, together with representatives from United Technologies (UTC Power). We started out on the assumption that BA had a good enough understanding of hydrogen and fuel cell buses and was in the market to acquire such new technology for ground transportation equipment. After all, British Airways is British Airways, and ‘nobility obliges’. We had been awarded an earlier contract from BA for a good number of diesel shuttle buses to operate crew transportation between the terminals and the airplanes. So, no harm in replacing them with new buses, while making a statement about BA’s environmental policy. Nothing of the kind. Interest in hydrogen and fuel cell buses was not even on their mind, let alone on the acquisition agenda. We therefore wondered why and what on earth had driven them to even bother with us. Not knowing how this visit originated, it appeared that BA representatives were just being nice in welcoming UTC delegates because of UTC’s reputation in the aircraft industry, Pratt & Whitney being a member of their business group. The other reason could be that it would meet their desire for more and better knowledge about the state of play in the industry, in line with the then-general interest in greening initiatives. In any event, it was hard to accept that BA would be unaware of the devastating consequences of the warming of the Earth. The UTC sales delegates, however, were equally amazed when I mentioned that the motive for BA’s interest may genuinely be their plan to limit CO₂ emissions on the tarmac.

It would take another 10 years before the world, including myself, was actually convinced that the motive driving the decision to take mitigating action would be the devastating effect of the excess of GHG emissions, with transportation being the diehard cause.

I still believe that one of the major reasons for this general lack of interest, and therefore for the absence of any tangible action, was that the industry at large was not even addressing CO₂ emission issues when designing and implementing transportation systems. This also holds for the EU institutions, including EU directives, in dealing with emissions. The so-called Euro standards for diesel engines, which were imposed in 1992 and have successively been upgraded from Euro 1 to Euro 6, were used to limit the tailpipe exhaust emissions that represented an imminent health risk, mainly NOx (and NO₂ in particular) and particulate matter (PM <2.5µm notably) in grams per kWh of the engine. They did NOT even include CO₂ emissions, as they were not considered a harmful pollutant. It is therefore important to distinguish ‘harmful pollutant emissions’ from GHG emissions, as the latter are not harmful as such. Only when causing too much of it to accumulate in the atmosphere will their impact be what we commonly designate as ‘climate change’.

Even when it is technically correct to distinguish between health-threatening pollution and climate change, both of their origins relate to burning fossil fuels with no less dramatic consequences on the planet and our daily lives.

CO₂ or Carbon Dioxide

CO₂ is the chemical compound of carbon dioxide.

It is used very often in carbonised liquids, including cold drinks. A substantial part of the CO₂ goes to the gardening industry. The reason is that the presence of CO₂ in enclosed areas, so-called greenhouses, at a certain controlled level, stimulates the growth of the plants and flowers, thus accelerating their blossoming and, consequently, the time to market. The same phenomenon takes place when an excess of CO₂ is emitted in the atmosphere. All modern languages therefore use the term ‘greenhouse gases’ (GHG) to define the CO₂ levels in relation to climate change. CO₂ is not the only GHG but is by far the most important one. Others are water vapour, methane, dinitrogen monoxide, and ozone.

On its own, CO₂ is a very important, read ‘vital’, gaseous substance in the atmosphere. A quantity of CO₂ gas of 0.03% in the atmosphere suffices to keep the average temperature on the planet at +15°C (Celsius). On planet Venus, temperatures average +420°C, as the thick atmosphere contains 96% CO₂. On planet Mars, the atmosphere is very thin, as almost all CO₂ is underground, causing the average temperature on Mars to be -50°C. Without CO₂ in the atmosphere,
The average temperature on Earth would be too cold for us, human beings, to survive. In other words, CO$_2$ is vital to plants as much as to the air we breathe on planet Earth. Unlike the harmful pollutants emitted by burning fossil fuels, CO$_2$ is NOT by itself harmful for mankind. However, the devastating effect on climate change is due to the fact that the CO$_2$ levels in the atmosphere are too high.

The emission of GHG in the transport sector (2017) was 7.2 Giga tonnes, accounting for about 27% of all GHG emitted in the EU, with the following split between the different transportation modes:

- Road transport: 72% of which:
  - Passenger cars: 44%
  - Commercial vehicles:
    - Light commercial: 9%
    - Heavy-duty commercial vehicles (trucks and buses): 19%
- Maritime: 13%
- Aviation: 14%
- Other: 1%

Note that the above GHG statistics for the transportation sector include international aviation as well as international shipping. Since 2017, GHG emissions from aviation had doubled from the 1990 level, while international shipping and transportation increased by one third and one fourth respectively.

In absolute terms, the CO$_2$ emitted depends on the actual fuel consumption, i.e. the burning of the fossil fuel, whatever the application and the device.

Burning 1 litre of diesel fuel corresponds to 2.65 kilograms of CO$_2$ emitted.

When adding the CO$_2$ that has been emitted during the production and distribution process, 1 litre of diesel fuel easily exceeds 3 kilograms of CO$_2$ emitted.

A car that runs on diesel fuel, consuming an average of 6 litres/100 km, driving around 40,000 km per year, will therefore have emitted a colossal 6.3 tonnes of CO$_2$ per year, or 63 tonnes of CO$_2$ when the car reaches its end of life mileage after, say, 10 years.

By comparison, a city bus that runs on diesel fuel, consuming about 40 litres/100 km, driving 800,000 km over a 12-year economic life in accordance with the EU Clean Vehicle Directive, will emit in excess of 70 tonnes of CO$_2$ per bus per year, i.e. in excess of 1 kg per kilometre driven, or 848 tonnes of CO$_2$ during its entire economic life. Multiply this number by about 200,000 city buses in the EU, and the total CO$_2$ emitted each year will be close to a staggering 14 million tonnes of CO$_2$, for city transport alone.

You can find the CO$_2$ value per kilometre for each car model on every advertised car in any retail showroom, passenger car exhibition, or leaflet in Europe. Remember that the CO$_2$ emitted is directly and exclusively linked to the effective fuel consumption, i.e. litres of fuel burned. Since the real consumption value, in each of the driving modes and topographic and climate conditions, cannot be simulated for each and every car on the street, the advertised CO$_2$ value shown by the industry will follow a defined duty cycle. The so-defined duty cycles help vehicle manufacturers to design and modulate engines to be as favourable as possible.

We were made painfully aware of how far away these values were alienated from real-life driving conditions by the Volkswagen Dieselgate scandal. Following this scandal, detailed more in-depth in another part of the book, two new emission tests were imposed in September 2018 to become mandatory for all new cars: WLTP (World Harmonised Light Vehicle Test Procedure) for engine compliance testing in the laboratory and RDE (Real Driving Emissions) to
measure emissions of NOx and PM from vehicles on the road, both designed to be much closer to real-world conditions. Although it was about time to stop fooling ourselves and the world, being closer to real operating conditions, the admitted values are higher than before. The downside, as shown in the subsequent years, is that any reduction in pollutants will be hinged to the increased limits. More importantly, with higher fuel consumption figures matching the new drive cycle, the CO₂ values have gone up accordingly and not surprisingly. Subsequently, the CO₂ statistics for road transport are not looking any brighter, nor are the overall CO₂ emission statistics. On the contrary.

It is common knowledge that, so far, transport has performed rather poorly in meeting the CO₂ reduction targets. The energy efficiency of an internal combustion engine has improved only a little or not at all. The number of cars in Belgium has grown from 387 cars per 1,000 inhabitants in 1990 to 499 cars in 2015. Even when producing fewer emissions per kW of the engine, the total CO₂ output of passenger transport has increased by 30% to reach a staggering 27,000 tonnes per year.

Whatever is undertaken, it is fair to conclude that it is not possible for any simulation to really match the multitude of individual real-life driving conditions, and no matter what, we will still be burning fossil fuels and emitting GHG. The world is not better off by changing standards when the only remedy is to actually stop emitting harmful pollutants and GHG.

As for the heavy-duty vehicles in the EU, be it truck or bus, neither the fuel consumption per 100 km (or mileage per litre), nor its corresponding CO₂ value, was required to be advertised. That did not limit public entities or even private fleet owners from including fuel consumption (and therefore CO₂ emissions) as an integral part of the procurement process. This option was made mandatory for bus procurement by public entities through the application of the EU Clean Vehicle Directive. For the few who actually used it, the directive came with a calculator, simulating the effect of fuel consumption on the final monetary outcome of the proposal by giving a monetary value to each of the emissions. Its perverse effect was not hard to guess when the tender did not specify the corresponding penalty, the penalty was not in relation to the benefit, or no documentary proof of the fuel consumption measurements was required with the offer. Another downside was that the abatement of CO₂ was valued at 15 euro per tonne, showing a difference of about 5,000 euro between a current diesel bus and a zero-emission bus. The incentive to go for alternative fuels or new zero-emission technology was just not effective. In conclusion, the initial Clean Vehicle Directive was essentially a comparison tool enabling buyers to assess the monetary value in the purchasing decision and making sellers aware of the relative importance of fuel consumption and emissions and the possible effect on the outcome of the tender. Under the revised version of the Clean Vehicle Directive, any contract for vehicles, whether purchased or leased by a public entity, or work performed by a third-party contractor for a public entity is now mandated to include measures for the replacement of the fleet by 25-50% zero-emission vehicles by the years set out in the revised Directive. Rather than being an instrument for comparing the monetary value of GHG and harmful emissions in the bids, zero emission is now a mandatory requirement which will turn out to be a game changer, considering that it is reasonable to assume that a dramatic technology change will have to be contemplated not for a percentage of the new purchases but, sooner rather than later, for all of the new fleet vehicles.

The problem with emissions, be they harmful pollutants or CO₂, was many times bigger than it appeared to be or that we were led to believe, and that has not changed. The VW Dieselgate scandal has laid things open but not necessarily solved the problem, even if EU technocrats have pledged that this will not and cannot ever happen again. And VW was not the only one.

Global Warming

Why and how is human activity generally believed to be the cause of excess GHG, and what is causing the planet to warm up and produce climate change? Technically, the short version is that the short waves from the sun radiate to warm the surface of the Earth. The radiated heat waves rise back up to the clouds and into the atmosphere. Nothing wrong with that. On the contrary. The naturally generated GHGs, and CO₂ in particular, in the atmosphere are basically acting like a blanket and protecting the Earth against cooling off too strongly (and avoiding a return to the ice age).

Too much GHG in the atmosphere, however, causes a reverse action in sending heat back to the Earth’s surface, which in turn causes the planet to warm up. In layman’s terms, when our bodies in bed are comfortable with one blanket, we would be sweating and cursing if another and yet another blanket were added. Understanding that the blanket theory is not a full scientific explanation, as radiation and intensity by colour also play an important role, the result unequivocally remains, and only a very small percentage of living souls would still challenge the statement.

The emission of CO₂ by human activity is believed to have started after the first industrial revolution (early 19th century). The current CO₂ level caused by human
activity is close to 6% of all GHG exchange in the atmosphere. Every increase will cause global warming to accelerate, assuming it is not already too late.

The natural uptake of CO$_2$ from any source on Earth is mostly achieved through the oceans and the plants. Failing any extension of forest areas on the planet, photosynthesis by plants only contributes temporarily and partly to mitigating this excess of CO$_2$ emissions. The speed by which the ocean’s uptake of CO$_2$ takes place is the only remaining factor. While CO$_2$ exchange by the ocean’s upper layers, both uptake and release, is relatively quick, transport and uptake in the lower water levels, ensuring final dissipation of CO$_2$ into the oceans, take several hundred years.

A new report by the EIA (Energy Information Administration in the US) states that the concentration of GHG in the atmosphere worldwide has increased at a rate of 0.6% per year since 1990 and keeps on rising, and the current rate is estimated to be 1.2% per annum, i.e. double the average.

It is amazing to note how the subject of global warming has evolved in the media over the last decade into the growing belief that the only options for getting rid of CO$_2$ produced by mankind is to either capture and sequester or ban it, or both.

Many and far-reaching consequences of global warming have been monitored and acknowledged for many years. Scientific models have been developed and improved with the purpose of mapping their devastating impact. Some of the still-remaining sceptics argue that the global temperature rise expectation cannot be assessed realistically, considering the many ‘known unknowns’. Given the scope of the possible consequences, it may be hard to predict. On the other hand, if that is the case, any deviation from the temperature rise prediction, both in absolute and relative values (let alone per geographical region) as well as in the estimated time frame, may consequently cause global warming and climate change to happen faster and more dramatically than currently assumed.

Arguably, the latter seems to be a more plausible scenario for which we should prepare.

In conclusion, and unlike other harmful emissions from burning fossil fuels, CO$_2$ is not in itself bad. Quite the opposite. It is the ‘overdose’ that triggers climate change, and that overdose has its origin in human activity.

Recent TED presentations by certified scientists provide strong arguments that a 1% global temperature rise is already irreversible, 2% as set in the Paris Agreement of 2015 is unlikely with the current measures and 3-4% is not unrealistic. Above 4%, the Earth as we know it will no longer exist.

In the US, the institutions and scientists who believe that climate change will happen faster and stronger than currently predicted are alleged to be manipulated by Democrats because they are said to be part of the Obama hype and to be following their money trail. Institutions and scientists with Republican leanings, on the other hand, do not share the belief that global warming and climate change are caused by mankind, in line with the vision of their former commander-in-chief, President Trump. To an outsider of American politics, meaning most of us, assigning the causes and impact of global warming to political views sounds completely ridiculous, as if the climate answers to political preferences and viewpoints.

Former President Trump is one of the actors on the world stage who advocates that global warming and its effects are an invention from the Chinese in an attempt to fool the world while they continue building coal-based power plants to still the energy hunger of their own economy. At best, he does not deny that the climate is changing, but then, he says it has always been like that.

According to him, there is no scientific proof that the rise in CO$_2$ levels in the atmosphere is caused by humans who are to be blamed. The Paris Agreement of 2015 has long been destined for the shredder by former President Trump, in favour of keeping what he calls “clean coal” alive. Luckily for the world, and as of 20 January 2021, the US is once again committed to resuming their unmistakably most important role in making the Agreement fly.

Yet, Trump is not the only one who still believes climate change has not been caused by men. To my astonishment, and closer to home, others have similar views, even if their motives are not necessarily the same. Fortunately, there seem to be fewer left as time progresses. A certain Jan Jacobs, a Belgian national with Bulgarian connections, is one of them. And still today, although rarely seen in public, each country still holds a handful of Jacobs’s.

Like most of them, Jacobs is not denying the climatological phenomena, but he believes we are fooling ourselves when judging the importance of climate change: we are trading billions of euro in emission rights on account of 0.04% of the air we breathe and for which the cost is passed on to us, earthly subjects.
He makes reference to a number of famous institutions who advocated less than two decades ago that the Earth was cooling off, to then turn their view 180° by stating that, contrary to earlier so-called scientific findings, the Earth is warming up. The ICCP (Intergovernmental Climate Change Panel) has produced many global warming scenarios, some more credible than others. Jacobs goes on to say that the transition cost from a fossil fuel-based world economy to a fossil-free one is many times bigger than the damage: a sea level rise of 30 cm per year or 3 metres in a century is not a challenge that mankind cannot cope with or manage. To counter the consequences of the temperature increase, governments have been putting taxpayers’ money into procuring wind farms and solar panels instead. Wind farms are the outrage of the 21st century, according to Jacobs. With plenty of fossil fuels available for hundreds of years and failure to store electricity on a massive scale, he goes on to say that the only realistic option is something completely new: nuclear energy on the basis of thorium. Dismantle old nuclear power plants and build new ones based on thorium, complemented by imports of gas.

Thorium as a future fuel? Never heard of it, but I am all ears now.

I found quite interesting information on the subject. Which I am happy to share.

**Thorium (Th)**

Thorium is not exactly a common word. Derived from the Norwegian God of thunder, Thor, thorium is a soft and white-silver metal. In simple English: scrap. A thorium reactor allows for a possible fission in combination with uranium. More efficient, less expensive, generally available and cleaner. Why does thorium then not already constitute the ultimate way to an efficient and cheap energy supply, harmless to the environment?

Wim Turkenburg (Dutch Professor Nature and Society) believes that “the development of a Thorium reactor to become a commercial process will need another forty years. We will live in the twenty-sixties by then. The question is whether we will not be too late already. Moreover it will take tens of billions of euros to build up a thorium cycle and infrastructure. Using the funds for already proven technologies from renewable energy sources to stop the climate change would be a much better way to spend the money.”

**Climate Change**

The consequences of global warming for climate change are immense:

Melting ice from the glaciers will reach the oceans. While cooling down the water temperature at first, the enormous mass of melted ice will raise the sea level. Large areas of lower lands will be flooded, making it hard or impossible to continue life as we know it. The Netherlands, Flanders, parts of Great Britain and France, Denmark, Sweden will most certainly be affected. Since the early monitoring process and instrumentation have been put in place and refined, we can calculate the impact of sea level rise as a function of global warming and actually show its impact on human habitats all over the world.

Scientists on Climate Change and the Potsdam Institute expect a sea level rise of more than 1 metre by the turn of the 21st century, even if we could ‘freeze’ the current CO₂ levels immediately and completely. This statement follows the fact that the CO₂ cannot be taken up by the atmosphere, the oceans, and the plants.

The sea level rise is expected to reach an average of 1.6 metres worldwide if temperature rise remains below 2°C, although there will be significant deviations between shores, depending on how much higher they are located above the

Here are the pros and cons of using thorium to change the world:

+ One tonne of thorium can produce the same amount of energy as 200 tonnes of uranium and 3.5 million tonnes of coal. As such, thorium has the capacity to provide energy to the planet and its inhabitants for thousands of years to come. Since scrap is everywhere and the quantities needed are not so extensive, the cost to produce clean energy is extremely low.

+ No tangible results leading to the next stages in the development and use. In the US, a small plant in the Oak Ridge National Laboratory was being used in the 1960s. The big nuclear players have not made any major investment since. Although only (!) radio-active for the next 500 years, the waste will need to be sequestered and, as we know with nuclear, accidents are never excluded.
sea level. In Copenhagen, as an example, the sea level will rise by 4.7 metres following a temperature rise of 2°C. Calculations have indicated that this will cause 255,000 houses to be submerged. When adjusting the temperature rise to 4°C, the sea level will rise 8.9 metres in Denmark, submerging about 400,000 homes. Worldwide around 280 million people will be homeless.

Flaws in these predictions may still hold when it comes to forecasting the real impact on a local basis, but the exact value almost becomes irrelevant in the bigger scheme of things. In any case, most scientists agree that the discussion about how much and where exactly the impacts will be felt cannot and should not be a reason to withhold action or the sense of urgency in mitigating its devastating consequences before the turn of the century, commencing HERE and NOW.

When applied to Belgium, and Flanders in particular, the situation does not seem to be much different. When browsing the coastal city of Ostend at www.beforetheflood.com (or www.geology.com), temperature and sea level rises are all but comforting:

- +1.5°C of temperature rise will cause the sea to rise 2.9 metres
- +2°C will cause the sea to rise 4.7 metres
- +3°C will cause the sea to rise 6.4 metres

At 2.9 metre sea level rise, the triangle Ieper-Diksmuide-Jabbeke, once the scene of the Great War at the beginning of the last century, will be completely flooded.

The situation may be different but no less dramatic when applied to coastal cities in the Netherlands and elsewhere.

**Climate Agreements**

The biggest producers of carbon dioxide gases are China, the USA, India, and Europe.

When addressing CO₂ mitigation on a world scale, it is obvious that no single country or even group of countries can solve the problem. The other way around, CO₂ mitigation can only be successful if all countries together or, in any case, the vast majority of the CO₂ emitting countries, work together.

