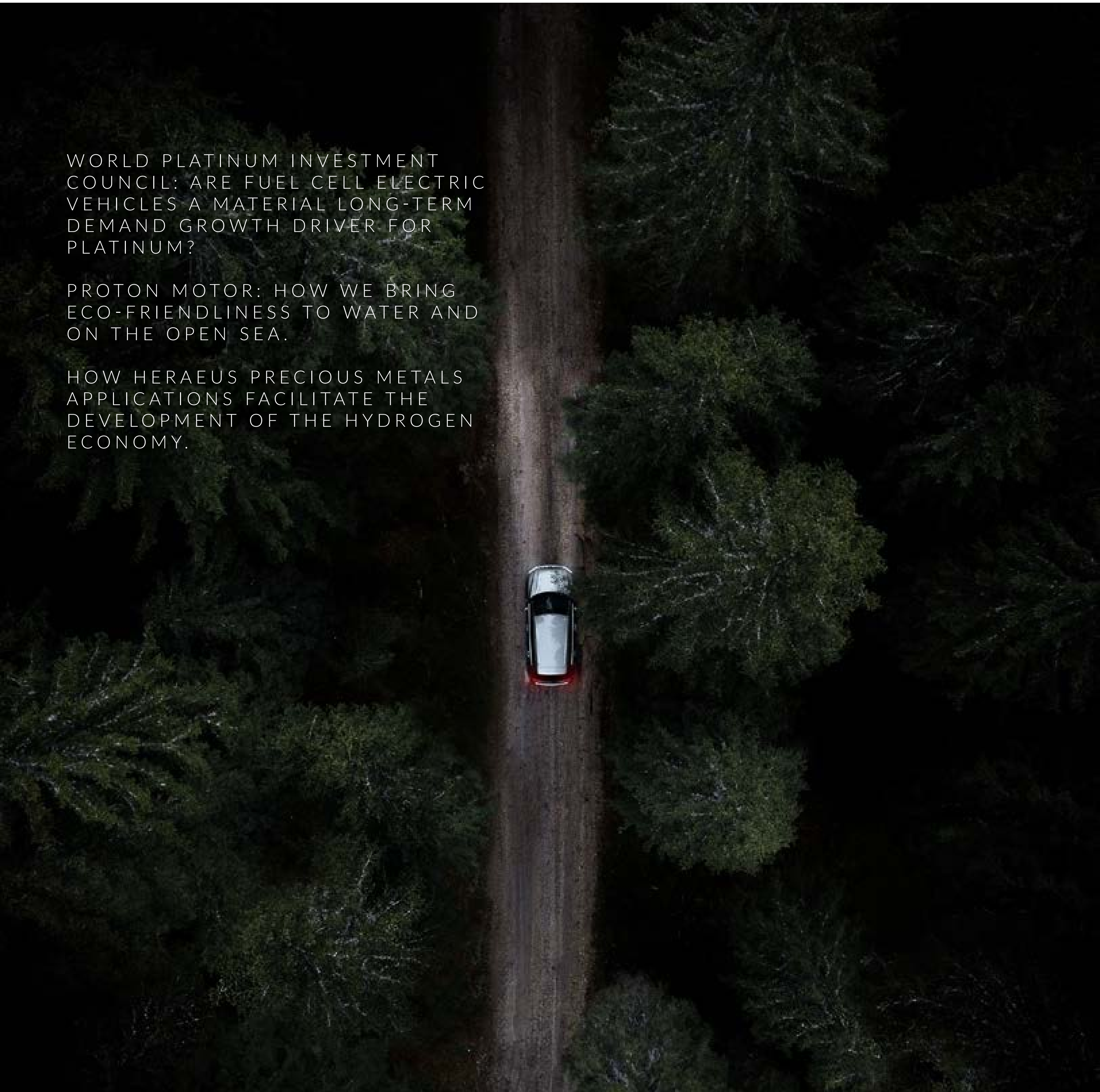
The Hydrogen Standard

The Leading Magazine on Global Hydrogen Developements

Q2 – 2022



WORLD PLATINUM INVESTMENT COUNCIL: ARE FUEL CELL ELECTRIC VEHICLES A MATERIAL LONG-TERM DEMAND GROWTH DRIVER FOR PLATINUM?

PROTON MOTOR: HOW WE BRING ECO-FRIENDLINESS TO WATER AND ON THE OPEN SEA.

HOW HERAEUS PRECIOUS METALS APPLICATIONS FACILITATE THE DEVELOPMENT OF THE HYDROGEN ECONOMY.

The Hydrogen Standard

The Leading Magazine on Global Hydrogen Developements

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A big thank you to all the contributors and everyone else who supports The Hydrogen Standard. We provide high quality content to provide a platform for all participants active in the hydrogen space to showcase their technology solutions and share their story.

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Welcome

Welcome to The Hydrogen Standard Magazine

The Hydrogen Standard provide insights into the developments of the hydrogen industry and how they interact with the wider energy and industrial markets. Through our various analysis you can stay up to date with the latest developments in the global hydrogen space.

This quartely publication covers various companies active in the space. It provides a platform to stay informed and get introduced with companies and organisations demonstrating their technological solutions.

Global Hydrogen Monitor is one of our other titles, and it is a monthly publication summarising the key developments in the global hydrogen industry. It looks at the main technological developments and breakdown of the key issues per major region.

China Hydrogen & Fuel Cell Monitor is also a title in our monitor portfolio. The China H2 & FC monitor provides a unique perspective into the inner working of the Chinese market. It provides insider access on topics related to hydrogen, fuel cells and e-fuels from an industrial and policy perspective.