In 1992, 20 years before climatologists were able to quantify, with an acceptable degree of certainty, the global warming phenomena, the member states of the United Nations joined together in the UNFCCC (United Nations Framework Convention on Climate Change).

After a lengthy and difficult start-up period, a first milestone was reached with the Kyoto Protocol in 1997, without the USA. In Copenhagen (2005) and Doha (2012) the members reached a preliminary agreement on the terms of a binding agreement, which was finally concluded in Paris in 2015. This Agreement is generally known as the Paris COP 21 Climate Agreement. COP 21 stands for Conference of the Parties and the number 21 for its 21st General Assembly meeting.

This Agreement includes the following important provisions:

- An ambitious objective of limiting global warming to below 2°C by the end of the 21st century and concerted efforts not to exceed +1.5°C when compared to 1990 levels;
- To limit the GHG emissions as much as possible forthwith and to commit to eliminating GHG emissions in the second half of the century (the cost of which is estimated at a minimum of 100 billion US dollars per year from 2020 onwards);
- To monitor, on an objective basis, the results every 5 years and to commit to a regulating mechanism when the results are below intermediate goals;
- To develop and exchange a methodology between the countries to cooperate in order to reach the overall objectives. It is allowed to balance and trade emission rights between the countries to offset any lagging of the results.

John Kerry, then the Secretary of State under the Obama administration, shared with the press that one last-minute snag almost jeopardised the deal: the word ‘should’ was replaced by ‘shall’, which has major legal implications in the US. Fortunately, this was prevented minutes before the deadline. Nobody could have ever imagined that, a little more than 1 year later, a new US President would toss the Agreement into a paper basket.

What preceded the Paris COP 21 Climate Agreement:

- 2015: The Paris Climate Agreement set new, ambitious, and binding objectives to keep global warming below 2°C;
- 2012: Decision at the COP 20 summit in Doha to extend the Kyoto Protocol until 2020;
- 2011: Call to continue the discussions and prepare for a new Climate Accord in Durham with the objective of having its final version at the Paris meeting in 2015;
The End of the Diesel Era

The End of the Diesel Era

- 2009: Climate summit in Copenhagen to keep the global warming objective at +2°C and support the developing nations financially;
- 2005: Kyoto Protocol in force;
- 1997: Signing of the Kyoto Protocol that defines measurable values of global warming for the first time;
- 1992: Start of the UNFCCC (convention on climate change);
- 1990: Assigning responsibility for global warming to mankind.

In the meantime, we have passed the COP 26 deadline set for Glasgow in 2020, which was cancelled due to the COVID-19 pandemic and is due to take place in November 2021. UN Secretary-General Guterres said limiting warming to 1.5°C requires that strategies be drawn up during 2020 in order to achieve emission reductions of 45% by 2030 and to reach net-zero emissions by 2050.

Fortunately, not all countries have let it slip by. On the contrary, the COVID-19 pandemic has fuelled the belief that manmade CO₂ is causing the climate to change, and countries have urged immediate action to stop the burning of fossil fuels.

The Promised Diesel Land

The Promised Diesel Land

In 2015, a total of 251 million cars circulated in the EU-28. The forecast is that this number will increase to 258 million in 2030 in a business-as-usual scenario. The number of buses and trucks in 2015 was about 13 million, with this number expected to hit 15 million in 2030.

It is public knowledge that Diesel cars were very popular in most European countries for a long time, not least in Belgium. In 2014, 53% of all cars registered that year in the EU were diesels. For the first time, the balance in new car registrations switched in favour of gasoline cars in 2016, a trend that will continue to grow dramatically in the coming years, if the market is not already overtaken by e-cars by then. The historic peak in diesel passenger cars, with 76% of all registrations, was reached in 2010, making Belgium the promised diesel land. As for its current share in the national car population, out of 5.6 million cars driving around, 3.4 million or 60% are still producing the legendary diesel fumes. Fortunately, diesel fumes have lost their blue colour visibility, and the typical penetrating smell is a thing of the past. You would need sophisticated measuring devices to detect any of the bad news associated with diesels, which makes them diehards for the many thousands who used to love them a lot, and still do.

It is expected that diesel-driven cars will be completely banned from the inner cities and city perimeters by 2025. It is therefore no longer a trend but a predictable game changer, which will affect all of us and not least the current diesel car owners. They will have no outlet in Europe for their second-hand cars, a phenomenon that is already being felt as we speak. I have experienced it myself when selling a 12-year-old TDI Volkswagen Tiguan. The price had dropped dramatically due to the fact that EU markets were no longer interested, but more importantly, all the second-hand diesel cars were being shipped to a handful of countries around the world, not least Africa, where they are probably harming the most. I would advocate that diesel cars legally be scrapped from the moment their residual value reaches a fixed CO₂ abatement cost that is relatively easy to establish. Of course, if CO₂ were the only reference for their scrap decision, the gasoline cars would not do any better. The mechanism would need to include all harmful emissions, not least particulate matter and NOx. I do not believe that the trading of CO₂ rights will provide the answer, as it is too complex and, at the same time, too volatile a mechanism that will not yield fundamental changes in human behaviour.

Companies leasing diesel cars, in particular, already find themselves confronted by this situation, and reality checks have already changed their mind as well as their purchase action for more environmentally-friendly counterparts. This behaviour change is tangible in big cities such as Paris, where hundreds of fuel cell electric taxis are taking the lead as the new normal.

Thanks to Rudolf Diesel

Still, it would be unjust and ungrateful to relegate the Diesel motor to the history books without sharing recognition for the man responsible and the impact of his invention. Haven’t we all enjoyed the diesel engine and its spectacular success in virtually all automobile applications? The on-cost of the purchase price and the tax penalty (at least in Belgium) compared to a gasoline car were largely compensated by lower fuel consumption and the more attractive fuel price, especially as performance and driving comfort grew tremendously over the years. Neither the fantastic technical improvements nor the environmental pitfalls could have been forecasted or predicted during the lifetime of its renowned inventor Rudolf Diesel.

The basic concept of the engine started out on the principle that it should be possible to suck outside air and compress it in the cylinders, such that the compression causes the temperature in the cylinders to rise (first stroke) to the point that the fuel brought in causes combustion in the cylinders (second stroke) without external ignition and causes the pistons to turn (third stroke). Finally, the
burned exhaust gases would be evacuated (fourth stroke). The heat produced by this process would increase the temperature in the cylinders even more, allowing the process to be repeated for as long as the fuel supply is available. The four-stroke engine concept was applied in a combustion chamber. Great.

Rudolf Diesel was eager to patent his invention and have it built under licence. To start with, Heinrich Buz, director of the then-operating company ‘Maschinenfabrik Augsburg A.G.’, and Friedrich Krupp in Essen agreed to have the first engine built and to share the cost of production. Unfortunately, one test after the other dramatically failed, with efficiency at merely 16%, much less than originally planned. With this in mind, Augsburg was no longer interested, and the venture was discontinued. Later, however, the attempts were given new life under different and stricter conditions, by implementing several improvements step by step. This approach led to a successful acceptance of the first engine on 17 February 1897, certified with an efficiency of 26%. This improved prototype engine (as shown on the photo) had a displacement of 19.6 litres and an output of 20 HP (horsepower) – broadly 1 HP per litre – or 14.7 kW.

The Vereinigte Maschinenfabrik Augsburg und Maschinenbaugesellschaft Nürnberg, commonly known under the abbreviated brand name M.A.N., was founded in December 1898.

On 23 February 1892, Rudolf Diesel was awarded a patent with the title ‘Arbeitsverfahren und Ausführungsart für Verbrennungskraftmaschinen’, roughly meaning ‘concept and implementation method of internal combustion engines’.

At that time, Diesel had already signed several licence agreements with France, Denmark, Sweden, Austria, Switzerland, Hungary, the United Kingdom, Russia, and Egypt.

The year following the patent award, Carels, a company located in Ghent, Belgium, was the first in the country to sign a licence agreement to build Diesel engines. It would allow Diesel to earn a fixed amount of money and a premium for each engine built. In 1904, a total of 160 engines were built with a total power output of 10,000 HP. Diesel was about to become a wealthy person.

But Diesel was more than a brilliant engineer. He was also very socially committed to improving the working conditions of small enterprises and the workers in general. His world image put people in a central position through his solidarity principle, referenced in German as ‘Solidarismus’. His invention, the combustion engine, would fit his universe, as it allowed for alleviating the strain of the workers in small workshops and enterprises. It would help them to compete while making the work sustainable at the same time.

But his fight was not over yet. The political situation in Germany at the time prevented fluid fuels from being produced in Germany, and their imports were subject to excessive duties, making the use of fluid fuels economically impossible. Around 1903, this awkward situation was resolved through the production of fluid fuel from tar oil from brown coal. Some years later, import duties on fluid fuel were lowered to the point that they no longer impeded the general import of fuel.

When Diesel, on expiry of his licences, wanted to start a new engine development with the purpose of making it commercially more fit for purpose, bigger companies such as MAN, Krupp, Deutz, and Sulzer had put so much development money into it that Diesel was no longer needed to meet the challenges ahead.
In the meantime, Diesel had spent a major portion of his wealth on real estate projects, which did not seem to give the expected return. A legal fight with a mala fide real estate agency over a 2 million German marks claim brought him to the brink of disaster and bankruptcy. Diesel never wanted to call upon his loyal friends in the licensing countries, probably for reasons of pride and self-respect.

In addition, his failing Solidarismus and the conviction that humans did not want to be saved and that the world did not embrace faith, fidelity, and justice were not helping his case. Nor were the growing comments in the press that his invention was a scam and that Diesel was a myth. Together, these arguments could offer an explanation for his presumed suicide, an act that nobody he had spoken to or met before his sad end could have anticipated, although several other theories of his unexpected death do not exclude murder. Rumours have it that the German Secret Service had been in contact with the Royal Navy in London, as there were plans to use the new engines in submarines of fighting powers. ‘Inventor thrown into the sea to stop the sale of patents to British Government’ was a newspaper headline the day after his disappearance. It was a fact that Diesel had chosen to make his invention available internationally without restrictions, rather than sell it exclusively to the then-ruling German or its friendly powers in the years preceding World War I. Other theories refer to competitive forces or, strange as it may seem, to petrol industrialists, as Diesel himself favoured biofuels, which obviously was troubling the oil tycoons to a large and very uncomfortable degree.

But where and how did his untimely death come about?

On 28 September 1913, Diesel was visiting the World Exhibition in Ghent, together with his friend Georges Carels, mentioned earlier. The following day, he travelled in the company of Carels’ chief engineer, Alfred Luckmann, aboard the Dresden, a vessel with a scheduled ferry service between Antwerp and Harwich. The final destination was Ipswich, where they would jointly open a new factory called ‘Consolidated Diesel Manufacturing Ltd’. The plan further called for a meeting with the Diesel Engine Company in London.

He was spotted during a joint dinner the evening of his departure from Antwerp. The morning after, however, on 29 September, both his bed and his luggage were found unused in his cabin. The possibility of an accident is virtually excluded. The sea was calm.

Ten days later, a Dutch ship finds a body but does not hold it. After recuperating his personal belongings, the body is returned to the waves as was customary at the time. His son Eugen confirms the belongings as the property of his father. A new search mission to repatriate the body fails. Consequently, an autopsy has never been performed. Rudolf Diesel’s death will ultimately remain a mystery for ever.

Despite the dramatic circumstances, Diesel was successful in making inroads into the United States of America, but it was Clessie Cummins who built his diesel empire to become the biggest engine manufacturer of our time. The book ‘The Engine That Could’ provides interesting leads as to how the story evolved in the USA.

Diesel was very keen on pursuing the US market from the early days, as he tried to build his fortune by licensing his invention, and no doubt America was one of the bigger fish. He was quite annoyed that there was no licence holder until 1897, when he met Adolphus Busch, an emigrated German citizen who tried to make his fortune, and eventually did, as a brewer tycoon. Busch paid Diesel 1 million German marks (the equivalent of 0.5 million euro) for the licence rights and agreed to pay Diesel 6% of every engine manufactured and sold in the US and Canada.

But, while success has many fathers, failure is an orphan. In this respect, Diesel was an orphan for a long time. Similar to his failures in Europe in the early years, his invention did not prosper that much, leading to economic hardships and disbelief. The papers printed in black and white that ‘it was unbelievable that so many people were led to believe in something that did not work’.

Diesel’s starting point was that, in a four-stroke engine, the fuel would burn without external ignition and the temperature in the engine would remain constant. These were the two main premises of his invention. According to these two principles, considering that there was no need for an external ignition and no cooling was required, the engine was able to burn a multitude of fuels, ranging from crude oil and coal dust to nut oil.

The heat that was produced by compressing the fuel brought into the cylinders would be neutralised during the decompression in the third phase. Heat could be transformed into mechanical energy, which would allow the efficiency of the machine to improve dramatically.

The persisting problem, it seemed, was the fuel injection system, especially with smaller (than 15+ litres) engines. Despite the fact that the compression
phase could be refined in several stages, the fuel consumption would suffer in combination with higher temperatures in the cylinders, thereby making cooling inevitable. In addition, the newly developed compression techniques were heavy and expensive. Practice had beaten Theory.

Busch was frustrated, since he was left without the assistance and support he had expected, receiving it from neither Rudolf Diesel nor M.A.N. Failure to conclude a successful venture with the American Diesel Engine Company in 1909 was the last piece of Busch’s history in the diesel engine business. Fortunately for him, not in brewing. Every man to his own trade.

Despite the emerging and persistent problems, the belief in the concept and the working principles of the invention remained strong on both sides of the ocean. The applications that were imagined at a time of industrial awakening were countless. While in Europe emphasis was on ships and submarines, the Americans were focusing on heavy industries, factories, mining, and large distributing firms.

In the meantime, others had started to experiment with similar concepts. A small firm in the Netherlands by the name of Appingedammer Bronsmotorenfabriek NV (in honour of its owner Jan Brons) developed an oil-engine to drive a bus-like vehicle. At about the same time, a similar development of an oil-engine was undertaken by a naturalised American Dane by the name of Hvik - the so-called Hvik engine. Clessie Cummins, who was gifted with above-average technical knowledge about combustion engines, learned about the Hvik engine through one of the licence holders, the Hercules Gas Engine Company.

Clessie ventured to use the patented invention and turn it into a commercially viable product for which he needed financial resources that were provided by one W.G. Irwin, who was a local investor in future-oriented technological products in light of the end of the First World War and the potential that lay ahead. The fact that 10 big companies were actually prepared to use the Hvik engine and had committed to sharing their experiences was sufficient for Clessie to turn his idea into reality. The Cummins Engine Company was founded in 1919, but it took them 20 full years, until 1939, before the shareholders were presented with the first profit account. And, as they say, the rest is history. The Cummins Engine Company achieved a turnover of 1.65 billion US dollars and employed over 46,000 people in 190 countries worldwide.

Because it has become increasingly obvious that diesel engines are now left with a limited validity date, not exceeding 10 years from now for most heavy-duty applications, Cummins has redirected its strategies by acquiring, among other ventures, the Canadian fuel cell stack and electrolyser manufacturer named Hydrogenics.

In addition to strategic decisions by large companies in the automotive arena, there is more than one lesson to be learned from the Cummins story when it comes to large enterprises: change philosophy or die. As far as hydrogen is concerned, Cummins has learned its lesson, taking over Hydrogenics, in 2019.

As to European heavy-duty engine manufacturers, it has taken them a decade to realise that major change in developing products is required as we accept that fossil fuels are no longer acceptable, and they have reacted accordingly. With volume being less of an issue, thanks to the vast number of in-house products carrying their own brand name, European manufacturers maintained the belief that they were in full control of the timeline. That has changed only very recently. Several heavy-duty diesel engine manufacturers, primarily Scandinavian brands, were in a comfortable enough position and had the audacity to refuse to supply their engines and other components to tier 2 vehicle assemblers for decades. Now, the likes of Volvo Trucks have made the bold decision to team up with Daimler Trucks to jointly develop fuel cells for their trucks. Similarly, CNH Industrial (including Iveco) is teaming up with US truck newcomer, Nikola, to launch a heavy-duty tractor unit based on their Class S platform. M.A.N., which remained silent for quite some time, as if immune to the new realities, decided to go for battery-electric while embracing, as a second leg, a hydrogen bus and truck version based on their combustion engine, redesigned for hydrogen by the company Keyou. A similar stance is currently being taken by Cologne diesel engine manufacturer Deutz. New kids on the block have entered the game.

Clessie L. Cummins in his first Cummins Diesel powered passenger car roadtrip was completed on January 6, 1930 as shown in the Automotive Hall of Fame in Michigan, USA.
hydrogen block are HYZON Motors in cooperation with Dutch driveline specialist Holthausen, forming Hyzon Motor Europe. These are major steps forward, making the heavy-duty truck market the new playing field for funding, product development, demonstration and early market prospects.

A contributing argument was no doubt that the world in which they had technologically and financially invested so much over more than a century was about to be replaced by a technology they had not, and still have not, mastered. Today, in the year 2021, there is absolutely no hesitation in stating that everyone with the goal of surviving in the automotive industry is poised to make the change as quickly as possible. Luckily for the hydrogen community, the pressure will remain on for the next two decades to come.

In addition to the competitive pressures, the end of the Diesel engine is near, due to the imposed legal and technical limits of the equipment, and the fact that the world has been deceived for a long time, making change for the better an absolute and urgent must. For the latter, it is Volkswagen and the Dieselgate scandal that deserve our gratitude.

**The End is Near – Legal and Technical Limits**

**Legal Limits**

Most car, truck and bus owners have become familiar with the EU standards for harmful emissions, imposed by and through European regulations on all internal combustion engines, but foremost on diesel engines. They are commonly known as Euro (emission) standards, from Euro 1 through Euro 6 (starting 1 September 2014 for new engines). You will notice that these emission standards do NOT include CO₂ or other GHG emissions. The reason is quite simple: EU legislators have prioritised the harmful emissions. Unfortunately, the more stringent harmful standards have increased the fuel consumption and consequently the GHG and CO₂ emissions. But why?

In the early 1990s, it was clear that pollutants such as nitrogen oxide (NOx) and particulate matter (PM) were the main concerns, as they were undeniable health threats to all human life on Earth. The excess of GHG emissions in the atmosphere was already suspected in the early 1990s, as were their presumably devastating effect on raising the temperature on Earth, thereby causing severe floods, tsunamis, fires, and overall climate change. However, they were not qualified as health problems, to the point that no urgent action was required in the Euro standards regulations. It’s hard to imagine today that so many people were not really impressed by CO₂ emission levels at that time, as long as we were able to limit harmful emissions. The media was not keen on following or even supporting early warnings. The proponents of climate change actions, such as Greenpeace, were not taken seriously.

A clear distinction between harmful emissions, i.e. affecting our health (mainly respiratory dysfunctions), and GHG emissions, i.e. generally known as gases that make trees and plants grow and give the sparkling sensation to fizzy drinks, is in order.

The Euro emission standards have cut the harmful emissions by 84% (NOx) and 96% (PM) since 1993. It must be said that their amazing reduction percentage is only relative to the way emissions were measured. It appeared that the duty cycle of the test engines was such that the measuring points on the test bench of the engine were chosen in favourable areas of the fuel lines. In real value terms, the measured values were up to 16 times higher than the legal limits under the Euro standards. The bomb finally exploded for Volkswagen with the Dieselgate scandal in the USA.