A publication by
The Hydrogen
Standard

Welcome to the third issue of The Hydrogen Standard. The recent events in the geopolitical spectrum with the Russia/Ukraine conflict has had major repercussions on how governments, particularly in Europe, want to redesign their energy requirements. Europe is already at the forefront when it comes to countries actively developing a hydrogen roadmap and has the ambitious target the roll out 40GW of green electrolysis hydrogen production by 2040. Following the recent conflict and the dependence on Russian gas, those commitments could well be lifted further and/or accelerated in the coming years. And hydrogen is expected to play an essential role in this development.

Generating the hydrogen from green sources is however only one side of the equation. What is also essential in implementing a successful hydrogen value chain is the off-take of the sustainable produced hydrogen gas. Hydrogen is very versatile and can take many forms either for transport and/or storage. But consumption to date, particularly in the transport sector, is mainly focused on utilising it in gaseous form.

One application that lends itself particularly well for the use of hydrogen are fuel cells, which come in different forms. Of the various fuel cell options available, Polymer Electrolyte Membrane (PEM) fuel cells are most widely used. They lend themselves well for transport applications, an area where hydrogen consumption is likely to find a major consumer in the near future.

Fuel cells are complex systems and require expert knowledge to be developed and manufactured. In this issue we address the role of precious metals applications that facilitate the catalysis of fuel cells and the importance they play in this field. One area of constant attention is R&D of these systems in order to achieve lower costs and higher efficiency. In trying to achieve both, the role of precious metals are frequently addressed. Alternative solutions have been found but nothing up to this point, seems to do the role as a catalyst as well as platinum and/or iridium on both the electrolysis hydrogen production side as well as fuel cells.

That is only one part of a complex ecosystem where various operators are offering their knowhow and technological solutions. We try to bring those companies to the fore and make people aware that electrolysis and fuel cells are not the only game in town and that for example, companies occupying themselves with providing cooling solutions or pressure options are at the heart of the hydrogen economy too.

Editor,
Johann Wiebe

Johann Wiebe

Q2 | 2022

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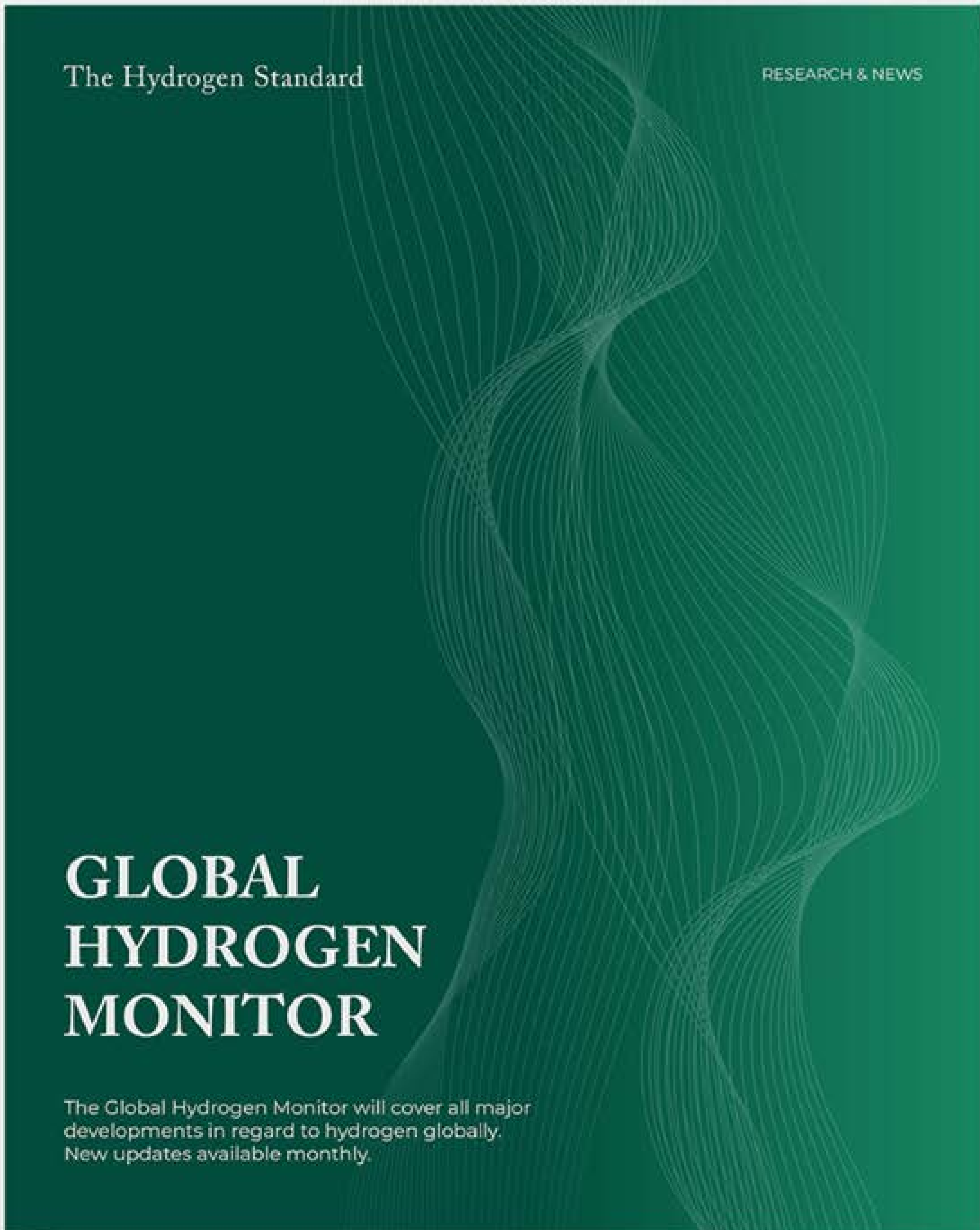
Global Hydrogen Monitor



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Company Profile

Proton Motor

Website

proton-motor.de

Point of contact for information exchange and inquiries about maritime applications: Sales Manager & Business Development Alexander Adrian, a.adrian@proton-motor.de, +49 / 89 / 127 62 65-1057.