Nevertheless, the Europe Commission is actually in the process of evaluating the effectiveness of Euro 6 standards, with a plan to either leave the emission limits at their current values with more accurate means of emission measuring or impose new and more stringent standards. The motivation is that current standards do not sufficiently contribute to the decrease in air pollutant emissions emerging from road transport, required for the move towards zero pollution in Europe and the protection of human health, with particular emphasis on urban settings. The following issues have been identified as stumbling blocks that prevent Euro 6 from effectively limiting the harmful emissions: they are hampered by their complexity, they no longer represent the state of the art in emission reduction (in particular, several pollutants that are of concern today were not included in the past), real-world emissions are still not measured under the conditions of use of Euro 6, and lastly, air pollutant emissions are still not monitored throughout the entire lifetime of vehicles on the road. Given that on-board diagnostics have not proven to be an efficient tool for either measuring or limiting the emissions, it is important to measure real-world emissions to prevent disproportionately high values.

Given the complexity of emission measurements in the real world, credit must be given to the initiatives for a couple of important reasons: the EU realises that it will take some time (presumably another decade) before the zero-emission technologies can become mainstream commercial products. For the sake of (economic) life between now and then, it makes perfectly common sense to
improve on the environmental impact of internal combustion engine technologies, rather than to just let them continue with their devastating impact on humanity before dying a natural death.

Other observations are related to the late timing of this evaluation and subsequent revision, in light of the Dieselgate scandal and the pledge that this would never happen again. The evaluation paper quite frankly and openly admits that the tampering of vehicles has not stopped since. Why are we not surprised? With introduction dates no earlier than 2023, the question is legitimate as to whether the new standards will yield some significant effect. Will the cure not be worse than the pain? At least for the cars in the inner cities, something tells me that the problem will be solved by then, as the move towards small electric vehicles at affordable prices, with the ability to be an integrated part of a ‘connected mobility-on-demand system’, is already well under way.

The Center for Automotive Research in Duisburg concluded that the diesel version of 24 car models had been aborted with another 40 models to follow in the next 2 years. Well-known carmakers such as Audi have announced that they will abandon the diesel version of the Audi TT and Audi A1, or reduce their number dramatically. The share of Fiat 500 L Diesel fell from 50% in 2015 to 7.6% in 2019.

Should we not be evaluating whether the admission of a new set of Euro standards really supports the ambitious Green Deal objectives and the mandate for carbon-neutrality by 2050? Will it not have a counter-productive effect on the introduction of green technologies which, if anything, need volume and markets in order to deliver on their promise? What we desperately want on the one hand may be jeopardised on the other.

The statement in the evaluation paper that current standards are not efficient, with specific emphasis on urban settings, is a remarkable and meaningful admission. It is no doubt referring to public transport, buses, rail systems, and delivery trucks. Both the revised Clean Vehicle Directive, which applies to all purchases or leases by public entities, and the potential offered by the new e-fuels could bring more alleviation than re-inventing Euro emission standards.

At the same time, Europe and its regions and cities are pursuing the ban on diesel cars to limit their impact on the liveability and health of the cities and their inhabitants. As more and more cities join the group, it is becoming increasingly difficult to find out whether or not your car is still welcome to enter the confines of the town. Europe was unsuccessful in imposing general city limits and countermeasures to halt pollution, so the degree of self-protection was left to each city, creating a myriad of different emission zones, compliance criteria, and fines. Even with appropriate mobile application software for mobile devices, it is not a sinecure finding out which city and city boundaries are no-go zones for older vehicles, and more importantly, what the options are when travelling from one emission-zone city to another, other than buying a new car. In the meantime, measurements have revealed that a ban on diesel vehicles in low-emission zones only has a significant positive effect on fine particles (PM <2.5µm).

Technical Limits

The diesel engine as we know it, which was a lifetime symbol for economy (in both purchase price of the fuel and fuel consumption) and the best buy option when used intensely, i.e. in excess of more than 25,000 km per year, has reached its technical limits. Or so they say, because a number of diehards argue differently.

Despite the huge technical improvements in favour of the environment when compared to the first generations, far in excess of what Rudolf Diesel could ever have imagined when he invented the machine, the end of the Diesel era, when it comes to offering the desired zero-emission alternative, is now in sight.

Without going too much into technical detail, the following is a brief description of the main and remarkable technical advances that have been made since the introduction of the Euro emission standards.

Injection Technologies

The injection pressure was dramatically increased to well over 1,000 bars. This was the case with so-called common-rail systems that allowed the fuel to be injected evenly and minutely in all cylinders. The injection process was electronically managed and controlled.

Cooling

Previously, the air intake needed to take place under a set of severe pressure and temperature preconditions. The turbocharger was one of the first devices in this regard. It allowed air to be pressurised and warmed up. Later on, the turbo got an addition, with the so-called ‘intercooler’, clearing the way for smaller displacement engines that were designed to offer the power and torque needed for the vehicle to outperform its earlier bigger siblings. Unfortunately, this resulted in even more harmful pollutants since the emission standards are expressed in grams per kW of the engine. Smaller but more powerful (in kW) engines were thus allowed to produce more overall NOx and PM. The power
output was key, not the displacement. It was a missed opportunity for the legislator to make this important distinction when it comes to setting standards.

The cooling system was later improved by modifying hardware and software. One of the first to introduce the so-called ‘Low Flow Cooling’ was Cummins Engine, followed by M.A.N. with the NT cooling (Niedertemperatur Kühlung).

A further step was undertaken by (in the end) all of the heavy-duty diesel engine manufacturers, through a cooling system called EGR (Exhaust Gas Recirculation). The basic design was an ingenious multiple chamber system between the exhaust and the turbo that allowed the already heated exhaust gases to be recycled.

**Exhaust Gas After-treatment**

Particulate matter and nitrogen oxide are formed because of residuals in the combustion of the fuel.

Injection and cooling technologies can improve and refine the combustion process. The remaining harmful gases need after-treatment. The first and most common after-treatment is the DPF or Diesel Particle Filter, designed to burn the particles on the spot. Because of the relatively low temperatures of the exhaust associated with modern diesel engines, the particles or soot had to be stored until a device literally burned them before leaving the tailpipe. The next step in the latest development of after-treatment was the CRT filters or Continuous Regeneration Trap. The fine particles could now be burned continuously, lowering the particles in weight by 90% or more. It seemed also to be the best way to reduce particles emitted by older engines, and many thousands of buses were consequently equipped with CRT filter systems.

M.A.N. and Scania were the only two European heavy-duty diesel engine brands in Europe that managed to meet Euro 5 emission standards without the complexity of SCR and CRT systems, but the fun ended when Euro 6 came around in 2014.

The after-treatment nomenclature is unfortunately not finished yet. By means of injection of urea, commonly known under its commercial term as ‘Ad Blue’, from a different tank on the vehicle, it became possible to trigger a chemical reaction, decreasing the formation of nitrogen oxide (NOx) in the exhaust. With the urea tank empty, the engine starts to de-rate automatically in power, leaving the driver no other option but to look for an Ad Blue station. For vehicles in a winter-struck region, the urea would crystallise at temperatures below -7°C. To avoid this inconvenience, an integrated tank heating system would offer help. To mitigate the risk of non-compliance of the vehicle, it became mandatory to have permanent on-board checks, starting from Euro 5. Every bus or truck was now equipped with a functional OBD (on-board diagnostics) system.

The emission standards include limits on the particles, but again, expressed in grams per kW output of the engine. Unfortunately, reducing the fine particles (<2.5µm) in weight was an even greater danger than for bigger particles. The smaller the particles get (less weight), the more and the sooner they will impact the respiratory human system and seriously endanger our health. To make it more illustrative, the fine particle emissions being referred to in engine exhausts are equal or smaller than 2.5 µm (2.5/1,000 of a millimetre).

For comparison reason, the thickness of one human hair is on average 70 µm, i.e. about 30 times thicker than the particles from diesel engines that are penetrating the human respiratory system. Whereas particles of 11 µm would get stuck in the nose, 7 µm in our throat, and 4 µm in the windpipe, soot particles of less than 2.5 µm will have already penetrated the lungs in a split second and will be close to reaching the lung sacs or alveoli.

Both the development towards higher-output engines and the ever-finer particles penetrating the lungs have a detrimental effect on human beings’ health.

“In conclusion, the diesel engine as we know it today is one with high-pressure injection, EGR combined with SCR, and CRT filters. In simple English, from injection to exhaust, the diesel engine is nothing short of a complex and delicate chemical process. And we CONTINUE TO BURN FOSSIL FUELS as if nothing is really wrong with this. How much longer?”

Modern diesel engines feature a myriad of combustion devices and aftertreatment techniques.
and welfare. For these reasons mainly, the maturity date for diesel engines is being shortened dramatically, despite the continued intent of the industry. The European legislator might have made a better case by setting targets per kilometre instead of power output. On the other hand, the conclusion that the diesel engine is to die out, better sooner than later, might not have hit us so quickly and so hard as it is now doing.

The EU will be introducing tighter limits on nitrous oxide and carbon monoxide, such that the certification of internal combustion engines is expected to be more severe. It is said that the European Union has effectively declared war on fossil fuel cars and the refuelling industry.

In the UK, sales of new diesel, petrol, and hybrid cars will be banned in 2030, while new plug-in hybrids can remain on sale till 2035. Norway had already decided to ban diesel, petrol, and hybrids, including plug-in hybrids, in 2025.

There are two other reasons why the palliative process of the diesel engine will soon be over:

First and foremost, the emission of GHG, in particular CO₂, is currently number one on the political agenda, in Europe and generally in the world. The item was centre stage when reaching the Paris Climate Agreement COP 21 in 2015 but has continued to grow in importance ever since. Being enemy number one in combatting climate change, CO₂-neutrality or major reductions are here to stay for quite a long period of time in the new century.

The second reason goes, with thanks, to Volkswagen and the Diesel scandal.

**Thanks to ‘das Auto’**

The Dieselgate scandal made it painfully clear that electronics and algorithms are capable of doing anything, including cheating on the emission measuring, even when compliant with the emission regulations at the time of the test. The final result is that the Diesel engine has become unpopular, and the authorities are undertaking whatever it takes to end the historical love affair with the diesel engine as quickly as possible. On the other hand, strangely enough, Volkswagen and the brand have not been massacred by the public in general or by its vast international customer base, as Volkswagen became the largest passenger car manufacturer in the world in 2016. It shows once more that, seen through the glasses of the consumer, the environment is something that others have to address, not them.

What exactly happened?

How and what exactly happened is probably reserved for the happy few within the Volkswagen group and the US courts. We, mortal subjects, will have to settle for the discoveries that were unveiled by the ICCT (International Council on Clean Transportation). The starting point was indeed the factual discovery that the car emitted more pollutants than formally published by Volkswagen. Where have we heard that before?

Additional testing by the ICCT in cooperation with West Virginia University brought to light that the harmful emissions measured in a number of VW models were dramatically higher than the limits imposed by the law. After the classic denial phase on who was to blame, VW decided to start a recall programme in order to ‘deal with the problem’. However, during the repeat testing of the recalled cars, which were supposed to be fixed, the huge differences as measured in the first default tests reappeared. Only later in the game would Volkswagen admit that the software had been tampered with, which is considered a serious felony in the US. The software seemed to have been programmed in such a way that it would use algorithms to show conformity during the test phase but continue to cheat when it was in regular service on the street. The connotation ‘tamper software’ became popular in no time.

Volkswagen was found guilty of implementing tamper software, and heavy penalties followed for the company and for individuals in the organisation. What really annoyed the Americans was the cover-up that took place. By the end of October 2016, VW was sentenced by the American courts to pay a lump sum of 14.7 billion US dollars, of which 10 billion was for the repurchase of the affected cars and buyer’s compensation, and the remaining 4.7 billion for a mandatory recall action that would really fix the problem this time. In addition, another 2.8 billion US dollars in fines and 1.5 billion US dollars in punitive damages were imposed, resulting in a total financial burden of a hefty 19 billion US dollars. When VW director Oliver Schmidt travelled to Florida in early 2017, he was immediately held in custody. Heinz-Jakob Neusser, head of engine development, and Jens Handler, head of engine division, were deemed to have committed criminal acts and fraudulent omissions. They have been advised not to travel to the US. All in all, some 11 million passenger cars were involved, of which about 600,000 were in the US.

Some months later, it appeared that other brands showed similar results, but since the European Commission was probably already aware of the significant deviation, the fallout was less severe. In Belgium, for one, it was agreed with
the car industry that such sensitive information be shared better and sooner with the authorities. In other countries, the initial strong language and threats of huge financial claims following class legal action subsided, with their respective car industries and many thousands of workers avoiding being left facing irreparable damage and a graveyard of bankrupted manufacturers.

“The ones that are crazy enough to think that they can change the world, are the ones who do.”

(Steve Jobs, 2011)
4. Run on Water – The Hydrogen Way

The Big Debate – Batteries and/or hydrogen? – wrong question

There is not a shadow of a doubt – and we have been advocating it over the last 15 years to everyone who is listening – that the future of road transportation is zero emission and, therefore, electric.

All means of road transportation and, in particular, heavy-duty transport are poised to go for zero emissions. Delivery trucks, bin lorries, and long-haul semi-trailer truck combinations are currently the focus of policy goals and measures, as examined later on. When considering future transport, these are the exact applications where fuel cells and hydrogen can take over, due to the limitations of battery-electric alternatives. The million-dollar question, therefore, centres around two aspects: one is time and the other is whether the electricity will be made on board or outside the vehicle. Too often you will find that the discussions between opponents and proponents of batteries/hydrogen – mostly heated – are centred around the either/or question. That does not seem to be the right approach. Most people in the industry that honour fair play, objectivity, and a level playing field (a term that is overly used in political jargon) have earned a right to be listened to. Despite the obvious quick-start of the battery-electric solutions, hydrogen is now in the fast lane and rapidly catching up. This does not preclude diehards from continuing to foster the separation into two camps for the fight to continue, as long as it fits their respective goals in life. Silly.

Both full battery-electric and fuel cell-electric vehicles are electrically driven, and therefore siblings. It is not the technology in itself, but rather the applications and the operational requirements that will be the decisive factor in whether or not to go for fuel cell vehicles, together with pure economic considerations. The differences in efficiencies, when disconnected from performances and cost, are all that seem to preoccupy the engineers, rather than purchase decision realities.

However difficult it may be to use in modern speech, the siblings should be and, in a professional context, are being referred to as:

BEV and FCEV

In emission wonderland, the level of greenhouse gas (GHG) and harmful emissions is dictated by their use (duty cycle), the fuel consumption (driving style, topography, climate conditions, outside temperatures, etc.), and the way emissions are measured (reference is made to Volkswagen Dieselgate).

BEV = battery-electric vehicles: they are fully electric vehicles, i.e. are powered by electricity only and do not feature a combustion engine, fuel tank, or exhaust pipe.

The charging can be self-sufficient until the (traction) batteries are emptied and need a recharge: we call them PLUG-IN EVs.

The charging can be ‘en route’: we call them OPPORTUNITY CHARGED EVs. This will be particularly the case with buses.

and

FCEV = fuel cell-electric vehicles: they are fully electric vehicles, except that the fuel is hydrogen (mostly in gaseous form), which is contained in tanks on board the vehicle. The electricity is produced by converting the on-board stored hydrogen into electricity, almost always by a fuel cell (rather than an internal combustion engine with hydrogen gas).

Traction batteries have experienced a remarkably rapid rise to the top. In the early days of electric drives, it was customary to use lead-acid batteries. My professional experience goes back to the early 1990s and the design of a 9-metre midi bus that housed 48 top-heavy lead-acid batteries on the roof. However, the bus still needed a hybrid drive system, with a diesel engine to provide the balance of power needed for its daily journeys, in conjunction with the batteries. To maximise the impact of the electric drive, the diesel mode could be used to provide full traction outside the perimeter of a city’s outer ring, in order to maintain performance while recharging the batteries. Inside the city’s inner ring, the diesel engine’s system was programmed to go into ‘whispering mode’, thereby reducing both noise level and vibrations. Finally, inside the city centre, the diesel engine would idle and let the traction batteries provide most, if not all, of the traction until the bus had left the city centre again. We were quite fond of the concept, but the complexity of programming the algorithms together with the excess rooftop weight of the bus, due to the batteries and hybrid drive, proved detrimental to the commercial success of a great idea before its time.
Most of the traction batteries used today are lithium-ion batteries. This also goes for your laptop and mobile phone, all kinds of consumer goods, and not least, a variety of electric transport means. The main reason is their favourable energy density, i.e. the amount of energy stored in relation to their weight. Despite this obvious advantage in many products, the Chinese themselves continued to use lithium-iron-phosphate batteries, probably because the axle and the total weights of the vehicles are less of a consideration in Asia.

**Traction Batteries**

To safeguard long and safe operation, including deep discharges, energy regeneration during the brake process, and driving the auxiliaries (such as the compressor, water pumps, etc.), it is necessary to design a suitable BMS, or battery management system. The battery cells also need cooling, be it with water or air.

Almost all cells are imported from Asian countries, such as Korea and Japan. As early as the turn of the century, Umicore, a major player in the lithium-ion battery market, had more than 100 engineers, scientists, and staff employed in both countries.

This is probably the ideal time and place for sharing the story of Elon Musk, Tesla’s commander in chief, when talking about hydrogen cars. Musk’s known statements are that hydrogen cars should be called “fool cells”, as they are “mind-bogglingly stupid” and “bullshit”. The reason that fuel cell cars, in Musk’s credo, are above-all stupid is because they use a lot of electricity to split water into hydrogen and oxygen, to subsequently buffer it into a refuelling station, and to reconvert the hydrogen back to electricity in the car to provide the traction.

Toyota took the insult literally and responded with a short film on YouTube called “Fueled by Bullsh*t”, to confirm that Elon Musk had a point. Bullshit, or manure from cows, can and is being transformed into hydrogen, which is used to drive the car. There you go, thanks to Tesla and Toyota.

**The proof of the pudding is in the eating**

On 26 September 2016, two cars set off from Santa Monica, CA, heading for the Basecamp Hotel in Lake Tahoe, a 710 km trip. The first car was an FCEV Toyota Mirai. The second one a BEV Tesla model X. The bet was on which of the two vehicles would reach the destination first, without racing. Both cars needed to

**Lithium batteries** are a family offering several compositions, dimensions and weight, depending on the number of cells, the required output, and the application. The reason for the growing popularity of lithium batteries in virtually all mobility applications (and beyond) is the high energy density, i.e. output relative to weight. With respect to the required design life and longevity, the battery should not be fully discharged during every cycle. For this reason, it is important that the so-called SOC (State of Charge) be monitored to stay within the limits set for each individual application.

**Lithium-titanate-oxide (LTO) batteries**, which are particularly suitable for stop-go applications, such as urban buses, are an improved version of the lithium-ion sibling. Thanks to improved coating techniques, they manage to store and release energy faster and more frequently, allowing for higher currents (up to a factor 10 compared to lithium-ion batteries). This is a key design element when considering mobile applications such as city buses. They will also recharge quicker than their lithium-ion counterpart. An LTO battery is more powerful and has a much longer life than lithium-ion ones (20,000 cycles instead of 2,000 cycles in the case of ion-based batteries). As a result of the absence of carbon compounds, LTO batteries are heatproof, protected against (self)ignition, and resistant to cold climates. Their properties (longer life and carbon-free) translate into less environmental impact both during and after their active life. On the flipside, they come with additional weight and are more expensive compared to standard lithium-ion family members.

Remember that a fuel cell bus would carry 24 to 36 kWh LTO batteries compared to 10 times as much on a battery-electric bus. Given the extra weight for the output required, LTO batteries are very suitable for fuel cell buses, whereas they may present weight and other challenges in battery-electric buses.

The next big thing is **solid-state batteries**. The electrolyte with these is fixed, thus making them lighter, offering longer life expectancy and less chance of leakage, ignition, and fire, and requiring less cooling. Their higher energy density allows them to double the output (about 500 Wh per kg) at half the weight. They can be charged more rapidly and/or increase the operating range. Their use in automotive applications is expected in the 2025-2030 time frame, and they have the potential to disrupt the industry. Again.
among politicians and the general public alike. At least, it was the case for sev-
eral years, if not more than a decade. Electric is the key, without the fuss of gas
under high pressure, presumed danger of fire, required safety measures, etc.
Everyone is familiar with a wall power socket at home. The fact that electric
appliances do not emit harmful substances is self-evident to even the smallest
kid on the block and should make all of us happy. Consequently, anyone with
an opinion on climate change and zero-emission transport should welcome the
change, ride the hype, and keep quiet. If this is of any concern to politicians in
Europe, we should ensure that we are the first to make better and less expen-
sive cars. In the eyes of the general public, this is the crux of the matter.
If the question is approached from another perspective, knowing that the aver-
age consumer is not obsessed about the issue, we may find ourselves surprised
by the realisation that there is more to it than meets the eye. But will we?

How ecologically and GHG-friendly are battery-electric vehicles?
Batteries are definitely not the most ecologically-friendly product. The
CO₂-emission footprint has three distinct levels: well-to-tank, tank-to-wheel,
and overall well-to-wheel. The latter is by far the most important one. It means
that all CO₂ generated during the production, and including the waste treat-
ment, is being considered—the life cycle footprint from the cradle to the grave.
While it is possible to determine the well-to-wheel emissions, most authorities
were/are satisfied with advertising zero tank-to-wheel, i.e. at the end of the
tailpipe or exhaust, which of course any electric powertrain would be able to
achieve. Here again, the tide is turning. If we really want to avoid cheating on
emissions this time around, the only truthful way is to consider the well-to-
wheel emissions, all of them, from cradle to grave.

An analysis of ‘how green the electricity is that we use to charge our EVs’ was
presented in the EAFO (European Alternative Fuels Observatory) newsletter of
May 2020. It is calculated based on country-specific carbon intensity values,
including the impact of electricity generation, upstream impacts related to fuel
extraction or recovery, and the transmission and distribution losses of the net-
work. It concludes that the weighted average of the carbon intensity (CI) for the
top 10 EU Member States in 2019 was 186 g CO₂ per kWh. The CI variations for
production of electricity alone are quite substantial between the various coun-
tries, ranging from zero in Norway and 100 gr/kWh in France to over 1,000 g/
kWh in Poland and Estonia, with an average of 302 g/kWh in 2019. The noted
improvement of 9% compared to 2018 values stems from the reductions in
CI of electricity supply in the different countries due to the growing share of
renewables.

The UCS (Union of Concerned Scientists) have reached the conclusion that the
amount of CO₂ emitted in the production of a Tesla car is equal to a standard
gasoline car, except for the batteries (85 kWh). These batteries add 1,000 kg
of CO₂ to an electric car, released during the lithium production in salt mines.
However, the CO₂ saved by running an electric car is not entirely offset by the CO₂ emissions during its production, such that the electric car can offer a net saving.

Several studies and calculations have been undertaken to prove the authors right. Joeri Van Mierlo from the University of Brussels (VUB) and part of the We are Paris Initiative calculated that the emission of CO₂ for an electric vehicle will be 15 times less than the amount for a diesel car, if and when the electric current is 100% green and major improvements take place in the production of lithium and in recycling batteries. As always, the road to heaven is paved with good intentions. Nevertheless, even if the electricity during recharge of the cars is derived from coal power plants, it could beat the gasoline sibling, depending on the mileage of the car.

A study by the University of Michigan calculated the well-to-wheel GHG emissions based on the source of electricity used to recharge and a country-by-country breakdown of those sources. In terms of GHG emissions, electricity generated by coal or oil would be equivalent to gasoline consumption of 8.10 litres/100 km, by solar power 0.67 litres/100 km, and by nuclear a spectacular 0.05 litres/100 km.

Dr Ernst, a university professor in Liège, Belgium, calculated that the mileage necessary for the EV to compensate for the CO₂ in a well-to-EV calculation was about 600,000 km, which of course would kill the electric vehicle. Upon discovering that the assumptions at the outset were perhaps not realistic, he showed that the CO₂ break-even footprint for a battery-electric vehicle when compared with a diesel or gasoline car could vary between 60,000 and 600,000 km, depending on many factors, not least the carbon intensity of the production and distribution of electricity. What a relief.

A recent new study on the subject, published by AVERE, the European Association for Electro-mobility, in support of the transition to electric mobility (look who’s talking) calculated that the electric car would outperform a gasoline or diesel car on CO₂ emissions, using several scenarios, including worst case.

In all fairness, we can conclude at this time that an electric car needs to run at least 3-4 years (at an average of 20,000 km per year with a reference emission of 130 gr CO₂ per km) to offset the higher CO₂ emissions during its production and distribution.

Are the batteries and the rare earths recyclable?

Fortunately, most of them are. Umicore, a world player in cathode material in batteries, states that 70% of the materials are recyclable at the end of their useful life. Metals like lithium can be reused up to 20 times. The other 30%, however, are not recyclable. In any event, a separate recycling industry would need to be set up once the volume reaches a critical value, presumably around 2025.

The batteries play a key role in Tesla’s products. To produce them, Tesla has built a massive manufacturing facility in Reno, NV, called the Gigafactory, with a production capacity exceeding the worldwide capacity of lithium-ion batteries in 2013.

Experts project 11 million tonnes of lithium-ion batteries will be discarded before 2030. A quick guide to battery reuse and recycling (dated 28 February 2020) indicates that the reuse, repurposing, recycling, and disposal are quite a challenge. The batteries are processed in a handful of large-scale facilities by smelting them and recovering cobalt, nickel, and copper. Lithium and aluminium are partly lost. In the case of a car battery, the usable life is considered terminated when the cell capacity is less than 80% of the rated capacity. It can be reused in products for which less stored energy is required. Pricing out used batteries for some other applications is highly dependable on the cost of a new battery, which fell more than an order of magnitude, while performance improved. Battery recycling comes down to recovering the highest-value constituent minerals on the cathode, cobalt being the most valuable component. Reducing the cobalt content in a battery means reducing the incentive for recycling. On the other hand, optimal cathode recycling offers potential in terms of materials supply. California is currently working to develop policies to ensure that 100% of electric vehicle batteries sold are recycled or reused at the end of life.

How long does it take to charge the battery-electric car?

Many sites offer simulator and calculator assistance.

Since the charge time can vary between half an hour and 10 hours, there is no single answer. Given the capacity of the battery, the duration will, in essence, depend on the overall power output of the charger.

A typical BEV will need 8 to 14 hours to charge a 120V AC battery or 4 to 9 hours for a 240V AC battery. The Tesla superchargers currently being installed at highway stations will need 30 minutes to charge your battery 50% and about 75 minutes for the full 90 kWh of your model S.
This is apart from the fact that you will have to wait in line for your turn, and even when the charge is free, the very long coffee break will not (always) amuse the rest of your family travelling with you.

Other relevant questions about all battery-electric vehicles include:

Will battery replacement not remain expensive in terms of cost?

Will Europe and its Member States not depend more on countries that own the feedstock and strategic materials (even more than we have depended on OPEC for oil)?

Are electricity providers happy with so much demand, and will it lead to even more shortages and winter outages?

Are there enough rare earths and materials to produce millions of battery-electric vehicles when all of us will be driving them?

How safe are electric vehicles, whether battery or hydrogen? There are several Teslas's that caught fire and were hard, almost impossible, to extinguish.

How will the parking and charging space in an urban setting be organised when cars are all flocking into the inner city again?

More questions than answers. Nevertheless, a deeper dive into the world of electric mobility is more fascinating than the discovery of a new oil field. New and exciting challenges are ahead of us: who will lead and who will follow, how will it change the balance of power, will old world countries have a greater chance at survival, will geopolitical balance be equilibrated? Finally, will it make the world a better place to live in for the growing number of people that inherit it? Let’s continue to find out more.

Availability and price of lithium and cobalt

The question of whether or not there will be sufficient lithium mined, if and when virtually all cars in the world are driven electrically, is entirely justifiable. China is the biggest producer, followed by Bolivia, Argentina, Chile, and Australia. Lithium is a silver-white metal being mined in massive salt mines and lakes. It represents about 1% of the cost of the battery and about 4 kg per vehicle, so that should not be the issue. What may be the issue in a battery-electric only scenario is that the majority of the total world production is in one hand only: China. Talk about a geopolitical monopoly.

In addition, a lithium battery includes cobalt, a by-product of nickel and copper mining. More than 50% of the world reserves of cobalt (116,000 tonnes) are mined in Katanga (Democratic Republic of the Congo) and Zambia, with only about 6% in the USA and Canada. Worldwide, the biggest producer of this hard, lustrous, silver-grey metal is China Moly. Considering that cobalt represents about 60% of the battery cost, it is not too farfetched to see that the world market will be dominated, if not controlled, by the Chinese. Assuming Tesla will be the brand of choice for 500,000 electric cars in the world as planned, they will account for 7,800 tonnes or 6% of the yearly world production of cobalt.

No wonder Elon Musk is securing long-term supply agreements for his own giant battery factory. One option seems to be to produce cobalt from deeper layers, which does not appear a big challenge technically, but may very well constitute a major risk and cost factor that nobody in the industry is anticipating. Again, we (have to) assume a scenario in which lithium-ion battery technology will prevail for at least another three to five decades before being overtaken, perhaps, by solid-state batteries.

Although prices for lithium-ion batteries fell dramatically following increased volume, several security of supply issues have already been experienced by the Audi e-tron and Jaguar i-Pace assembly line due to excess demand issues at LG Chem in Poland.

Charging Infrastructure

In Germany alone in 2019, there were some 7,400 charging points for a total of 34,000 electric vehicles, and 170,000 stations in Europe.

According to the NPE (National Platform für Elektromobilität) in Germany, the total number of charging points needed is 10 times that level, in order to cope with the plan for 1 million e-cars on the road in the early 2020s. Despite the absence of charging points, the uptake of electric vehicles in Germany rose to over 21,000 cars in September 2020, an increase of 260% compared to the same month last year. The expected share of electric and plug-in electric vehicles in Germany marked a turning point, according to the Centre for Automotive Management (CAM). For the first time, EV registrations surpassed 300,000 vehicles, or 10% of all car registrations, in 2020. The typical historic chicken-and-egg controversy seems to be resolved, together with the belief that we have reached the point of no return. It is only a matter of years before this argument will no longer stand.

Subsidies

Many Member States have put their own policies in place with regard to subsidies. Most leading nations, such as Germany and Norway, have granted up to 4,000 euro per vehicle. But money should not be the only drive behind going for electric mobility. Norway implemented an array of accompanying measures, such as priority of way and exemption from the regular traffic tax. Accord-
ing to the latest studies, other reasons making success in the market so difficult include the current cost of the batteries. Another chicken-and-egg controversy. High production volume is needed to lower the cost, but the market is not prepared to respond until the cost of the e-car has been reduced dramatically. Elon Musk (him again) believes that a cost level of 100 euro per kWh of lithium-ion battery will trigger the downward cost curve.

Even so, within a competitive and global race for the best option, and in light of the CO₂ emitted in the battery production, another tribe is seeking attention: synthetic fuels from renewable sources. New chemical compounds can be considered for a long-term, acceptable low renewable energy cost, including the production of SNG (Synthetic Natural Gas) and RNG (Renewable Natural Gas). Exciting new prospects, new challenges, and new conflicts.

Der Verband der Deutschen Automobilindustrie (VDA) heavily criticised the German environment ministry for neglecting the option of synthetic fuels in the transport sector, which they maintain will be badly needed to reach the 2030 climate targets. They advocate that green hydrogen should be reserved for sectors that are difficult to decarbonise otherwise, such as steelmaking and chemicals, and that its use in the transport sector be limited to aviation, shipping, and heavy freight. The fight over the future of combustion engines flared up when Volkswagen threatened to leave the organisation due to the differing positions on the choice between electric cars and synthetic fuels for combustion engines. Interesting.

The electricity grid cannot cope
When assuming that virtually every single vehicle will be driven electrically and that charging times cannot be subject to long coffee breaks or managed in a well-organised manner, it is very likely that the grid will not be able to cope. One view of an electricity provider is that so many e-cars will act as a buffer for the energy produced in off-times of use, such that it will balance the grid and allow for overall lower production costs. This may be true to some extent but will likely fail when all of us will be using the grid, as the production and use of electricity are not synchronised. On a substation level, the problem may occur much sooner. A report in the UK suggests that, in particular city streets and areas, the energy shortages may occur due to six vehicles charging at the same time. The study concludes that, with the exponentially growing numbers of e-cars and vehicles, the grid and infrastructure needs are to be addressed sooner rather than later to reduce or eliminate the risk of blackouts and skyrocketing energy costs.

Charging points as parking space
IBM has calculated that more than 30% of the traffic congestion in the inner cities in the US is caused by cars that are looking for a parking space. In New York, the average queue time is 20 minutes per day, and 4 out of 10 cars need 40 minutes.

With electric cars, the situation will only worsen. With centralised charging poles in the city, the car will hook up in the morning and remain parked (until charged, and way beyond) for as long as possible. To either impose fines because the user has not removed their vehicle, or alternatively, require them to leave the building after a couple of hours to remove it are not workable options.

The Future of Mobility
The world population has increased more than sevenfold since 1800, from 1 billion to 7.7 billion people today. Since the beginning of the 20th century, population growth has reached 360%. In a business-as-usual scenario, the peak is expected to reach 9.7 billion people in 2040.

Around 108 billion people have inhabited this planet throughout its existence. This means that the current population size is about 6.5% of all humans ever born. Every year, 70 million more people need to find a home, food, and clothing. Close to 4 billion people are living in urban areas, and this number is growing.

Mobility is a basic human right and key to the quality of life itself.

The cities will need to either be green or not exist at all.

Worldwide, the number of cars per 100 people, very much in relation to population and wealth, has increased by 40% and the space occupation by 50% in the last two decades. The way this phenomenal human mass manages to move freely and safely in the future will be decisive for the livelihood of our metropolises and, by extension, our planet. The first electrified metro in Europe (London) only dates back to 1890. Currently, 157 metro systems are in operation in 55 countries. The first automobile with a four-stroke engine and four wheels (Karl Benz and Gottlieb Daimler) is only 5 years older than the London metro. Trolleybus systems date back to the early 1900s. Only 300 networks of once amounted to 800 systems have been maintained, and they are experiencing a well-deserved revival, meeting all current standards for emissions,
noise, and durability. The motorised ‘omnibus’ (meaning ‘for everyone’) also hails from the period 1896-1910. All motorised and mass transportation is just over one century old. Mobility is now in need of a totally different approach when it comes to keeping the planet liveable. And not only in the developing countries or areas.

On 22 February 2016, the Environmental Performance Index showed that air quality in Belgium was among the worst in all of Europe, second only to Montenegro. In Belgium, the Brussels area is the worst.

Less than 20 years from now, the smell of exhaust will no longer be any more tolerable than the smoke of cigarettes in restaurants today. Harmful emissions from public transport will no longer be acceptable. In Stuttgart, and in many places elsewhere, city councils have been accused by displeased citizen groups of ‘failing to act’, i.e. not taking the appropriate measures to meet applicable air quality standards and not mitigating the devastating consequences of traffic congestion. Calculations show that the number of early deaths (1 to 3 years early) in the EU-28, caused by air pollution (especially NOx and fine particles), will reach 500,000 per year. This number increases to 7 million when including all world figures. On average, one in five chronic diseases, such as Alzheimer’s, is proven to be caused by fine particles in the air. This share can reach 90% when it comes to elderly people and places where high concentrations of fine particles have been measured.

To understand this revolutionary transition of urban mobility, it helps to distinguish and understand the four layers that have to blend together.

The basic underlayer is the physical infrastructure: roads, bridges, stations, bus stops, parking areas, garages, etc. In many older cities, the basic infrastructure has hardly changed over the last 100 years. It is likely that the evolutionary path in changing infrastructure will remain slow.

The second layer covers rules and regulations: traffic plans, frequencies, speed limits, authorisations, and cost structure. We will see a swift move from tight regulations to flexible ones, mainly because all transportation modes will have to work in with each other to achieve better use of road space, harmonisation in ticketing and flexible payment methods, and smart priority signs at crossings and intersections.

The third layer is the vehicles: cars, trains, metro, light rail, buses, motorcycles, and bicycles.

The fourth and final layer is the interface with users: how will mobility be consumed? The user wants to decide for him or herself how, when, and at what cost they want to reach their destination, in the blink of an eye by simply touching their mobile screen.

### Four Pillars

The four pillars on which tomorrow’s mobility will thrive have already been identified, as quantified data is needed to make long-term forecasts for building business cases:

- Zero Emission through Electrification
- Use of Renewable Energies
- Connectivity – Mobility on Demand
- Autonomous Driving

### Zero Emissions through Electrification by Renewables

In their blog dated 12 November 2015, Roy Cobbenhagen and Lex Hoefsloot from Eindhoven University of Technology revealed what we can reasonably expect for the future of mobility. According to their findings, the answer is electrification based on energy that is no longer a derivate of fossil fuels but quite the reverse. One of three options – E-fuels, batteries, or green hydrogen – will be the technology of choice for the market to decide.

Different formulas are being developed by the Ubers of this world and, strangely enough at first sight, by the car manufacturers themselves, contributing to limiting the simultaneous inflow of cars into the cities to avoid even more congestion and pollution. In Belgium and the Netherlands, companies are offering car use at 100 euro per month, on condition that the car can be used by third parties for a minimum of 2 days per month. Getaround, an existing car sharing company, already claims it has over 2.5 million users in Europe and the US. With more than 40,000 private cars in their portfolio, covering car makes and models ranging from 21 to 39 euro per day, they seem to be the big car sharing company of our time. They advertise up to 500 euro a month of income for those willing to share a standard VW Golf car less than 3 years old.

Car sharing options include those that do not require the user to return the car to its pick-up location. Inefficiencies due to queuing, congested inner cities, pollution, and parking issues are all being addressed by the Ubers, Googles, Teslas, and Moovits of this world and will continue to be addressed by many others to come. Recognising the problem seems to be part of the solution. Rather than selling more cars, the manufacturers are playing their part by turn-
ing mobility problems into commercial opportunities. Software and knowledge are gradually becoming an active part of the connectivity and the services offered, as opposed to simply supplying more hardware.

**Mobility On-Demand (researched and narrated by M. Pecqueur)**

Everyone has their guilty pleasures. One of my little vices was once the TV show ‘Who wants to be a multi-millionaire?’ In it, candidates had to answer questions on diverse subjects. Every correct answer made money. In the Belgian version, the main prize was 20 million Belgian francs, about 500,000 euro. Although a scientific question in the programme was about as common as rain in the desert, and the tension arcs were clearly staged, I was still faithfully on the job every week.

Today, it is enough to know the answer to one question to become a multi-millionaire. Multi-billionaire even. What will the propulsion system and the corresponding energy form for vehicles in the future be? Electricity? Hydrogen? Methanol? E-fuels? Anyone who can demonstrate this incontrovertibly can count him or herself rich.

The issue of the drive system of the future is particularly topical and leads to stress. Private users have choice stress when purchasing their car. They wonder whether they will be able to refuel with the vehicle they are buying now or whether they will be able to charge it. Professional users and leasing companies do not have an overview of the total costs of their fleet or of the residual value when vehicle rental periods expire. In short, there is a lot of uncertainty in the car and transport sector.