Key Features

Focus: Integration-Ready Fuel Cell Systems
CEO: Dr. Faiz Nahab
Twitter: @protonMotor
LinkedIn: Proton Motor Fuel Cell GmbH

How we Bring Eco-Friendliness to Water and on the Open Sea:

Emission-free fuel cell drives from Proton Motor for maritime mobility.

Europe's leading hydrogen fuel cell producer Proton Motor Fuel Cell GmbH (www.proton-motor.de) enables ship and maritime manufacturers to implement climate-neutral fuel cell propul-sion systems in the inland and offshore sectors. The company specialises in modular systems "Made in Germany" and uses graphitic bipolar plates, as only these meet the technical and commercial performance requirements of the applications.

Emission-free mobility from customer-specific concept to certification.

The core components of the Proton motor systems are the high-performance fuel cell stacks developed in-house with their globally unique double integration possibility. Thanks to the modular system for hydrogen, air and cooling, specific requirements can be implemented quickly or can be easily delivered as pre-assembled "plug & play" solutions. Customers and partners are accompa-nied from concept development to implementation as well as throughout the entire product life cycle plus they will be qualified respectively certified on request. 25 years of electrification knowledge and a large supplier network from related technical areas, such as hydrogen storage systems, are also available.

New emission-free HyShip system for the green energy and mobility transition.

Since 1998, Proton Motor has bundled all areas – hydrogen fuel cell development and production as well as system assembly incl. testing – at one location near Munich. With over a hundred employees, fast, flexible structures are guaranteed. Precise, tailor-made service is ensured by our own maintenance teams. As a reliable supplier of alternative green drive technology, the company is excellently positioned for the future.

For example, the internationally active CleanTech specialist has a series production production plant and has successfully established itself with maritime references for 15 years. Currently, this includes the delivery of the new fuel cell system "HyShip 72" to the largest European shipbuilding group "Fincantieri" as well as the cooperation in the project "Ma-Hy-Hy" (Marine-Hydrogen-Hybrid), which is being implemented together with "Torqeedo GmbH" for the development of a marine high-voltage hybrid propulsion system with battery and hydrogen fuel cell.

Maritime references confirm Proton Motor as a long-standing technology partner.

The UK company "ACUA Ocean" was supplied with a fuel cell "Made in Germany" in 2021 for the world's first CO_2-free unmanned ship for maritime surveillance and protection. At EU level, the company is also an internationally recognized technology partner in the "e-SHyIPS" project. The aim is to define guidelines on the effective introduction of hydrogen in maritime passenger transport for a clean and sustainable environment.

Already in 2008, Proton Motor – a member of the "Association for Shipbuilding and Marine Tech-nology" – designed the "Zemships"-funded (Zero Emission Ships) fuel cell passenger ferry "Alster-wasser" with an alternative drive solution for "ATG Alster-Touristik GmbH", which was in regular ferry service until 2014.

02

Company Profile

World Platinum Investment Council

Website

platinuminvestment.com

The World Platinum Investment Council was formed by the leading platinum producers to develop the market for platinum investment demand.

Key Features

Focus: Platinum Investment
CEO: Paul Wilson
Twitter: WPIC
LinkedIn: World Platinum Investment Council

Are Fuel Cell Electric Vehicles a Material Long-Term Demand Growth Driver for Platinum?

Recent research by the World Platinum Investment Council (WPIC) highlights the potential for fuel cell electric vehicle (FCEV) demand for platinum to equal current automotive demand as early as 2033. Trevor Raymond, Director of Research, WPIC, explains why.

Fuel cells are a proven technology that has been around for decades, so why has FCEV adoption so far been slow to materialise despite the clear environmental benefits?

The long-promised adoption of FCEVs has been held back due to limited early production of vehicles and hydrogen fuel restricting economies of scale as well as a lack of hydrogen refuelling infrastructure. We think these challenges are now being overcome with the mature application of fuel cell technology in heavy- and light-duty vehicles, supportive hydrogen policies in key markets globally and improving green hydrogen production economics.

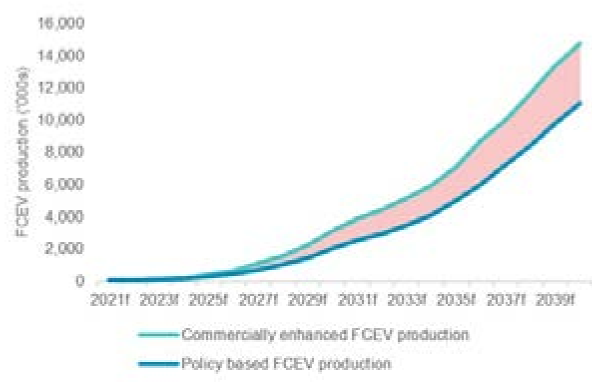
A number of regions and countries around the world have announced hydrogen and FCEV policy support and targets, in many cases together with associated funding details and commitments. We see these as being the cornerstone of FCEV adoption. Of course, the purpose of these policies is to engender growth in the production of hydrogen and the FCEV industry until economies of scale, and/or practicable usability factors result in self-sustaining broad-based commercial adoption.

How are recent geopolitical events influencing the outlook for FCEV adoption?

The current Russian-driven geopolitical crisis and the need to reduce European reliance on Russian gas supplies (currently c.40% of European demand), as well as high natural gas prices, should further accelerate supportive policies for green hydrogen in Europe. To put this into perspective, a big focus has been to bring the cost of green hydrogen down to ~US$1/kg to make it cost competitive with fossil fuels; however, the reverse has happened with the cost of oil and gas rising to above parity with green hydrogen production costs as a result of Russia's invasion of Ukraine. While oil and gas prices are currently artificially elevated and are likely to pull back, Europe has announced plans to replace up to 50 billion cubic meters of Russian natural gas with green hydrogen by 2030, which should significantly improve the economies of scale of green hydrogen production and maintain its cost competitiveness as the price of fossil fuels corrects. A side effect of this is that a significant expansion in hydrogen production and transportation is supportive of the development of hydrogen refuelling networks in Europe, which in turn should accelerate broad adoption of FCEVs.