Autonomous mobility will put an end to this uncertainty. This is a new form of stress-free mobility where the focus is no longer on ownership but on use. People will no longer own a car but will instead order a ride via an app on their phone when they need it. They will choose their mode of travelling and with whom they travel. The principle of autonomous mobility is similar to that of current public transport but on an individual level or with selected passenger profiles next to us in the car.

The evolution towards autonomous mobility is already visible. More and more cities are declaring war on king car with initiatives that discourage individual car ownership. There are fewer and fewer parking spaces, the available car parks are far from the city centre, and parking is becoming more expensive year after year. Cities are very creative with measures that make the life of the individual motorist more difficult.

Autonomous mobility is also facilitated by the way our public transport is organised. It is quite an adventure getting to your destination by public transport. The nearest stops or stations may be at a considerable walking distance from your home or workplace, and direct connections are scarce. Trains, trams, and buses are packed at rush hour, and punctuality leaves much to be desired. In addition, as soon as you get out, you usually have to walk again through wind and other unpleasant weather conditions to reach your destination.

Even people with a high Indiana Jones adventure level will not enjoy this particular adventure. For most users, public transport is not a conscious or first choice but the only option. Autonomous mobility will offer these people a full and affordable alternative. The consequence? Public transport in its current form will no longer exist in the future.

It will be custom work. We will evolve from mass public transport to personal public transport. You will be able to plan your ride with an app. You will enter a number of parameters – such as your departure location, your desired departure and arrival time, your destination, whether you want to walk or cycle or make a stopover to eat or drink something, which profiles you want next to you during your journey, and so on – and the app will give you the best option. The more profiles you allow, the faster you will be able to leave and the cheaper your ride will be.

To organise autonomous mobility and personal public transport, producers will build a network of mobility points on a platform between which autonomous shuttles commute. The shuttles’ body will meet the requirements of the party that wants to offer mobility. When a mobility provider is not using the platform, they will be able to rent it out to other providers. For example, it will be possible to use a platform during the day for passenger transport and at night for freight transport. Only the bodywork will need to be changed from shuttle to cargo. This will allow the platform to be used 24/7. Manufacturers will remain owners of the platform and will be responsible for safety. Autonomous mobility will also be a high-quality marketing tool. If you have planned a ride, it is not inconceivable that you will receive a message from the travel agency whose website you looked at the day before, in search of the dream trip you have been wanting to make for years. The agency will offer to take you to your destination with their autonomous shuttle for free. During the ride, you will see a personalised video of your dream trip. In this way, autonomous mobility and marketing will go hand in hand. Offering your potential customers free mobility will allow you to approach them personally without appearing obtrusive. After all, they don’t have to buy anything.
This concept will thoroughly redesign the current marketing landscape. Major car brands are now the icons in the world of mobility. Brand image will no longer play a role in the future. Shuttles will also be able to carry advertising from travel agencies, barber chains, or food stores. And every shuttle will be of the same quality. A user will only be able to choose the price and comfort class.

Mobility will proceed according to the standard pattern in the current aviation sector. A customer books a trip with a travel agency, and the travel agency – taking into account the budget and the desired comfort of the customer – books a flight with an airline. The customer then gets on an airplane without knowing whether it is a Boeing or an Airbus. An airplane has no brand image. And that does not interest a customer either, as long as they enjoy the comfort they paid for.

It will be the same in the mobility sector. It will be a world where everyone is equal. There will only be a difference between the price and the comfort level of a trip. Mobility providers will face fierce competition where corporate image and brand identity no longer have any value.

Will personal public transport and autonomous mobility not lead to more journeys? Yes, of course they will. But that’s not a problem. On the contrary. More travel means that people will leave home more often and will therefore contribute more to the economic activity and prosperity in their region. And, despite the increase in travel, the number of traffic jams will decrease. The average occupancy rate of a vehicle is currently 1.1 people. If we use shuttles with an average of 3 people per trip for our autonomous mobility, the number of vehicles on the road will therefore decrease by almost a factor of 3. Autonomous vehicles will thus contribute to more mobility and fewer traffic jams.

And the impact on the environment? This will be closely related to the form of energy chosen to power the shuttles. If we choose hydrogen or electricity, there will be no direct emission. The biggest ecological challenge for autonomous mobility will be the tires.

Another advantage of autonomous mobility? Groups now dependent on others for their mobility, such as the elderly and people with disabilities, will be able to move independently more easily. In addition, the number of road casualties and accidents will decrease. Autonomous vehicles do not have a driver. And that is positive because drivers are people, and people make mistakes. Machines are much better at performing repetitive tasks than humans, and they cannot get distracted or tired. This will reduce the number of accidents on our roads to almost zero. More than 3,400 people die in traffic every day. That’s the equivalent of 7 jumbo jets a day! So, we won’t have to worry about that in the future.

In short, autonomous mobility has many advantages. But what energy source will we use to power the shuttles? The answer to that question is very simple: the cheapest legally-allowed energy source. The producers and operators of autonomous vehicles will be companies that pursue their goal: making a profit with the utmost respect for the wishes of their customers and applicable regulations. In places where zero emissions are required, that energy source will be hydrogen or electricity. If we look at the transport sector, autonomous trucks will be powered by methanol based on sustainable hydrogen and CO₂ captured from the atmosphere.

Whatever direction we take in tackling our mobility challenges, one thing is certain: hydrogen will be part of it.

The Future of Public Transport

How can public transport and hydrogen be part of this new world reality?

Will public transport in its current form still have a place in the future?

In order for public transport to be part of the solution to congestion and emissions in crowded city centres, rather than being part of the problem, it will have to be resilient. In order to be more resilient, it will have to undergo major changes, especially in light of the sector (mostly) being run by public entities.

It is obvious that public transport will need to claim its place, not by imposing itself on the public or by subsidising it for the sake of competitiveness with other means. Public transport will have to earn its deserved place by playing an active and a pro-active role in the transition, probably as the backbone of an integrated urban system and not by just being there or handling the typical geographic crossings, from North to South and from East to West. It will have to be part of the new, flexible pick-your-number approach, where the end users are and need to go.

Policymakers, in charge of public transportation, will need to start electrification of fleets now, before other competing means of transport start forcing
solutions on them. The revival of the bicycle, as a fast and efficient way of reaching destinations within the confines of the city centre, is already noticeable. Bikes cannot go on buses easily. However, bikes cannot be ignored in cities. Both modes need to find ways to be used in a complementary and efficient way. New bicycle paths and dedicated bike highways need to be linked to and integrated into the public transport network. Most cities in the Netherlands are exemplary in this respect. I am convinced that the system can serve as a good practice example in other parts of the world. If a copy-paste approach is not possible, modifications can still be made to adapt to local operating circumstances and cultural differences, on the condition that this ties into accompanying measures, including bicycle lanes, traffic lights and right-of-way strategies, safe parking spaces with secured bike racks, etc.

Buses should be equipped to accommodate this trend, as are light rail and commuter trains and metros. If not, the many small electric cars, now moving into becoming mainstream through reduced cost and quicker charge times, will be invited again to choke the city. On many an occasion, I have warned that the trend towards small EVs will, sooner rather than later, cause many thousands to flock into the city centres, creating new forms of congestion and major parking and space occupation issues. Buses getting stuck in congested city streets due to small EVs is not an option. In Paris today, urban buses are idling for over one third of their active service day. While lined up in the city’s car-congested streets, their average commercial speed is less than 10 km per hour, or about 150 km in a full day of operation.

Sometimes, less is more. Public transport should take the necessary steps to avoid being part of the new problems. Instead, it should offer new solutions, in terms of both cost and efficiency. To upgrade efficiency in this digitalised world and in a highly competitive market environment, it is extremely important for public transport to offer:

- Nothing less than zero tailpipe emissions: it is absolutely and urgently imperative that no harmful emissions are released into the urban air. Electrification is the best and only answer to meeting this goal.
- More efficient transportation. Whenever optimised digital systems of data processing and mapping are offered to the traveller, they risk being jeopardised by congestion, accidents, strikes, or a combination of the above. There is no acceptable rationale for not operating buses in their own dedicated or semi-dedicated lanes, as is the case for light rail, metros, and trains.
- More comfortable commutes. To cope with increased ridership, safety, and comfort, buses should apply a strict density standard, i.e. not exceeding 4 people per square metre, comfortable seating, air-conditioning, work spaces with free Wi-Fi connection, etc. This vision is shared by the UITP in their recommendation to double public transport in 2025 from 2015 levels. More buses or high-capacity buses are the answer, on condition that they move while private cars risk getting stuck in traffic.

### The Future of Hydrogen in Mobility

Hydrogen and fuel cells offer very distinct advantages to most means of public transport, including taxis, buses, and commuter trains. A more detailed look into their opportunities has been the subject of many studies on urban buses. I will name just a few, including McKinsey (Urban buses: Alternative Powertrains for Europe, a fact-based study – 2012) and Roland Berger Strategy Consultants (Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe – 2015), commissioned by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

Discussions, which are often fiercer than not, about the role of hydrogen in transport (versus batteries) are still ongoing on social media, in position papers, and during conferences, workshops, and high-level reports, and aim to inform the European Commission at all of its decision-making levels. The fact that those reports and position papers cannot always claim full objectivity is easily explained when their editors are being funded by specific interest groups.

It is becoming increasingly clear, however, that hydrogen is an undisputable factor in the energy transition.

The question is no longer if but when the breakthrough will happen.

The US and many other nations, such as the Netherlands, Germany, and the UK, have already laid out or are in the process of laying out roadmaps for the introduction of hydrogen into transport applications. Surely, even for this sector alone, both the timing and the priorities in transport applications will be different. Reference is made to the state of play in chapter 2 that summarises the
'Roadmap to a US hydrogen economy'. As for Europe, Automotive World published a special report on ‘The timeline for electric commercial vehicles’, quoting Bernd Heid, McKinsey’s head of commercial vehicles, saying that “in long haul applications, fuel cell electric trucks are better than both battery-electric and diesel trucks in terms of total cost of ownership. It is ultimately the best solution”.

The numbers, both the number of niche markets as well as their volume, are expected to grow exponentially. General Motors has expressed their view that fuel cell applications stretch “way beyond passenger vehicles” and stresses the argument that GM is developing a land, sea, and air strategy with fuel cells. Battery-electric vehicles (BEVs) and fuel cell-electric vehicles (FCEVs) will soon be here for a long time to come. And for good reasons.

Regardless of its application, hydrogen offers the capability of storing electricity produced by renewables under their rapidly falling cost curve, which may very well prove to be the single most important factor in enabling a smooth energy transition and in ensuring the ability to meet the decarbonisation goals of the European Commission.

**Mobility Applications**

Instead of being part of the problem, hydrogen in mobility is part of the solution, in terms of helping to reach CO₂ reduction targets and countering climate change by offering ZERO tailpipe emissions at all times, or as close as possible to ZERO well-to-wheel emissions, subject to the production site and method of producing hydrogen.

The SUV (Sport Utility Vehicles) and SAV (Sport Activity Vehicles) are here to stay. Only 10 years ago, they were believed to be the odd ones out, an add-on offering that would never be mainstream, as the public mindset was on smaller cars, not bigger! Today, SUVs are extremely popular and have outranked the family car as we used to know it. Virtually every carmaker offers a complete range, which definitely includes crossovers and SUVs. It has now become obvious that the second car will be a small one, to be used by one of the individual family members to commute to work, school, the gym, or nearby activity centres, with daily mileage not exceeding 100 km (which is almost 90% of all car use). Hence, the battery-electric propulsion will be most suitable for this overwhelming part of the fleets.

Consequently, the family car will almost exclusively be an SUV, serving its full purpose whenever space for (hobby) equipment and all-family trips, as well as comfort and range, are required.

These are the future targeted world markets for fuel cell cars.

The time needed to (re)fuel is way better for a fuel cell car or bus than it is for a battery-electric one. Issues and hurdles associated with BEVs, such as long charging times and low operating ranges, do not exist for fuel cell cars. Car owners, putting more money on the table for an all-electric drive, will not accept the pitfalls of its multi-tasking use. This may very well turn out to be the biggest advantage for the fuel cell cars’ future success.

As for buses, it is clear that the fuel cell bus will allow for full operational flexibility. The size of the hydrogen tank, given the hydrogen consumption in a hybrid driveline, is the only relevant or limiting factor for the range of the bus, which is still comparable to or better than diesel buses today. This is very important, as bus operators in general do not wish the buses to be refuelled and interrupt a day’s work, no matter how hard or long it is. It would be a loss of time and money and require the operator to change the traffic plan, adjust the routes, purchase more buses than necessary, or do some combination of the three. A fuel cell bus does not require the operator to do any of that.

The only piece of infrastructure is the fuelling station (HRS) at the operator’s own site. This can be a small hydrogen refuelling station with a buffer and dispenser, identical to what they are used to for diesel buses. By their own choice – or via political support – the operator can decide to have a hydrogen refuelling infrastructure (HRI), with a small electrolyser on site, producing their own hydrogen from water and taking control of their own independence from fuel suppliers. This would be quite an improvement over the current fossil fuel supply chain.

A staff member of Transport for London once told me that the use of hydrogen in public transport is a no-brainer from an operational perspective. I am sure that many operators will agree with this statement once they embrace hydrogen in their own fleets.
In addition, the application of hydrogen in buses is a dream come true, for even more reasons related to serving the needs of operators.

As an example, the city of Pau, France, has selected hydrogen fuel cell power for its new tram-bus (Fébus) as part of its bus rapid transit (BRT) system. And the motives were not only related to zero emissions, which saw close competition between battery-electric and hydrogen fuel cell options. Instead, they opted for the solution that best fit their specific requirements, including performance and service, while also considering the operating range, passenger capacity, and amenities as well as the geographical and climate conditions.

The result was quite astonishing: to accommodate the projected ridership, 14 battery-electric articulated buses and two recharge terminals would be needed to meet the same operating needs that could be met by 8 high-capacity hydrogen fuel cell buses. Other quantifiable motives to support the purchase decision for fuel cell buses included: equal performance and range in winter and summer and no impact in the event of a power shortage or interruption.

Commissioned by the French authorities, this project laid the basis for the national ‘1000 hydrogen buses’ by 2023 project developed by the Association Française pour l’Hydrogène et les Piles à Combustible. The key message is that any public tender for electric buses should include the hydrogen option for the following reasons:

- daily autonomy of 250-400 km is needed on one fill/charge;
- high performance in challenging climate and geographical conditions;
- flexibility in planning refuelling infrastructure;
- lower total cost of ownership when considering all cost elements.

Despite the many different ways public transport is being organised in the individual Member States, the market for urban transport (buses, trains, tramways) is a public market or, in any event, a regulated market. The authorities themselves are in the driver’s seat as far as defining what is best for their electorate, in terms of air quality policies, healthcare, and safety, and also in support of local industries, innovation, and employment. This is unlike private markets.

At the same time, it is impossible for one region or even one country or Member State to meet the environmental challenges of our times. The objective exceeds the capabilities of individuals and can only be achieved through large-scale initiatives, backed by as many stakeholders as possible.

The reason that the private fuel cell car will nevertheless face an uphill struggle is the geographical coverage of fuelling stations, although the network is rapidly extending. The problem of full geographical coverage (a minimum of one station for every 300 km in any direction seems to be the medium-term goal), and the chicken-and-egg controversy it entails, does NOT exist for fuel cell buses. With a consumption of about 30 kg of hydrogen per bus per day, a fleet size of 20 buses will need about 600 kg of hydrogen on each of the 365 days of the year. This is sufficient to make a fairly large hydrogen station economically viable, including the buffering unit to allow for all 20 buses to refuel successively in fast-fill mode, or even simultaneously overnight in low-fill mode.

The third reason for its fitness for purpose is the maintenance. With most of the buses being maintained in-house or in a third-party organised workshop, the expertise needed is available or can be acquired by means of in-house training sessions. Already now, maintaining the hybrid electric driveline of a bus does not hold many secrets for the majority of operators. To picture the fuel cell as something from outer space or impossible to master is, therefore, in conflict with current, everyday reality. There was a time when the larger operators had workshops and expertise to repair almost any mechanical or electrical component on a bus. Today’s bus workshops no longer have such repair facilities or equipment for the main componentry, whether they are working with diesel engines, fuel systems (diesel or gas), automatic transmissions, or specialised electronic equipment in a bus. The sheer number of electronic components is staggering. Wrenches have been replaced by laptop computers. Wires have been replaced by computer nodes. Virtually every functionality in the bus, from engines to brakes, doors, steering, and safety features, is electronically operated or managed. The fuel cell module is just another component in the long list. Hooking it up to a computer, which reads the traces generating tons of information about its performance, current state of health, and expected performance, is already a reality.

As for maintenance and repair, the system can diagnose defects through an internet connection and conduct remote readings with corresponding repair options. If needed in real time and online, engineers and specialist technicians at both ends, together with bus and component manufacturers, will all have access to view the issues at hand and consult about the best way forward, with the sole purpose of having the bus on the road again as quickly as possible.

Although the success rate of fuel cells in transport applications may differ, a number of complementing applications will reinforce each other and support their accelerated deployment.
This may very well be the case for long-distance transportation by bus, coach, train, vessel, and aircraft as well as for people transportation and forklifts, delivery trucks (especially overnight deliveries), military vehicles (including unmanned underwater vehicles), and drones in goods and other transport areas. In the meantime, trains and long-distance trucks running on fuel cells are becoming serious new contenders in their own respective fields. Alstom, Nikola, Hyundai, and GM are just a few examples of companies leading the transport industry.

Any OEM (original equipment manufacturer) of rolling stock that chooses not to take these applications seriously may very well find itself alone and possibly out of business.

The debate between BEVs and FCEVs is still raging. If one wants to dig deeper into the subject, the phrase ‘look who’s talking’ springs to mind. It is strikingly true that once you know the person or company voicing one or the other preference, the answer is already given. If not in the category of either advertising or marketing, the arguments for one faith or the other are plain to see if you know who is behind the statements, obligatorily backed by studies and references to make them appear indisputably true. Their foreclosure mindset is mostly due to bad experiences, old-school theses and beliefs, and most of all, the use of outdated data. It is amazing that disbelievers – against the evidence provided by better professional knowledge – keep banging on about the disadvantages of hydrogen. Arguments include poor efficiencies compared to batteries, production emissions of steam-reforming production methods, absence of fuelling stations, and many other fixed thoughts, all of which are currently on their way to the history books.

Many costly studies and fact-based in-depth research projects later, it is fair to state that both technologies have their respective advantages and disadvantages and that the application will have a major role to play when it comes to making the decision about the technology of choice.

Customers and their preferences will decide which way to go in each of the market segments. It is for the industry to lead the way as much as possible and to safeguard and foster their competitive advantages, as long as it is on an equitable basis.

The question of whether battery-electric or fuel cell-electric will prevail as the zero-emission technology of choice in mobility applications is definitely the wrong question. A distinguished number of independent experts have addressed this question and, in an attempt to provide guidance on selecting the most suitable technology for any application, have developed questionnaires to help authorities and public agencies make the best decision given the number of impacting variables. As an example, Hydrogen Europe in Brussels (www.hydrogeneurope.eu), the Center for Transportation and the Environment in Atlanta, GA (www.cte.tv), and many more organisations offer such assistance. Although designed foremost for urban transport applications, these resources serve a similar purpose for fleets of vehicles, be they long-haul trucks or port equipment.

It will be interesting to see how today’s picture of the automotive world, both private and public, evolves, as not one single product or service on the market today will survive a maturity date of more than 10 years in its current form and content.