Automotive demand for platinum is in long-term decline as internal combustion engine vehicles are phased out – can demand from FCEVs really come to the rescue?

Balancing the acute need to decarbonise the world calls for a multi-pronged approach that incorporates not



WPIC has modelled two scenarios examining the potential rate of FCEV adoption. Under the 'commercially-enhanced' scenario FCEV demand for platinum could match 2022 forecast automotive platinum demand as early as 2033.

only battery electric vehicles (BEVs) and FCEVs, but also more efficient internal combustion engine vehicles (ICEs), including mild-hybrid gasoline and mild-hybrid diesel powertrains. It is worth mentioning that diesel versions still emit far less CO2 than gasoline ones.

We expect ICEs to remain a significant portion of the global drive train mix well into the 2030s; from a platinum demand perspective, likely volume declines will be fully offset by tighter emissions standards and correspondingly higher platinum loadings, plus platinum substitution for palladium.

At the same time, passenger FCEVs are likely to achieve cost competitiveness with BEVs over the next decade as hydrogen fuel and FCEV economies of scale are achieved. FCEVs outperform BEVs in roles that require long range, lower system weight, high capacity utilisation or remote operation, already being particularly well suited to long distance heavy duty haulage. We expect the FCEV share of the heavy-duty vehicle market to grow far quicker than that of the light-duty segment. We believe there is growing recognition that FCEVs are complimentary to, rather than competitive with, BEVs.

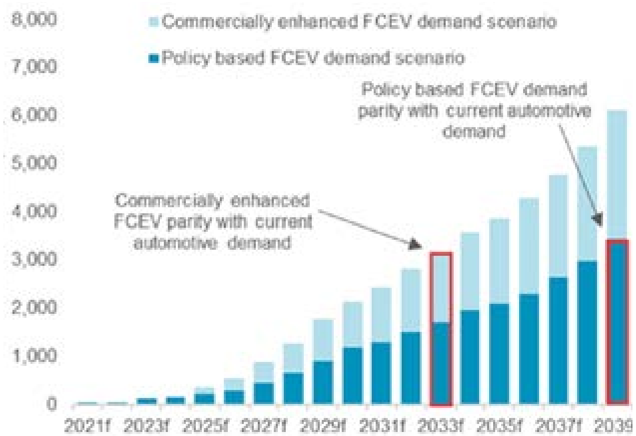
Our recently published research suggests that FCEV demand for platinum could match 2022 forecast automotive platinum demand as early as 2033, adding over three million ounces to annual automotive platinum demand in eleven years, assuming expected policy support is accelerated by economically attractive broad-based commercial adoption. Supportive hydrogen policies alone are already expected to see this achieved in 2039.

WPIC is positing two potential cases for FCEV adoption – can you elaborate?

We have examined two scenarios. Firstly, a policy driven scenario, where FCEV adoption is driven by government and regional subsidies, incentives, and legislated targets. And secondly, a commercially-enhanced adoption scenario, where government and regional policies have engendered infrastructure critical mass and FCEV and hydrogen production economies of scale sufficient to promote widespread adoption on the grounds of costs and practicable usability.

In our view, the biggest early adoption challenges facing FCEVs are infrastructure- and policy-linked. In a rather chicken and egg scenario, hydrogen refuelling stations (HRS) are needed to make FCEVs a viable consumer option, but the automakers are reluctant to invest too heavily in FCEV development until the HRS networks are in place, and governments are reluctant to support HRS rollout until they know that FCEVs are available for consumers. However, national policies are being enacted around the world to support the development of hydrogen production and hydrogen refuelling networks which are overcoming these challenges.

As a result of policy, things are moving, with accelerated development of HRS networks and with a number of countries and regions announcing hydrogen and FCEV strategies and targets. While targets help drive implementation and indicate progress, these can be based on a diverse range of criteria from electrolysis capacity and HRS network scale to FCEV sales, with care required when making comparisons. Countries and regions to highlight include China, targeting 1,000 HRS by 2030, South Korea, which is targeting 80,000



Under WPIC's 'commercially-enhanced' adoption scenario where government and regional policies engender infrastructure critical mass and FCEV and hydrogen production economies of scale sufficient to promote widespread adoption on the grounds of costs and practicable usability.

FCEVs on the road and 310 HRS by 2022, and Germany, which is planning 400 HRS by 2023. Longer term, South Korea is targeting the production of 6.2m FCEVs p.a. by 2040 of which 3.2m will be for export. Vehicle emissions policies that already target fleet CO2 levels, long standing in North America and new to Europe in 2021, already provide automakers with an incentive for FCEVs to reduce fleet emissions.

Overlaying the policy drivers is the question of the pace of FCEV penetration – what is your view on that?

Forecasting the pace of FCEV penetration is a tricky business. What we do have is good visibility on light vehicle FCEV production numbers to date, as well as planned fuel cell production capacity plans for some of the major players, although whether those fuel cells are destined for on-road, offroad or static purposes is not always clear.

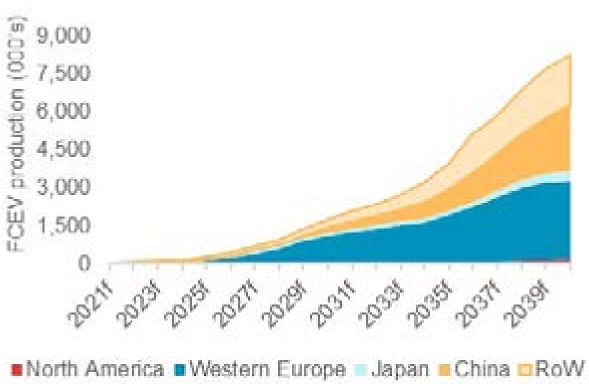
Hyundai, for example, currently has fuel cell manufacturing capacity of 23,000 units per annum and is planning to commission two further 50,000 unit factories by the end of 2023, taking its total capacity to 123,000 units per annum, which it is aiming to increase to 700,000 by 2030 (500,000 for FCEVs). But if we assume that all are using the power and estimated loadings of the fuel cell used in the Nexo, 123,000 fuel cells a year equates to platinum demand of 175 koz p.a, while 700,000 units equates to a million ounces, although we would expect the loadings per kW to be further reduced between now and then.

It is worth noting that production volumes are the key driver to achieving economies of scale to bring down the system cost of FCEVs and move towards parity with ICE.

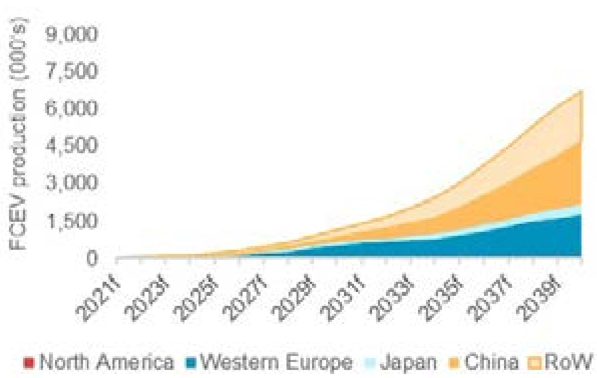
In our projections, while fuel cell vehicle numbers grow from low levels, the projected penetration rates and volumes are very similar to those seen in the penetration of BEVs since 2012 and those currently projected to 2030.

What demand profile do you envisage emerging under either scenario over the next two decades?

Pulling together the FCEV production estimates, fuel cell power outputs and platinum loadings results we see that, under both scenarios, FCEV demand is initially very modest with the first real step up in demand coming with the commissioning of larger fuel cell production facilities in South Korea in 2024. Over time, however, the demand begins to become more meaningful, in



Under the enhanced commercially-driven scenario, FCEV adoption is greater in Europe and North America.



FCEV demand for platinum under the policy-driven only scenario is dominated by RoW, Europe and China.

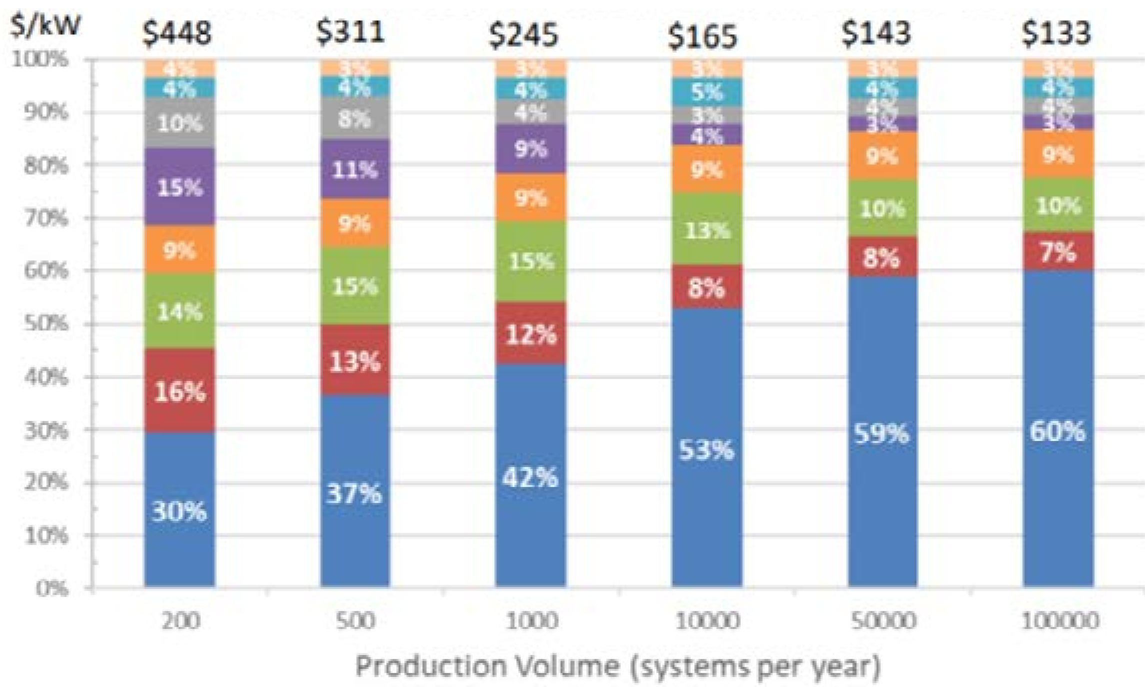
the policy-driven scenario reaching 1 Moz p.a. by 2030, continuing to grow to almost 4 Moz by 2040. The initial trajectory is similar in the commercially enhanced adoption scenario, before accelerating to 1.3 Moz p.a. by 2028, moving on to almost 6.7 Moz by 2040.

What do you think this long-term hydrogen-based platinum demand growth does for platinum investment demand today? Is this something investors should wait until 2030 to act on?

The significant demand growth from FCEVs over the next two decades is being recognised by more investors considering platinum as an investment asset. However as these investors look at the hydrogen-related impact on demand, it is the current constrained supply and short-term demand growth potential from automotive platinum demand that is more likely to drive their investment now in what is increasingly seen as a strategically critical 'green' metal.