In public markets, the hunt is more open than ever before. Asian products, whether established or new, EU developments in conjunction with new and challenging production methods, and more importantly, attempts to achieve the lowest possible production cost, will mark the next decade. EU customers, who were once keen on buying what was made locally but then switched to products ‘designed in a named EU country’ but manufactured or made in a ‘low-cost one’, are now heralding ‘designed and made in a named Asian country’ with brands never heard of before. The once-embraced procurement method, which included value chain elements and local assembly/employment, innovation, and exports, is currently a very different song, no matter the language. At the same time, countries and their presidents are showing up all over the globe preaching the ‘My Country First’ gospel, mimicking the US slogan, making promises to their followers without understanding or considering the damage to world trade and to the long-term prosperity of their own citizens.

Currently, politicians are calling on the general public to procure local products from local industries and businesses as a response to COVID-19’s disastrous economic impacts. At the same time, many public entities continue to procure imports from low-cost countries, hiding behind the ‘most economic procurement’ principle.

As for passenger cars, the strategies being developed have been firmly translated into marketing plans, including dates of introduction. Most of the major carmakers have reached the right conclusions that both BEV and FCEV technologies have their respective ‘raison d’être’.
The expectation is growing that renowned car brands featuring a full model range will have both battery- and fuel cell-electric versions on board in specific models. This has already materialised in the extended range offered by BMW, Mercedes, Audi/VW, Hyundai, Toyota, Honda, and others. Peugeot, Citroën, and Opel are turning to fuel cell versions. Very few companies, mostly start-ups addressing niche markets, offer fuel cell cars only. Toyota and Honda offer fuel cell versions for sports cars and sedans, while Toyota’s Mirai (meaning ‘Future’ in Japanese) and Honda’s vision for a family car seem to be competing for the same market segment. Japan is renowned for using fuel cell cars and buses and has also secured a head start elsewhere, in housing and heating.

Hyundai, Mercedes, and Audi are focusing on SUV (Sport Utility Vehicle) models for their fuel cell versions, some in two versions or with the fuel cell as the range extender. They represent the vision that a portion of the market will need more autonomy and/or longer and/or stronger performance offered by the fuel cell once the fuelling network has been completed. Whereas Mercedes suddenly decided to stop production of the fuel cell-electric GLC for alleged production cost reasons and because it prioritised the switch to heavy-duty trucks, the Hyundai Nexo seems to be consistent in keeping the view that fuel cells are the way to go for SUVs and their intended function.

The same goes for the Nikola Bagger SUV. Others will follow, as it is generally accepted that battery-electric vehicles have their limitations when it comes to the operating range, especially in remote areas. The military is another market in that category where fuel cell vehicles are proving their unmistakable operational advantages.

This broadly leads to the conclusion for cars that there will probably be two families and user groups, on the assumption that no other game changers come into play: 80% of users will either not own the car anymore or, when owned, use a smaller one for their daily commute to and from the workplace, i.e. less than 100 km per day, which is perfectly doable with a small battery car. The second category is that of the spacious and powerful family cars, mainly SUVs for all of the family members’ leisure needs. The SUV, already very popular, will better satisfy the individual needs of their many and distinct family users, while offering the range, space, and comfort required for each and every one of them.

How that would translate into a clear and definite split of the two electric siblings was still unclear 2 years ago. On reviewing a questionnaire about the expected number and share of fuel cell-electric passenger cars in 2017, the result was that 17 brands declared a total of 70,000 cars in the 2027 production time frame. They all agreed that it was too early in the game and that no one could predict and, consequently, declare reasonable expectations with so many known unknowns at that time, not the least of which was the infrastructure deployment.

We should therefore not be surprised, or panicked, that they were all looking for answers and following a two-way strategy until the answer became apparent. In the meantime, the answer is becoming increasingly clear: 12 carmakers have formally decided to build fuel cell cars. The once-noticeable exception of both French (PSA) and Scandinavian (Volvo) brands no longer seems to hold, as they too have decided to prepare for the hydrogen road. From a technical perspective—be it somewhat generalised—the addition of a fuel cell as a range extender or as the main source of traction is not that difficult when starting from a finished battery-electric vehicle. It seems that this wild card is being held back by most carmakers.

Also not surprising is the fact that carmakers were and still are looking to collaborate with technology developers in different ways, if only to share the tremendous development cost and, even more importantly, move forward in the time-to-market race. It is true that the automotive world is still experiencing mood swings when it comes to its strategic decisions on whether or not to develop fuel cell versions (yet). Toyota, Hyundai, and others have voiced their clear and positive vision. Others, such as Volkswagen, have recently indicated that they will bet on battery-electric. Sometimes the motives are more related to a new board and/or a newly-appointed director in charge of technology and/or strategic priorities and/or other factors, rather than technical grounds. Given the sense of urgency in bringing the products to market, a number of OEMs have decided to engage in a cooperation effort, such as BMW with Toyota and GM (General Motors) with Honda.

The automotive industry is on the brink of a worldwide revolution, rather than an evolution. To recognise the challenges is to make use of the opportunities. The drive is not what is best for the industry but what meets the new expectations of the world markets, ensuring competitive conditions and recognising that the market urgently needs zero-emission transport. Because of the sense of urgency and the competitive challenges, the battle for survival is not far off.

This pressure underlies their stop-and-go approach in defining and redefining their strategies.
It will be interesting to see whether the strategic moves from Chinese, South Korean, and Japanese automotive OEMs have a stimulating or destructive impact on the future of their European competitors and whether or not they can meet the challenges. It is my personal belief that saving the European car industry, both through stimuli and through protective measures that are being put in place, will force them to go where Europe wants them to be: leading the green hydrogen revolution. The recent shift towards hydrogen by European car and truck makers, from Audi and Opel in Germany to PSA in France and Volvo in Sweden or DAF in the Netherlands, is driven by the belief that the rescue has its price, and hydrogen is one of the triggers.

Recent developments and the shift in emphasis to commercial vehicles, rather than to private cars, merit a closer look into the three categories of mobility applications that are believed to be fit for fuel cells and hydrogen:

**Trucks**, from a broader perspective of different applications, ranging from long-haul trucks (no doubt the biggest segment) to delivery trucks, including parcel delivery vans, bin trucks or refuse trucks, cleaning trucks, drayage trucks at ports, etc.

There has been a notable shift from fuel cell cars to heavy-duty commercial vehicles, for many good reasons: the required daily operating range, the fuelling time, weight limitations, payload considerations, etc. If tied into and supported by a firm commitment from the European Commission and Parliament as well as national hydrogen plans, as is becoming increasingly the case, the marching direction will be very much towards fuel cell vehicles. Not surprisingly, this trend has already led to a couple of interesting industry trends:

Hyundai’s XCient FC truck is set to become one of the first trucks in the world leading the transition to hydrogen. The truck carries 32 kg of hydrogen at 350 bars for a driving distance of around 400 km in a 34-ton truck-trailer combination. The joint-venture with H2Energy will enable them to lease the trucks on a pay-per-use basis to commercial operators without requiring an initial upfront investment. With the sale of 1,000 units in Switzerland to be shipped by 2025 and the first 50 already on their way, the company is poised to make fuel cell trucks a big success. The business case seems to be a prime facilitator: the Swiss road tax on commercial vehicles does not apply to zero-emission trucks, which nearly equalises the hauling cost per kilometre of the fuel cell truck compared to a regular diesel truck. The marketing concept, as applied by Hyundai, of guaranteeing a life cycle cost, including fuel, not exceeding that of a diesel truck, takes away any remaining doubt and completes the selling arguments.

The major truck manufacturers, Daimler Truck AG and Volvo Group, have signed a joint-venture agreement for a 50% share each, at a cost of 600 million euro, to develop, produce, and commercialise fuel cell systems for heavy-duty vehicle applications, including a 300 kW version for their long-haul models. This means basically two things: the recognition that electrification is key to achieving the required carbon-neutrality and, secondly, (in the words of Martin Daum, Chairman of the board of Daimler Truck AG) “by forming this joint-venture, we (both Daimler and Volvo) believe in hydrogen fuel cells for commercial vehicles”. The fuel cell trucks for long-haul applications are set for series production delivery by the second half of the decade. The joint venture will include the Mercedes-Benz Fuel Cell GmbH operations, with production facilities in Nabern, Germany, and Burnaby, Canada. They both hasten to add that they will remain competitors in all other areas. Good to know.

Iveco (part of CNH industrial) and Nikola Truck, relying on Bosch as a technology partner, have discovered that more similarities than competition are present in their product range and philosophy of cooperation, enough to pool their efforts in the launch of a common platform for fuel cell truck versions.

Hyzon Motors, together with Holthausen, have decided to build a new assembly factory for 500 to 2,000 of their trucks per year in Windschoten, the Netherlands, banking on the positive attitude of the Dutch hydrogen community.

Paccar, the American owner of Kenworth and Peterbilt, has made the decision to develop the Kenworth model T680 based on the fuel cell system of the Toyota Mirai. Dutch truck builder DAF, an affiliate of Paccar, is reported to be closely following the project.

Renault Commercial Vehicles is poised to follow suit and is reported to be developing hydrogen versions of some of their models.

Other new fuel cell truck applications include refuse and bin rubbish trucks, mitigating emissions and noise during the many hours they operate in city centres and at very low speed. Several units are in service and have been ordered, including in the North Netherlands and Antwerp.

Drayage trucks in ports are the next vocational application. A drayage truck picks containers up from or delivers them to a seaport, border point, inland port, or intermodal terminal, with both the trip origin and destination in the same urban area. Drayage trucks sit idle for long periods and stop/start very frequently, creating less than optimal power performance and generating the
highest concentration of emissions within the transport service industry. While not so visible and not included as part of the queue statistics, large ports such as Los Angeles and Long Beach in California, known as the San Pedro Bay Ports, operate a staggering 17,000 heavy-duty drayage trucks.

**Trains:** Amongst the totally new and very promising applications of fuel cells in mobility are the shunt and regional trains that are presently run on diesel fuel and produce both harmful and GHG emissions where it hurts most, in or near city centres.

Alstom is the first train manufacturer to have understood the potential of fuel cells and is currently operating a line in Germany to show it to the public, fostering international interest in fuel cell train applications. A cooperation agreement with SNAM in Italy to develop and deliver fuel cell trains has been signed.

Another 14-million-euro fuel cell train project in Europe, known as FCH2RAIL, is also underway. Run by the Spanish CAF on the basis of their Civia Class 463 three car, it is scheduled to be tested in Spain and Portugal in 2023. The objective of the project is to develop, build, test, demonstrate and homologate a scalable and modular fuel cell hybrid power pack for different rail and heavy-duty applications.

In the meantime, Siemens Mobility and Deutsche Bahn announced a joint development programme for the next generation of a hydrogen traction system, based on its Mireo Plus regional train. The train will have 1.7 MW traction power and a top speed of 160 km/h. Green hydrogen will be produced locally, and trains will be refuelled in Tübingen.

**Drones:** the next in line seems to be drones, whether for surveillance, package delivery, military use, or commercial taxi services, as recently advertised and researched trends suggest. All of them are targeting specific applications based on the simple fact that batteries are too restrictive and could have major issues with recharging when on a battlefield or airborne with insufficient operating range. Plug Power and Ballard Power Systems are among the candidate suppliers.

**Airplanes:** how airplanes will deliver zero-emission tailpipe solutions and by when in the future remains to be seen, but programmes are underway to try out e-fuels as well as hydrogen. For smaller jets travelling up to 800 km, gaseous hydrogen may be a valid option, while for larger planes with 8,000 kilometres of operating range, for example a Boeing 737, the focus is on using liquid hydrogen due to the limited space and storage system requirements.

Off-road applications, such as excavators, scrapers and cranes, are added to the list on a regular basis. Most OEMs already recognised this opportunity some time ago (notably forklift manufacturers) or just recently (for example, major truck and excavator OEMs). Sometimes the drive to do so is different depending on how the markets are organised or how the business plan is generally set up. An example would be the case of forklifts in the US. The frequent changes of batteries in huge warehouse facilities seem to be more time-consuming than filling up the hydrogen tank once a day. The productivity gains, otherwise marginal in other applications, is tilting the needle in favour of hydrogen. This is also valid for large container cranes in ports, where a good number are working both day and night.

**Challenges**

As much as the world has been longing for green hydrogen to make the energy transition really happen, the many known obstacles to success, each of monumental dimension, have fuelled a sense of disbelief. Not surprisingly, for those following the sector, it is obvious that all Member States must pledge their political support, and even then, vast amounts of funds will be needed, together with a battery of accompanying measures.

Somehow, in the summer of 2020 – which we will all remember as a war-like, health-threatening period characterised by humanitarian and economic dramas due to the COVID-19 pandemic – it all came together. Facing a devastating death toll and hardship for hundreds of thousands of people, Europe came to the conclusion that the only way to recovery is to merge economic efforts and financial burdens to mitigate climate change, foster innovation, and create jobs. Understanding how this would translate to the energy and more particularly the hydrogen sector made me discard all earlier reservations.

The blueprint for how and to what extent hydrogen will play out in the automotive sector at large has, however, changed rather dramatically. Whereas it was initially thought to be the playing field of major automotive, read ‘car’, manufacturers, the shift is now certain, with priority being given to commercial vehicles and applications. This shift may be deployed by many of us, myself included, as the car industry needs to stand out, lead the way, and show how industries can cope with the new world by helping build it. As it stands, it will be difficult enough to keep the car industry alive, as many work forces will depend on its survival. In Germany alone, as many as 800,000 workers. If survival comes with a temporary or even definite setback by excluding fuel cells in private cars, so be
it. As long as zero emissions and certified CO₂ mitigation in real-life conditions are the result achieved, the hydrogen fanatics will live with this.

Acting today as if it were already a done deal would be premature and perhaps naïve. Given that the availability of hydrogen at the place of use at affordable, read ‘competitive’, prices is a work in progress, it makes sense to elaborate on some of the remaining challenges: safety, infrastructure, and cost.

**Safety (researched and narrated by M. Pecqueur)**
Hydrogen as a fuel is a safe and ecological solution without any risk to our environment or the climate.

For many people, hydrogen will not appeal to the imagination. Mendeleev’s table contains elements that are much more mysterious, or that at first glance seem a lot more interesting than hydrogen. Even so, since my first encounter during chemistry classes, I have had a strong bean for hydrogen because it is a fascinating fabric with some special properties.

In order to work safely with a substance, two things are essential: human behaviour and substance properties. We record human behaviour in procedures and protocols that must ensure safe storage, correct handling, and risk-free use. We design those procedures and protocols on the basis of the substance’s properties.

Hydrogen has the highest possible energy content by weight of all energy carriers. In practice, it boils down to a hydrogen car consuming about 1 kg of hydrogen per 100 km. This high energy density makes hydrogen very interesting for aviation. A Boeing 747 now flying from Paris to New York consumes 110 tonnes of fuel. If we were to replace the engines with hydrogen engines, consumption for the same flight would drop to 36 tonnes. That means that the aircraft could carry 74 tonnes more cargo. That is therefore – together with zero emissions – the strongest asset when using hydrogen as a fuel in aviation.

Hydrogen also has the highest possible laminar flame velocity. That is the speed of a flame in open space without the influence of movement of the gas. If you set a newspaper on fire, the flame will move relatively slowly. This is because the laminar flame speed of paper is low. Thanks to the high flame speed of hydrogen, combustion is very fast. This gives engines greater efficiency.

The auto-ignition temperature of hydrogen is remarkably higher than that of methane (natural gas) and petrol. Hydrogen therefore ignites spontaneously at a higher temperature than those two substances. This means, in concrete terms, that it is more difficult to ignite hydrogen compared to methane and petrol if you work spark-free.

The stoichiometric ratio is the ideal ratio for burning a fuel. It is the ratio at which you get maximum energy from your mixture and yet fully use up all the available fuel. The stoichiometric ratio between hydrogen and air is very high, at almost 30% by volume compared to methane and petrol. Due to its low density, hydrogen in open space will quickly drop below the 4% ignition limit, making it nearly impossible to reach that 30%. In the free atmosphere, it is difficult to ignite hydrogen. And, if you succeed, the ignition will never be optimal because the ideal ratio of 30% in the free atmosphere is unfeasible.

The golden rule for hydrogen? Make sure it doesn’t get trapped. Hydrogen escapes very quickly and can be released into the atmosphere without impact on the environment and climate. There, it is almost impossible for flammable mixtures to form. The hydrogen safety strategy must therefore be aimed at preventing the build-up of hydrogen in a closed space. A leak detection system must immediately detect any leak and ensure the safe discharge of hydrogen to the outside.

Like all gases, hydrogen has a lower explosion limit, or LEL value. That is the flammable concentration of the gas in the air expressed as per cent by volume. The lower explosion limit of hydrogen is 4% by volume. To ensure safety, it is recommended to install sensors that give a signal when 10% of the LEL value has been reached.

Pipes that transport hydrogen are always in an enclosing or other protective conduit that opens onto the free atmosphere.

What happens if there is a leak in the pipe? All valves in the system will close, so that no more hydrogen flows from the storage tank to the fuel cell or the engine. The sheathing protection conduit ensures that the gas does not escape but is instead discharged into the free atmosphere.

Filling tanks of industrial vehicles, such as buses and forklift trucks, with hydrogen takes place under a pressure of 350 bars. In passenger cars, this pressure is 700 bars. Due to the particularly low density of hydrogen – even at this pressure – you can fill the tank of an industrial vehicle with about 21 kg per cubic metre and the tank of a passenger car with 40 kg per cubic metre.
Filling a passenger car tank with hydrogen under a pressure of 700 bars has consequences. During refuelling, the car and the refuelling system must communicate with each other continuously. This is done via an infrared link to the filling pistol. The car informs the filling system of the pressure and temperature in the tank, which then adjusts its delivery accordingly.

What happens if the temperature in the tank rises too fast? The refuelling system adjusts the speed at which refuelling takes place in order to improve the maximum temperature and maximum pressure of the tank. This guarantees safety with every refuelling.

The tanks used in passenger cars and industrial vehicles are also not standard tanks as with other gases, such as natural gas or LPG. They are composite tanks that can withstand high pressure. Metal tanks are not an option because the molecules of hydrogen penetrate into the crystal structures of metal. This phenomenon is partly responsible for cracks in the reactors of nuclear power plants. No matter how thick you make the wall of a metal tank, if you wait long enough, hydrogen will find its way out. Composite tanks, on the other hand, have an adapted inner wall and are impermeable to hydrogen. They undergo a series of tests for their homologation.

During a burst test, a tank is tested for its resistance to a pressure much higher than normal pressure. A tank for a passenger car is subjected to a pressure of 1,000 bars. This ensures that the tank will remain intact under all circumstances. With a crush test, it is then determined whether a tank can withstand a serious crash. During such a test, the tank is exposed to a force of 1,500,000 newton. In other words, it must be able to withstand a weight of 150 tonnes. A bonfire test then serves to prove that the tank is fire-resistant. During the test, the tank is placed in an open fire. To prevent a tank from exploding when the temperature increases, it is equipped with a safety valve that allows the hydrogen to escape when the maximum temperature is reached. Finally, in a gunshot test, a 7.62 mm projectile with an impact speed of 853 metres per second is fired at a tank, which must not tear or burst.

In other words, the pressure resistance of a tank is an important parameter in the storage of hydrogen. Sometimes, hydrogen is also stored in liquid form. In this case, there is not so much pressure resistance, but temperature is a major challenge.

To liquefy hydrogen, the temperature has to drop to 20 degrees Kelvin or -253 degrees Celsius. This means that a tank must be extremely well insulated.

The part of the tank that does not contain hydrogen is filled with gas. As you consume hydrogen, the level of liquid hydrogen in the tank drops. The consequence? The pressure in the tank also drops. As a result, part of the liquid hydrogen will evaporate, resulting in a temperature drop in the tank. So, with consumption, the problem of a warming tank does not exist.

What if there is no consumption? The temperature in the tank will inevitably rise over time under the influence of the outside temperature. This rise in temperature will cause an increase in the pressure in the tank. There is then only one option left: let the hydrogen escape from the tank.

Liquid storage of hydrogen will increase in the future. At 71 kg per cubic metre, it is the most condensed form of hydrogen storage. Liquid hydrogen will play an important role in aviation in particular. Just think of the European Stratofly project in which hypersonic liquid hydrogen aircraft will fly around the world at speeds of up to 9,500 km per hour.

The safe storage of hydrogen, like all other substances, involves special points of attention. Because hydrogen is stored under high pressure or at a low temperature, these points of interest are different from those of more traditional fuels such as petrol, diesel, ethanol and methanol (natural gas). There are similarities to the storage of natural gas, but the storage of hydrogen remains an exception due to the specific and deviating properties of the substance.

I just want to emphasize that hydrogen is no stranger to us. On the contrary. It has been used in industrial applications for over a century. We therefore have experience and expertise in handling this gas. The use of hydrogen in hydrogen vehicles does not present any additional risk to users or the environment. Moreover, an accidental escape of the gas into the atmosphere has no impact whatsoever on our environment or the climate.

**Infrastructure**

Fuel cell cars, but where are the refuelling stations?

The hydrogen opponents will not hesitate to point out that there are no refuelling stations around, and consequently, no one is buying fuel cell cars. Another chicken-and-egg controversy and one that nobody can ignore.

The infrastructure for hydrogen is being deployed through a multitude of programmes, starting with H2 Mobility focusing on Germany and the UK with a plan to have 100 filling stations in operation by the end of 2020. Speed is picking up.
In the US, California has regained pole position in terms of deployment, aiming to have 400 stations in service by the end of 2023.

In Japan, Prime Minister Shinzo Abe is committed to building a hydrogen society, even if the hydrogen is not locally available. The number of filling stations will extend from 160 in 2021 to 320 in the next 5 years, enough to fuel 40,000 cars and buses in 2020, to showcase hydrogen as the energy carrier of the future, starting with the Tokyo Olympics. Toyota is planning to have 30,000 hydrogen cars on the road and signed up for a subsidy programme valued at 400 million euro.

Total has made major inroads in California and is now directing resources to Europe. So are Air Liquide in France, Shell in the Netherlands, and Linde in Germany and Austria.

As of today, 87 hydrogen refuelling stations are in operation in Germany. The European Commission’s Sustainable and Smart Mobility Strategy of 9 December 2020 plans to build 1,000 refuelling stations by 2030, half of which are due to be built by 2025. In the USA, 42 stations will be operational shortly, almost all of them in California. Do not forget that heavy-duty applications (buses) use 350 bar pressure while passenger cars go up to 700 bar pressure. Smart buffering and suitable hardware for both applications at the same service point at the stations will help alleviate and resolve the issue.

The EU’s Fuel Cells and Hydrogen Observatory (FCHO) provides statistics, facts, and analysis covering the entire hydrogen sector and is a reliable source of information on all hydrogen mobility aspects.

Faced with one of the key questions about the tank infrastructure for hydrogen vehicles, several magazines on hydrogen have been digging for answers lately. The progress made between early 2015 and today is overwhelming, as the number of stations has quadrupled. The grand total of publicly accessible hydrogen stations at the end of 2019 was about 432, with Asia (Japan and South Korea in particular) and Europe (Germany and France notably) each having about 180 stations.

Cost and Competitiveness

The question of when the total cost of ownership (TCO) of hydrogen vehicles will be competitive compared to current, more polluting technologies is probably the most difficult and most tricky one, but it is essential to their future success. Not only are there a lot of variables, both known and unknown, but there is almost always a twist in the approach to providing the answer.

Among the known variables is the impact of material costs and their volatility in terms of volume and risk, the future cost impact of CO₂ allowances (well-to-wheel), the cost of warranties and the many different production methods, given local preconditions and circumstances, as well as distribution and recycling costs.

A very detailed recent study entitled ‘Path to hydrogen competitiveness – a cost perspective’ commissioned by the Hydrogen Council, provides expert insight into several aspects of the cost factors, not least the big drivers of cost reduction, as well as the timeline for cost competitiveness for the different applications. Of the 40 hydrogen technologies and 35 different applications, I have opted to summarise the ones related to transport.

In general terms, the study concludes that scaling up the hydrogen value chain is the biggest cost-reduction driver. At a manufacturing scale of 600,000 vehicles per year, the TCO will fall by about 45% compared to today’s cost level. Up to 70% of cost reductions for transport applications are from scale-up of manufacturing equipment.

The timeline for transport is particularly interesting. In the immediate future (before 2025), the applications most likely to offer competitive alternatives, or other operational buyer incentives, are:

• Regional trains
• Heavy-duty trucks (long haul)
• Medium-duty trucks
• Long-distance coaches
• Regional urban/intercity buses
• Taxi fleets

Taking a close look at the drivers of cost reductions in heavy-duty transport, one needs to understand the composition of the TCO. About 45% of the TCO is the cost of hydrogen, 30% hydrogen distribution, 23% equipment capex, and 9% other opex. The cost reduction levers for reaching the targets are 50% through scale-up of the supply chain and the industrialisation of fuel cell and hydrogen tank manufacturing.

Hydrogen trucks and long-distance coaches will likely achieve cost parity before 2025, mainly because the full battery alternatives fail to meet commercial vehicle requirements due to the high cost and heavy weight of the batteries (reduction of payload) and the long recharging times.
For urban buses, hydrogen is likely to remain more expensive than comparable battery-electric solutions, on condition that the duty cycle (topography, number of stops, daily mileage, climate zone, passenger capacity, etc.) and other operational requirements do not switch the technology of choice in favour of the fuel cell bus. Operators who have to either recharge during the day or buy more buses to meet the same passenger capacity demands are better off with fuel cell buses. The exception to the rule for urban buses is the so-called tram-bus rapid transit (RT) systems. Reference is made to 25 metre long double-articulated vehicles, with a capacity of up to 160 passengers. Their use as an alternative to light rail (narrow track and width, no flexibility, and requiring huge capex investments) or to trolleybus systems makes the fuel cell tram-bus an ideal adversary with a TCO that is highly competitive. Such RT systems are already in operation in Pau, France, and Austria.

For passenger cars, the findings in the study reveal that taxi fleets and SUVs with range requirements of 500 to 650 km are probably the earliest competitive markets. For the mid-size car with a 400 km range requirement, fuel cell cars are expected to achieve cost competitiveness around 2030. Urban cars with 200 km ranges are not expected to achieve cost parity before 2040.

Why the Future for Hydrogen and Fuel Cells is HERE. NOW.

A Hydrogen Strategy for a carbon-neutral Europe

‘Europe is at the vanguard of the hydrogen economy’ says Dr Fatih Birol, Executive Director of the International Energy Agency.

The objectives of the European Climate Law for a carbon-neutral society by 2050, writing the European Green Deal into law, and the largest-ever stimulus package following the COVID-19 Recovery Plan are tied in together.

Without copy-pasting the text of the European Commission’s Communication of 8 July 2020 on the hydrogen strategy for carbon neutrality, it is not short of ambition and vision, two characteristics which signal a thorough understanding of its mission: meet at least 14% and up to 25% of the total energy needs in the EU, while contributing substantially to the climate-neutral goal of the Union. To achieve this upper-level objective, a total of 150 billion euro in subsidies and as much as 470 billion in investment will be needed by 2030, followed by up to 10 trillion by 2050.

The roadmap towards hydrogen ecosystems by 2050, as targeted by the Commission’s Communication, outlines the following phased deployment:

- **Phase 1 (2020-2024)**: 6 gigawatts (GW) of renewable electrolyser capacity or up to 1 million tonnes of green hydrogen, scaling up both capacity and fuelling stations. Large refineries, steel, and chemical plants as well as commercial on-road vehicles are targeted markets.
- **Phase 2 (2025-2030)**: at least 40 gigawatts (GW) of renewable electrolyser capacity or up to 10 million tonnes of green hydrogen. Steelmaking plants, trucks, rail, and maritime applications, together with energy system integration into hydrogen valleys and EU-wide logistical infrastructure (pan-EU grid).
- **Phase 3 (2031-2050)**: maturity and competitive green hydrogen at a large scale in all sectors, including hard-to-decarbonise ones, such as aviation, shipping, and industrial buildings.

As for the mobility sector, it is flanked by EU Directives, all of them revised or in the process of revision, such as: the Renewable Energy Directive (known as RED II), the Alternative Fuel Directive, and the Clean Vehicle Directive.

This Communication from the Commission is a remarkable document that is already being considered as the cornerstone and the tipping point for hydrogen to become a priority-one category, for the following reasons:
The first, and perhaps most important, one is the financial investment plan of up to 470 billion euro, with emphasis on scaling up electrolyser capacity to a staggering 40 gigawatts (GW) by 2030, establishing transport networks and hydrogen pipelines, and growing the refuelling infrastructure.

The second, and perhaps most promising, one is the belief that only an integrated approach can be successful in developing production, distribution, and markets at the same time, gradually but expediently, to meet climate objectives.

The third, and perhaps most striking, one is that it acknowledges that money alone is not enough. This major endeavour is bound to fail if not accompanied by innovation, cooperation between Member States, and support for Important Projects of Common European Interest (IPCEI) as well as international cooperation through the International Partnership for a Hydrogen Economy (IPHE) and Africa-Europe Green Energy Initiative.

The fourth, and perhaps most remarkable, one is the inclusion of supporting measures, such as the need for EU-wide certification of low-carbon and renewable hydrogen, a common low-carbon standard on full life cycle GHG performance, a carbon border adjustment mechanism to ensure competitiveness with imports, revisiting state aid and competition frameworks when it comes to reducing subsidies to polluting industries and supporting carbon-neutral industries, revising the emission trading system (ETS), increasing carbon prices, lowering break-even for zero-emission technologies, imposing minimum shares of quotas for low-carbon or zero-carbon products, and introducing carbon contracts for difference (CCfD). Wow.

The fifth, and perhaps most humbling, one is the recognition of diversity between almost all the Member States when it comes to the ways in which their respective contributions can help reach the decarbonisation goals of the Union. With the historic experience that diversity constitutes an open invitation for the Member States to act as they see fit, the supervision by the EU and the control of strict adherence to national plans will be of prime importance.

To flank this ambitious EU strategy, and amidst all restrictions following the COVID-19 pandemic, a total of five National Hydrogen Plans and Green Hydrogen Roadmaps were approved and publicly launched in the summer of 2020:

**Netherlands**: April 2020 – Investment: 9 billion euro – 3-4 GW electrolysers by 2030

**Germany**: June 2020 – Investment: 9 billion euro – 5 GW electrolysers by 2030

**Spain**: July 2020 – Investment: 8.9 billion euro – 4 GW electrolysers by 2030

**France**: September 2020 – Investment: 8 billion euro – 6.5 GW electrolysers

An additional 11 countries are in the process of setting out their hydrogen plans, the majority primarily targeting industry and transport.

On 17 November 2020, on the brink of leaving the EU common market without a trade agreement, the UK announced a 10-point Plan for a Green Industrial Revolution that will mobilise 12 billion pounds of government investment to create 120,000 green jobs, putting green hydrogen very much on the agenda by quadrupling offshore wind, generating 5 GW of low-carbon hydrogen, aiming to develop the first town heated by hydrogen by the end of this decade, investing in zero-emission public transport, supporting manufacturers, accelerating the transition to more electric vehicles, transforming the infrastructure, and becoming a world leader in carbon capture.

The 2x40GW Green Hydrogen Initiative (of which 6 GW is a captive market) by Hydrogen Europe is designed as a roadmap for 40 GW electrolyser capacity to produce green hydrogen in North Africa and Ukraine by 2030, at a competitive cost compared to grey hydrogen.

To support those ambitious plans, a complete arsenal of instruments needs to be in place, including the European Development Fund, European Cohesion Fund, European Trading System Innovation Fund, European Regional Development Fund, InnovFin Energy Demonstration Projects, investEU, and the European Investment Bank. This is an impressive myriad of tools, perhaps too many, as it will take time and expertise to find out who is responsible for what and how to access the instruments that are most effective. Small and medium-sized companies and individuals, who are very much welcomed, if not mandatory, in all of the projects may give up the discovery process before it even starts unless there is a coordinating agency that takes over the burden of allocating and managing their applications.

For those who do wish to participate in an EU-funded programme or make use of the many tools available, I can share my experiences in EU-funded demonstration programmes in urban transport (Programme Framework 7):

- **High V.LO-City**: as the project coordinator and the supplier of the buses to: First Group through Aberdeen City Council, Scotland; De Lijn, Antwerp, Belgium; Riviera Trasporti, Sanremo, Italy; and Qbuzz, Groningen, Netherlands.
- **HyTransit**: as the supplier of the buses to Stagecoach through the Aberdeen City Council, Scotland.
Following a detailed study undertaken by Roland Berger Consultants in 2015, it was established that a more aggregate programme for potentially 300 fuel cell buses would drive the cost down in support of the attractiveness of buying fuel cell buses. In view of the far-reaching implications for the budgets, it was decided to have two consecutive programmes, commonly known as JIVE1 and JIVE2. This has resulted in order numbers ranging from 10 to 35 units per order, as well as new bus operators and cities that could benefit from the overall market uptake. RVK Cologne and Aberdeen, as an example, have already chosen to build their up their fleets with fuel cell buses, extending the numbers to well over 50 units. This has resulted in the price dropping about 30% from the previous programme. It has undoubtedly set the trend for pre-commercial products and considerably fuelled the appetite of many first users and potential users, leading to a good number of competitors in the market, both old and new, such as Solaris, VDL, SAFRA, and Caetano, as well as Asian players, such as Toyota, Hyundai, BYD, Yutong, and others. Even the big EU players, such as Mercedes, are no longer reluctant to tell the world that a hydrogen version is due sometime in the first half of the decade, be it as a range extender or, as the case may be for MAN, with a version of an ICE (internal combustion engine) running on hydrogen. With the acquisition of a majority stake in H-TEC SYSTEMS early this year by substituting the shares of GP JOULE, MAN is the latest name in the truck and bus industry to show their interest in pursuing hydrogen and fuel cell solutions in heavy-duty transport applications.

We shouldn't forget that the electric trolleybuses that have remained popular in countries like Italy and many of the East European countries have now discovered the option of having a fuel cell on board as an APU (auxiliary power unit) instead of the polluting diesel APU on a clean electric bus. With adequate autonomy, trolleybuses can now leave the central catenary lines and venture emission-free through the city streets without any form of additional infrastructure.

The projects I was able to help put together by signing up many of the industrial players, partners, and third parties, as well as assuming the task of coordinator, was a unique professional experience.

The Fuel Cell Bus demonstration programmes have set an example of what can only be achieved in the bigger scheme of things: mitigate dramatic consequences of climate change, ensure energy independence, and help enterprises to achieve leadership, objectives that no one industry and no one country or Member State can fulfil on its own. Cooperation between nations, individuals, small and medium-sized enterprises, large corporations, and knowledge centres and institutions is necessary to achieve such overarching common goals, with this important add-on: the contribution from the EU does not end by informing, studying, developing, regulating, or even subsidising. Europe contributes literally to all aspects necessary for creating self-sustaining commercial markets, including the risk of failure. It is a good example of how ecology and economy go hand in hand in order to achieve higher objectives, creating jobs and economic prosperity at the same time. So, the first and foremost question is whether your project, product, or service is intended to serve a bigger purpose. If not, it is really not worth the trouble.

Here is what I have learned in the process.

Already during the early stages of the EU programmes (CUTE), I discovered that the calls for proposals, launched and published by the FCH JU, were not following the same process as the commercial tenders I was used to. I was in disbelief that this process was working against the basics of the Union objectives, i.e. creating open competition under the EU public procurement rules that were designed to create a level playing field for all businesses across Europe.

A semi-formal complaint about our presumed inability to bid in the early calls for proposals led to a series of contacts with the tendering agencies and a bunch of lawyers, explaining why and how calls were to be handled if anyone wanted to be successful in the search for new developments and applications. I vowed to be successful the next time around.

The difference in definition and approach between open tenders and awarded bids in demonstration projects helps explain the distinction: a commercial tender is published by a (mostly public) entity to select a service provider for a specific product or service and for their internal needs.

By contrast, a call for proposals in a PPP or public-private partnership context, is published by institutions with the purpose to contribute to and support innovative products that meet the strategic needs as set out by the EU. When successful, the winning bidder (consortium) will be awarded a contract to deliver, and the consortium partners will receive a contribution for the work performed in accordance with the work plan. The EU contribution covers only a percentage of the eligible costs (mostly less than 50% of the total budgeted cost), with the
balance being funded by other sources or own funds. This allows for the uncertainties in a joint venture for a new product and the risk involved in achieving the objectives set out in the project tender.

With this understanding, it was still not obvious to many of the participants and partners in the consortium and their legal departments whether or not they could by-pass the EU and national procurement laws by just placing orders for goods and services with other partners in the consortium without any form of competition. In reality, some did, but others did put out a procurement tender as it was not forbidden to do so. When it came to developing and demonstrating new technology and opening up new markets, the major part of the risks was assumed by the partners themselves, both financially and operationally. In addition, it was never a completely closed deal amongst the partners: the definitions, the project objectives, the key performance indicators (KPIs), including minimum technical performance and availability as well as price ceiling targets, together with project milestones, risk assessment, financial reporting and dissemination activities, within the confines of the agreement, were sufficiently stringent and burdening as it was, without any competition framework. Add to that the standard condition that the consortium needs to include companies and institutions from at least three Member States and small and medium-sized companies as well as knowledge centres. An EU project with total investments running over 20 million euro as it was is no walk in the park for anyone involved. This is probably the biggest misconception of EU projects.

The second pitfall was the selection of the partners and their credibility. The composition of the consortium is vital to the success of the project. To avoid mistakes, check your partners carefully before signing them up in the consortium, whether you assume the responsibility of coordinator or of partner. The qualifications should include their technical and financial capabilities but also, and more importantly, the level of their understanding of the project rules, not least the extent of the administrative burden. Most of the time, many partners from different Member States are new and unaware of the implications. It is a common mistake to presume that they are knowledgeable because they qualified on the related EU website by filling out a form. Of course, you want to win the tender, but not with your eyes closed. The worst thing that can happen is a partner who believes that, by receiving EU funding, its company will be back in business in no time, especially when it is ailing already at the time of signing up. Given the limited time frame before submitting the bid from the publication date of the call, to screen and approve 10 or more partners is no sinecure. Nevertheless, it is vital.

Speaking as a partner-supplier, two other caveats to a successful project are worth warning about: the time required between signing the grant agreement and placing or commissioning the order. In my experience, at least 12 to 18 months elapsed before starting to execute a supply contract. With most of the projects having a duration of 5 or 6 years, starting from the signing of the grant agreement, the time for ordering and the time for building resulted in the teething period of the operation starting after 24 to 30 months. This means that no data, no cost allocation, no depreciation, no reports, no dissemination, and basically no payments were to be expected within the first half of the project duration. With intermediate milestones defined within that period, the first periodic report will show dramatic shortcomings. The reason, quite understandably, was that, to find and secure co-funding, write technical requirements, approve procurement tender documents, publish tenders, receive and compare bids, and submit and obtain necessary permits and planning approvals (especially when it comes to building hydrogen infrastructure), it typically required months and months of preliminary work. Even with dedicated project leaders and operators, many of which were proponents embracing the new technology, the process was nothing short of frustrating.