Country	2030 depoyment targets	Public investment committed
Australia	N/A	A$1.3B (US$0.9B)
Canada		C$25M by 2026 (US$19M)
California	200 HRS by 2025	US$20M p.a. Grants of US$4,500 to US$9,500 per FCEV
China	1,000,000 FCEVs 1,000 HRS by 2030 2,000 HRS by 2035	No coordinated central funding or subsidies as yet
EU	40GW electrolysis	€3.8B by 2030 (US$4.3B)
France	6.5GW electrolysis 20,000-50,000 LV 800-2,000 HD 400-1,000 HRS	€7.2B by 2030 (US$8.2B)
Germany	5GW electrolysis	€9B by 2030 (US$10.3B)
Japan	800,000 FCEV 1,200 FC bauses 10,000 FC forklifts 900 HRS	¥699.6B by 2030 (US$6.5B)
South Korea	Annual production of 6.2M FCEV 1,200 HRS 80,000 FC taxis 40,000 FC buses 30,000 FC trucks 15GW stationary FC produced	₩2.6T by 2030 (US$2.2B)
Netherlands	30,000 FCEV 3,000 FC HV	€70Mpa (US$80Mpa)
Spain	4GW electrolysis 5,000-7,500 FCEV (LV+HV) 100-200 FC buses 100-150 HRS	€1.6B (US$1.8B)

National and regional targets help drive implementation and indicate progress, although these can be based on a diverse range of criteria from electrolysis capacity and HRS network scale to FCEV sales, requiring care when making comparisons.



Increasing economies of scale are key to bringing down fuel cell system costs of FCEVs, enabling the move towards parity with ICEs. Modest annual production volume increases significantly reduce unit costs.

03

Why Things Work and Why They Don't: An Interview with Quentin Meyer

Quentin Meyer is a Research Associate at the University of New South Wales in Sydney, Australia, where he focuses his studies on hydrogen fuel cells, renewable power sources, and electrochemistry. With over 39 published papers under his belt, and a runner-up prize for Young Electrochemist of the Year 2021 from EDRACI, he is proving himself to be an incredibly formidable researcher.

We sat down with Quentin to talk about his pioneering work with fuel cells, how he got to where he is today, and his plans for the future.

Asking why

So, how did it all begin?

"I was previously working in general engineering, but I had always found fuel cells really interesting," Quentin tells us.

"Before my academic career, I used fuel cells for the first time during a short project in my Masters. What struck me then was that small fuel cells were really easy to build and operate—but scaling this up to a product that works on a larger scale was much more difficult."

While working with these mini fuel cells—that are made for things like toys—Quentin wanted more. And so, as a student he approached Intelligent Energy, the largest fuel cell company in the UK focusing on fuel cell stacks.

"When you are a student you've nothing to lose, really," Quentin laughs. "So, every day for a week I picked up the phone and called their HR department. Eventually, someone picked up and put me through to someone else—and from there I was on a six-month internship."

Quentin describes his time with this company as a hugely fruitful experience.

"I was involved in the R&D side of the company, trying to improve fuel cell performance. This was hugely complex, digging down into things you might not expect from fuel cells like flow dynamics to temperature variance. I learned that there was a lot going on in these cells," he tells us.

"But I found there's a bit of a problem with working R&D in industry. If a product works, there is less motivation to dig deeper into the why behind how the product works. This means there can be less of a foundation when starting to develop the next generation of product."

Into academia

From that point, Quentin began his academic career. It was 2011 when he started his PhD at University College London in the Electrochemical Innovation Lab. This project focused on the same problems he was working on with Intelligent Energy, but with a twist.

"The typical doctoral project in this field at the time was to build a fuel cell from scratch. Mine was a little different—and was, for me at least, the ideal PhD. Again, it was a question of asking why."

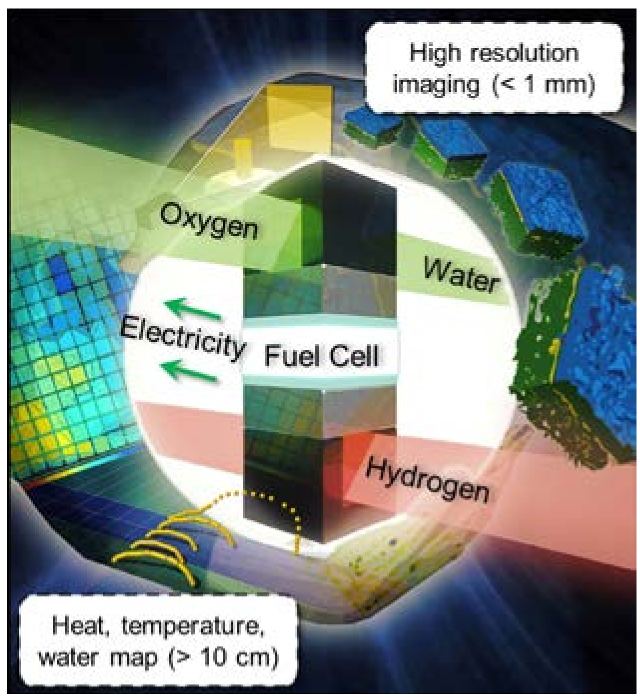
For this project, Quentin was given a commercial hydrogen fuel cell stack—a low-temperature PEM fuel cell, to be precise. It wasn't understood at the time why these cells would operate so well at a given temperature, but their performance would deteriorate once the temperature increased. By trialling temperature, density, and water content changes and capturing them with advanced techniques like neutron imaging and current mapping, Quentin was able to capture and correlate the cell's behaviour in different conditions—and from this breakthrough he was able to publish 15 academic papers over the course of his PhD.

The main finding?

"When a fuel cell is started, the periphery systems need to be powered externally before they can draw energy from the fuel cell itself. It's a bit of a chicken and egg situation. If you want to start the fuel cell quickly, you risk damaging it —but if you let it happen slowly, you're reducing your uptime. There's a happy medium somewhere in the middle," Quentin explains.