Another drawback with the early introduction of fuel cell buses into fleets related to operators of the vehicles. Operators that were not a named partner in the consortium and had to find out through the press or contacts with the city or regional agencies who did sign up were not amused by the prospect of having to cope with a new type of bus, this only adding to the usual worries of their operation. The expectation that this new technology would foster more problems in the battle to survive was a prelude to disappointment from the moment the spotlight on the proud politicians dimmed. Only those operators that understood their mission embraced the new technology and handled it with utmost care.

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I have considered the idea of providing information together with my own assessment of all the key players, but that seemed too optimistic. Not only would it take time and effort to try to capture their ‘reason for being’, but reading would not help you to fully understand their roles and vocational value. I have therefore decided to give an overview of the main actors, in addition to commenting on those that are most relevant for the mobility sector, since this is the subject of this book. I also recommend contacting them directly, as they have an interest in seeing as many companies and organisations as possible convey the message.
Hydrogen Europe (www.hydrogeneurope.eu) is the most influential European association representing the interest of the hydrogen and fuel cell industry and its stakeholders, with hydrogen being the enabler of a zero-emission society. With more than 160 companies, 78 research organisations, and 25 national associations as members, the association encompasses the entire value chain of the European hydrogen and fuel cell ecosystem collaborating in the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

Hydrogen Europe serves two main goals. As a trade association in the traditional sense, it plays a crucial role in promoting best practice, helping companies become more competitive, and formulating effective public policy. Hydrogen Europe acts as a coordinated voice of industry and research when talking to policymakers and offers great value in terms of disseminating messages about regulatory decisions and policies to members. In innovation, the association partners with the FCH JU.

I had the opportunity to witness their professional dynamism in convincing the world that green hydrogen is key to the energy transition and that the sector coupling (wind, solar, gas) in combination with developing selective market applications (transport and greening of industry) is the best way forward. In that respect, it is safe to say that the dedication and high-level professional work of the Hydrogen Europe team were paramount in the drafting of the Green Deal objectives and the Green Hydrogen Strategy.

Fuel Cells and Hydrogen Joint Undertaking (https://www.fch.europa.eu/) is a unique public-private partnership supporting research, technological development, and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realising their potential as an instrument in achieving a carbon-neutral energy system. The FCH JU under Horizon 2020 has a total budget of 1.33 billion euro, provided on a matched basis between the EU, represented by the European Commission, industry, and research. The projects under the FCH JU will improve performance and reduce the cost of products as well as demonstrate on a large scale the readiness of the technology to enter the market in the fields of transport. The FCH JU issues calls for proposals, approves or refuses the bids made by industry and research centres, and administers the related EU funding programmes.

Whereas the FCH JU was responsible for all hydrogen projects in the past, the calls for proposals for innovative end-user products and their market entry related to all zero-emission transport segments (battery as well as hydrogen) will now be governed by the 2Zero Partnership, one of the six newly established partnerships. It builds on the European Green Vehicle Initiative (EGVI) and the work done earlier for the introduction of the battery-electric vehicles.

The Fuel Cells and Hydrogen Observatory (FCHO) (www.fchobservatory.eu) provides data (statistics, facts, and analysis) and up-to-date information about the entire hydrogen sector. The FCHO focuses on technology and market statistics, socio-economic indicators, policy and regulation, and financial support. Funded by the FCH JU, the Observatory has been created for the use of policymakers, industry stakeholders, and the general public.

The European Clean Hydrogen Alliance: following the successful example of the European Battery Alliance, the European Clean Hydrogen Alliance is an initiative that brings together industry, representing the whole hydrogen value chain, public authorities, research and innovation community, civil society, and other key stakeholders to facilitate the scale-up of renewable and low-carbon hydrogen production, distribution and deployment until 2030. The Alliance will mobilise resources to develop an investment agenda for the roll-out of production and use of renewable and low-carbon hydrogen and build a concrete pipeline of projects, through the following six round tables:

- **Renewable and low-carbon hydrogen production**, e.g. electrolysers, solar/wind/hydro, plant engineering, equipment, materials, carbon capture and storage (CCS) and pyrolysis
- **Clean hydrogen transmission and distribution**, e.g. pipelines, liquid organic hydrogen carriers (LOHC), liquid hydrogen (LH2) and ports
- **Clean hydrogen in industrial applications**, e.g. steel, chemical, refineries, e-Kerosene/e-Fuels, fertilisers, industrial heat and cement
- **Clean hydrogen for mobility**, e.g. trucks/buses, light-duty vehicles, trains, ships, fuel cells, drive trains, tanks and hydrogen refuelling stations (HRS)
- **Clean hydrogen in the energy sector**, e.g. re-electrification, mega storage and electricity grid/balancing
- **Clean hydrogen for residential applications**, e.g. district heating, combined heat and power (CHP) and solid oxide fuel cells.

It would be unjust not to mention the importance of the Hydrogen Council (www.hydrogencouncil.com) launched at the World Economic Forum in Davos in 2017, at a time when the future of hydrogen was very uncertain and definitely in need of a boost in terms of commitment by the business community worldwide. For the first time, this global initiative of leading energy, transport, and industry companies voiced a united vision and long-term ambition for hydrogen to be a part of the energy transition and pledged to invest considera-
ble financial means to achieve it. Their membership list grew from 20 founding members to more than 90 large corporations, together powerful enough to make the difference, including brands such as Shell, Siemens, BMW, EFD, Alstom, Michelin, etc. to just name a few.

**Best Practice Projects**

Any societal change of global proportions will need time and, more importantly, commitment. Pulling together the world’s largest and most renowned players, as mentioned earlier, is an absolutely necessary condition. While it is true that a large percentage of the projects die in their early years, mostly due to a lack of funds after the financial well has dried up, the current avalanche of game-changing projects deserves respect and recognition. I will focus on naming and briefly describing two in the Netherlands and an EU-wide pipeline roadmap launched by 11 European gas infrastructure companies in July 2020.

Currently, perhaps the most advanced and best articulated plan in Europe pertains to the Government Strategy on Hydrogen plan in the Netherlands, in line with the Dutch National Climate Agreement. The declaration states that “for the transport sector, hydrogen and fuel cells are crucial to achieving zero emissions. The scaling of green gas and hydrogen is essential.”

The motives of the Dutch government for this strategy paper are clearly laid out, well understood, and supported by a broad group of stakeholders in the country:

- First, an affordable, reliable and sustainable energy supply chain, considering that the Dutch economy has a high number of energy-intensive industries. Over 250 companies with operations in the hydrogen sector have been identified. The Netherlands can become the linchpin in that supply chain, using existing infrastructure for that purpose.

- Second, the Port of Rotterdam is currently acting as a hub for energy flows internationally.

- Third, the Northern Netherlands is being recognised as the first Hydrogen Valley of Europe, and an integrated approach with other regions, including Zeeland, Zuid-Holland, and Noord-Holland, is being developed.

- Fourth, the Netherlands, after Germany, is the largest producer of grey hydrogen in Europe, as about 10% of Dutch natural gas is used for the production of hydrogen, and comes with significant CO₂ emissions. Physically blending the natural gas with hydrogen, starting with 2% and gradually up to 20%, will result in cleaner natural gas.

There is no doubt that the Dutch strategic plan wants all hydrogen produced to be ‘green’, and the gaseous energy will need to provide at least one third of the total energy consumption.

In order to support said climate goals in the road transport sector, the National Climate Agreement, in a cooperation agreement with the stakeholders, is targeting the deployment of 50 hydrogen refuelling stations, 15,000 fuel cell vehicles, and 3,000 heavy-duty vehicles, which will be hitting the road by 2025, with 300,000 vehicles in total by 2030. Now that’s ambition.

With a clear plan that includes world players, North Netherlands secured the FCH JU’s approval for their ‘Hydrogen Valley’ project (under the acronym HEAVENN: Hydrogen Energy Applications in Valley Environments for North Netherlands), based on three main pillars: storage and infrastructure of hydrogen for the industry, turning hydrogen into heat and power for residential areas, and providing green mobility. In a public-private partnership, the total investment will be 90 million euro. This example of integration and sector coupling will most certainly be followed by other Member States and regions.

The second one is a joint project with Gasunie (subject to name change later), Groningen Seaports (GSP) and Shell Nederland, launched in March 2020, under the project name NortH2: the production of green hydrogen using renewable electricity generating between 3 and 4 GW in 2030, using a mega offshore wind farm and growing it to 10 GW around 2040. The green hydrogen produced is expected to amount to 800,000 tonnes and save about 7 megatonnes of CO₂ per year. With the planned production, the cost of green hydrogen is expected to reach 2.2 euro/kg by 2025 and drop to about 1 euro/kg in 2030.

The justification for this major project is both simple and obvious for the Dutch policymakers: “the energy transition calls for guts, boldness, and action. The neighbouring North Sea for the production of wind, the ports as logistical hubs, and the industry clusters in a highly densely populated area, make the switch to green molecules and a suitable transport network, self-evident.” It can hardly be said better. Perhaps it helps to have a dynamic and energetic fellow citizen assuming the role of European Commissioner and Vice-Chair of the European Commission, Mr. Frans Timmermans, who is known to be the intellectual father and the executive leader of the European Green Deal.
As mentioned earlier in Chapter 2, a truly European initiative emanates from 11 gas infrastructure companies from 9 Member States creating a dedicated hydrogen pipeline network of almost 23,000 km by 2040, to be used in parallel with the natural gas grid. The proposed network will run through Germany, France, Italy, Spain, the Netherlands, Belgium, Czechia, Denmark, Sweden, and Switzerland. The amount of electricity required to transport hydrogen over a distance of 1,000 km is equal to 2% of the energy content of the transported hydrogen, making it inexpensive relative to the anticipated size of the hydrogen market. Nevertheless, the investment cost estimate runs at the staggering amount of between 27 and 64 billion euro. The first 6,800 km, approximately, should be installed by 2030. With natural gas being on the expected return, it is relatively easy to transform them into hydrogen pipelines.

In Conclusion
It is true that there have been false starts for hydrogen in the past. This time, however, is different.

Recent reports thrive on the strong belief that we are getting there. And ‘getting there’ means creating the necessary conditions to produce, distribute and use clean hydrogen economically and competitively while substantially mitigating the climate change challenge. The words and expressions currently being published are adamant that we will achieve the final goal: the Hydrogen Society.

On 13 March 2020, the very day we were told to stay at home to limit the coronavirus’s devastating threat of deaths, as we found out only weeks later, H2Vision listed 10 visible signs that the promise of hydrogen is happening now. With some generalisation, the list can be reduced to five major ones:

- The belief among big corporations and their pledge for major investments and the structure of their commitment spearheaded by the Hydrogen Council. Putting your money where your mouth is has always been a tangible sign demonstrating the degree of seriousness. This is especially true for large conglomerates. They are much slower on the draw, as their best interest would be in just keeping business as usual for as long as possible and securing the investment and profits, rather than venturing into new and uncertain developments. Once decided on the next step, however, and given the time to act, big companies get on board with a vengeance. This is exactly what is happening with hydrogen, green hydrogen in particular.

  In early 2020, Toyota unveiled plans to build a city of the future, powered by hydrogen fuel cells at the base of Mount Fuji, called Woven City. It will be a living laboratory, populated by 2,000 Toyota Motor Corporation employees and their families, visiting scientists and industry partners. No wonder their President, Akio Toyoda, called it “my personal field of dreams”, with the prospect of selling many tens of thousands of next-generation fuel cell Mirai cars in the years to come.

- The build-out of infrastructure.

  Governments all over the world are now recognising hydrogen as critical to reaching their energy and climate targets and are rolling out long-term hydrogen strategies. They all seem ready to fight for their part of the action, as if the ‘hydrogen region of the world’ award is worth the contest. Prime Minister Abe proclaimed recently that “Japan will be the first in the world to realize a hydrogen-based society”. The postponed 2020 Olympics intends to showcase the hydrogen flame. Thousands of heaters in housing projects already run on hydrogen. Unfortunately, green hydrogen is currently imported from New Zealand and Norway.

  Five of the German Länder (Bremen, Hamburg, Mecklenburg-Vorpommern, Niedersachsen and Schleswig-Holstein) have developed a joint strategic plan to build up to 5 GW of electrolyser capacity.
The realisation of a large new 2,500 km hydrogen pipeline with 6 GW capacity, running from Egypt via Greece to Italy, requiring an investment of some 16.5 billion euro, will see about 7.6 million tonnes of hydrogen per year able to be transported. It would be beneficial to unlock renewable energy exports in North Africa if the countries of the Maghreb were to convert electricity into hydrogen and transport it via pipelines to Europe.

The sectors relate not only to transport but also, and perhaps more importantly, to energy, industry, and heating. Blending green hydrogen (up to 20%) in the natural gas network is being undertaken in the UK and France. Heating devices are now being upgraded and modified to burn hydrogen.

• The European Commission is now giving clear mandates to all the Member States, together with massive funds, expertise, and a vast number of accompanying policy measures designed to ensure that the GHG reduction objectives are being met, as detailed earlier.

• The production of hydrogen plants and hydrogen distribution networks are being deployed in a massive way. Whereas this kind of information was scarce and more of a prophecy a couple of years ago, just keeping track of the vast number of projects, agreements between countries, and agreements between energy and technology providers is a real challenge and is the very reason the FCH JU has embraced the initiative of commissioning an observatory to perform this task.

• Last and certainly not least, the international response to the invitation to join forces is encompassing the world. The type and scope of commitment by economic blocs, nations, regions, and their leaders, supported by the pro-active participation of all of the industry branches and of individual companies of all sizes, are overwhelming signs that the final breakthrough of all hydrogen is happening, here and now.

To provide a conclusion on the literally tons of information provided and projects created, it is hard to believe that hydrogen will not play an important part in our future, despite the fact that or maybe because our lives have been in jeopardy since March 2020 when COVID-19 came along for a global wake-up call of pandemic proportion. Perhaps it is not in spite but because of the COVID-19 pandemic that the world has finally understood that business as usual is no longer an option.

In transport, it is mind-boggling to see how new ventures and new applications are anxiously waiting, or jumping ahead, in the fuel cell-electric vehicle ranking. This will notably be the case for long-haul trucks, regional long-distance coaches, regional trains, military vehicles, both parcel and passenger drones, some marine vessels, and potentially even airplanes.

They are all offering the undeniable operational advantages of range and refuelling times. In commercial heavy-duty applications, these operational requirements are part of a purchase decision, in which lower energy efficiency compared to batteries is not the issue.

Finally, the future of hydrogen in transport is linked to the successful production and distribution of green hydrogen at a total cost of less than 1.5 euro/kg. The initiatives to ramp up the electrolyser capacity to dimensions of 50 and more MW are significant in opening up new markets worldwide for green hydrogen. Where and when necessary, green hydrogen can be transported in existing but upgraded natural gas pipelines and new dedicated ones over long distances throughout Europe, while excess production from renewables can be stored underground in caverns for longer periods of time.

The contest is currently on to become the best, biggest, and least expensive producer of green hydrogen. Efficient ecosystems, hydrogen valleys, and carbon-neutral regions are taking positions for a great start.

The realisation that there is no other way but the one that leads to clean transport, clean heating and clean industrial processes is making headway. It has reached the minds of the people, financiers, scientists, and industrialists. The belief that time is of the essence and time is running out is gaining momentum, which is vital if we want to secure the future of our children and grandchildren. These are not unknown people in a remote country but people we know and love, the ones that we want to protect by leaving them a liveable planet. Our generation is the one that has both the responsibility and the means to act. And we have only this one chance to do so.

Our generation has for too long lived in a world on wheels running on oil. With today’s knowledge of the negative side effects of fossil-based fuels, in terms of both human health risk and climate change, its replacement by a clean alternative is imminent. The ways that green hydrogen can be produced and distributed will enable products to be used in new applications in world markets both now and in the future. Green hydrogen is delivering on the promises the world needs.
To even think it is possible, in the very near future, that the world on wheels can and will be transformed into a world that is running on water seems as surreal as believing that humans will be able to fly on their own or that they will be able to go back in time. Yet, it is about to happen. And hydrogen, being the most abundant substance in the universe, is the enabler. With green and clean hydrogen on the planet, the circle will start to close. Mobility will still be a basic human right, and its users will be able to choose the ultimate climate-neutral way by RUNNING ON WATER. At long last.

Iveco Trucks (part of CNH) has teamed up with Nikola to design and build a fuel cell truck version for the EU market. (Website/Press Release)

HYZON has teamed up with Holthausen in the Netherlands to assemble its fuel cell truck line for the EU market in the Netherlands. (Website/Press Release)

Commercial truck applications and niche markets are among the targeted fuel cell applications in transport.

Iveco Trucks (part of CNH) has teamed up with Nikola to design and build a fuel cell truck version for the EU market. (Website/Press Release)
Mercedes Gen2 Concept Truck has teamed up with Volvo to develop fuel cell truck versions for each of the brands. (Website/Press Release)

Hyundai is supplying a vast number of fuel cell trucks to Switzerland following the concept that the OEM guarantees cost parity with diesel trucks including fuel, maintenance and the CO₂ penalty otherwise applicable to diesel trucks. (Website/Press Release)

Hyundai Nexo next generation SUV with fuel cell technology. (Courtesy of HE)

Toyota Mirai 2020 (Japanese for 'the Future') including better operating range and efficiency, readied for head-on competition with Tesla. (Courtesy of Toyota)
Alstom has developed a fuel cell electric train which is already being marketed after successful validation and testing in several EU Member States. (Courtesy of HE)

Siemens Mobility has developed a new platform – Mireo Plus – to test, build and deliver regional and local fuel cell electric trains. (Website/Press release)

Several FCH JU projects, such as CHIC, High VLOCity, HyTransit, 3E-Motion and Jive 1 and 2, have demonstrated the feasibility, the cost-down potential and the technology readiness of fuel cell buses for EU and world markets.
Wrightbus first fuel cell double-decker at Marshall College, Aberdeen City Council (Jive Project). (Courtesy of HE)

H2.0 is ADL’s next generation double deck hydrogen bus which will deliver a zero-emission range of up to 400 km. It will be powered by a Ballard Power fuel cell using the latest Voith Electrical Drive System. (Website/Press release)

Caetana Bus 12 m 2-axle fuel cell bus at a bus show (Jive Project). (Courtesy of HE)

Safra, France fuel cell bus with extra wheel at the rear end (Jive Project). (Courtesy of HE)
Celebration time: the vehicle fleet for Aberdeen City Council, operated by First Group and Stagecoach, has reached the Million Mile mark.

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With hydrogen already delivering on its promises to play an active role in both the societal and energy transition, Run on Water is a new publication that gives you every reason to act. Based on a true story of the power of determination and cooperation, it reveals and unfolds how change can be instigated as part of a business culture and what challenges the European automotive industry faces in playing a leading role in achieving the European Green Deal’s ambitious objectives. Comparisons with other parts of the world and important aspects of the big debate between batteries and fuel cells are not left out.

The book is based on the author’s life-long experience in the bus industry and as a coordinator of two major European fuel cell bus projects. The book contains documented lessons from the projects and insightful contributions from academia on new and exciting future developments in energy, safety, and automation.

The book is supported by Hydrogen Europe, the hydrogen association acting on behalf of its many international industries and research members.

“Hydrogen presents opportunities in terms of security of energy supply, job creation, technological competitiveness, and environmental protection for Europe. It can contribute to Europe’s industrial leadership in clean technologies, stimulate growth and pave the way for a more circular low-carbon economy.”

**Jorgo Chatzimarkakis**
Secretary-General of Hydrogen Europe

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