"But there are a lot of other factors that come into this. There's operating temperature, the power output, the size of your fuel cell stack and the space limitations. Every application will have a different optimal design—with all the different factors influencing each other in different ways."

These ideas Quentin explored further during his postdoctoral research in the same group, but at a much smaller scale.



"In the postdoc I was looking at micro problems in fuel cells, as in just a couple of millimetres blown up into 3D. With that image you could separate different materials and focus on different parts of the cell. That research was really about figuring out how these materials would respond to different conditions such as heat and compression. Thinking about the end product of a fuel cell, the stakes are really high because you could be losing - or gaining up to 20% of efficiency."

Current research

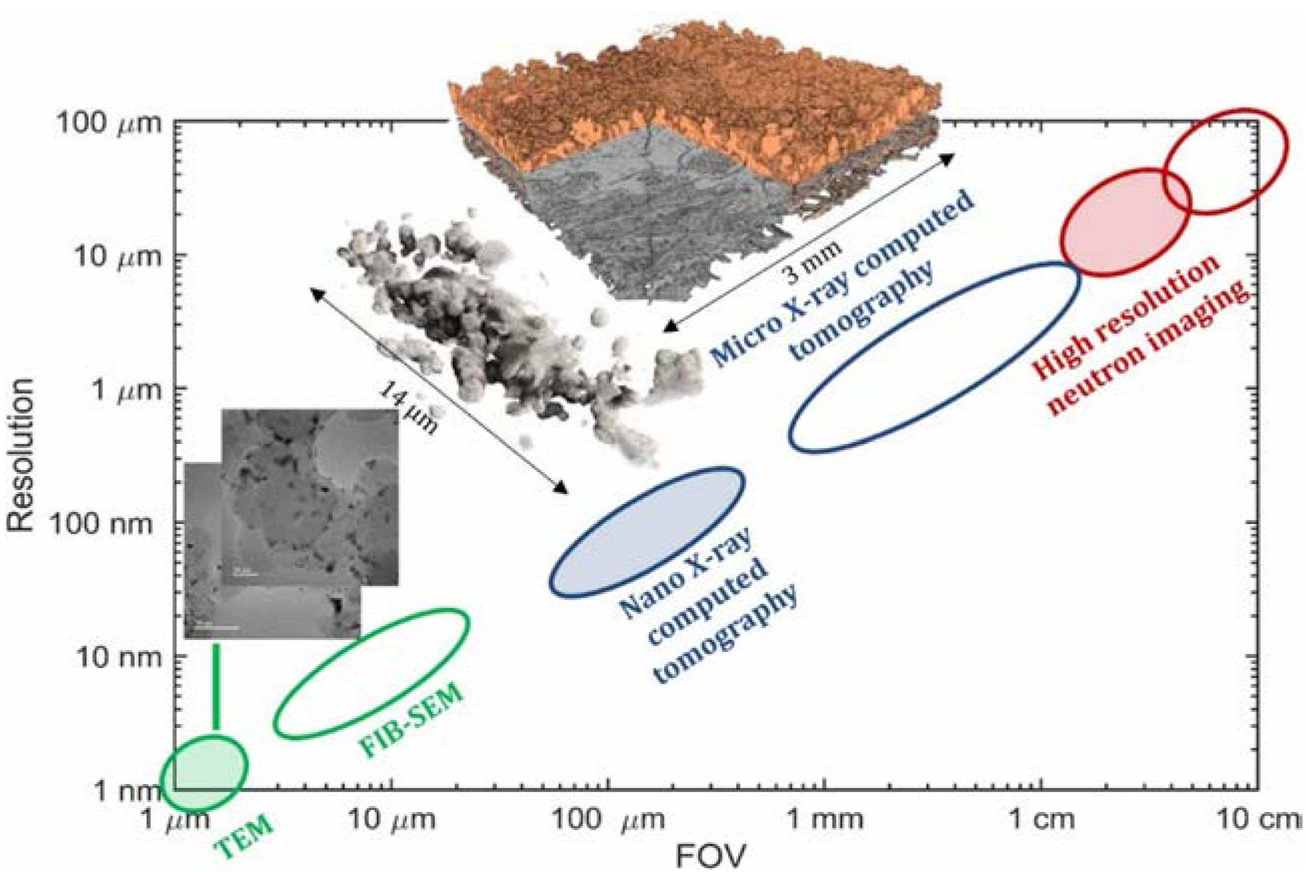
Today, Quentin continues this line of research at the University of New South Wales. But he's trying to find ways to make this work more structured.

"In the beginning, I was randomly selecting the areas of the fuel cells to focus on. Now I'm trying to work out how to determine which area to sample to get the best representation of the fuel cell at large, or to study an interesting issue. Temperature mapping, for example, can help - or looking at the relationship between the fuel cell's structure and its performance."

Yet Quentin is also engaging with new avenues of research.

"Right now, I am trying to raise funding for a new type of fuel cell catalyst in the University of New South Wales (Sydney, Australia) in the NanoElectrochemistry group. These days, commercial hydrogen fuel cells use platinum, because their performance and durability is really high, somewhere between five to twenty thousand hours. But obviously, platinum is also one of the most expensive metals on the planet —so it doesn't really make sense in the long run.

"What we are trying to do is find a low-cost alternative that will deliver similar performance and durability. That's not going to happen overnight, and there is a lot of active research in this field. It's challenging, it's exciting and eventually we will get there."



04

Company Profile

Heraeus Precious Metals

Website

Heraeus-precious-metals.com

With a history dating back to 1660, Heraeus has spent nearly four centuries investing in and developing crucial technologies for industry, the environment, and health. Its current goal is based on precious metals, to help the world secure net zero by 2050.

Key Features

Focus: Precious Metals
CEO: André Christl
Twitter: @heraeus
LinkedIn: Heraeus

How Heraeus Precious Metals Applications Facilitate the Development of the Hydrogen Economy

With a history dating back to 1660, Heraeus has spent nearly four centuries investing in and developing crucial technologies for industry, the environment, and health. One of its current goals is based on precious metals, to help the world secure net zero by 2050. We spoke to Dr Christian Gebauer, head of Hydrogen Systems, part of Heraeus Precious Metals New Business Development, about the contribution Heraeus is making to fuel cell vehicles, recycling, and more.

"Heraeus is a company with a long and rich history, but our work has always been looking forward. Primarily, right now, in Heraeus Precious Metals we're working toward a more efficient use of precious metals, and to reduce our carbon footprint in order to contribute to fighting the climate change."

Dr Christian Gebauer, head of Hydrogen Systems at Heraeus, tells The Hydrogen Standard that there are three primary areas in which the company's efforts are now directed.

Heraeus Precious Metals is the global business unit of the Heraeus group that is mainly specialised on precious metals. Firstly, with precious metals trading, there is the provision of precious metals to the industry and markets. Then, there are all kind of precious metal-based products in a huge variety of industries and applications. And finally, there is a commitment to precious metals recycling in order to achieve sustainability and manage the scarce raw materials in the cycle.

Dr Gebauer's personal responsibility is research, and his focus is largely on proton-exchange membrane (PEM) electrolysers and fuel cells, applications that play an important role in the hydrogen ecosystem. Thanks to a large testing site, where Christian's team can study the behaviour and applications of precious metals, they're hoping to make breakthroughs with serious implications for the hydrogen industry.

"For example, in order to generate hydrogen out of water," he explains, "you need a catalytic conversion. And those catalysts are built with precious metals—something we obviously have a lot of experience in. A such, we believe that we are well positioned to supply these components to the hydrogen economy."

Even if Heraeus isn't directly involved in the energy transition, the company will play an absolutely crucial role, nonetheless. While governments will provide a wider roadmap for the energy transition—including the move toward hydrogen—businesses like Heraeus need to implement strategies to make the component supply work.

"You can't trick physics."

That's why Heraeus is focusing largely on PEM electrolysis, a technology that's crucial for hydrogen generation. However, even with state-of the art use of precious metals there isn't sufficient supply of precious metals to enable Europe to meet its goals for electrolyser capacity, as Dr Gebauer explains.

“PEM electrolysers use iridium catalysts. Europe alone is planning to build 40GW of electrolyser capacity by 2030, and there is simply not enough iridium around to produce so many electrolysers in the way that they’re currently being built. Thus, we need to work on the levels of iridium required. And this is exactly what we do: Heraeus is trying to find ways to reduce the amount of iridium that each application uses. For achieving the target, the reduction of costs and raw materials is crucial.”

Dr Gebauer’s research goes down to the cellular level to improve these efficiencies—as different precious metals affect the way that the electrolysis works.

“One of the main challenges is choosing the active metal in the catalyst. This decision depends on so many different parameters. Iridium, for example, is very active, but it’s quite slow compared to Ruthenium which is even more active—but has stability issues. However, since Electrolysers are likely to run for 20 years or more, stability is really important.”

“This is why,” Dr Gebauer continues, “manufacturers usually try to be on the safe side and use Iridium, not Ruthenium. But they want to make sure that the process works, so they use more iridium than is actually needed. Recent data, for example, shows that up to one gram of iridium are typically used per kilowatt. Given the scarcity of iridium, that’s just too much if these electrolysers want to be rolled out globally.”

Instead, Christian suggests that using iridium oxide can help stability and efficiency, so that as little as a fifth of typical iridium levels are used. With the latest low-iridium solutions of Christian’s lab the amount of iridium can be further reduced without compromising the activity levels. ”Actually”, he says, “each electrolyser shouldn’t be using more than 0.2 grams of iridium per kilowatt. Thanks in part to Heraeus, that’s now possible.”

“Ultimately, balancing efficiency with other factors remains a challenge. You can’t trick physics, but you can look for ways to get as much out of the material as possible.”

The problem of platinum and passenger cars.

As the applications of different precious metals change, demand will change too. Into the future, it was imagined that millions of fuel cell cars would begin to hit the road, each demanding their own precious metal catalyst. This predicted boom in fuel cell cars has not quite been realised—yet. However, the need to improve efficiencies in this hardware remains as important as ever.

“Most fuel cell systems are platinum-based,” Christian says, “although there are some systems that use a second metal. The most important thing is to improve the output, but this is easier said than done, as there are so many different factors that affect this — from vehicle usage to power demands to the way that the system physically fits into the vehicle.”

In this respect, there’s still a long way to go to improve hydrogen fuel cells for vehicle use.

“Honestly, for passenger cars, I think battery electric vehicles will always have better efficiency than fuel cells,” Christian admits.

“That’s simply because batteries don’t require an energy conversion. But fuel cells still have their use. Over longer distances they’re great, because refuelling times are lower. We expect fuel cells to increase, particularly if China gets on board. And for other transport options, such as aviation or maritime applications, they also hold a lot of potential."

Beyond fuel cells

However, it's not only PEM electrolysers and fuel cells that Heraeus works with. Rather, Heraeus is engaged with many other parts of the hydrogen value chain. For example, Heraeus is engaged with gas purification catalysts, in which precious metals are required, as well as hydrogen storage and transport, for example involving ammonia.

"Specifically, we're looking into the process in which hydrogen gas is converted into liquids so hydrogen can be transported," Christian says.

Transportation of hydrogen is crucial for mobile applications, especially when there is no re-fill possibility just around the corner. Think of maritime, where for long distances there is no possibility to recharge batteries or refuel. For this kind of applications R&D is working on storing the hydrogen atoms within ammonia. To transform the hydrogen to ammonia and then back into hydrogen again, precious metals catalysts are applied.

Beyond the catalysts itself, Heraeus is also working to improve recycling processes for electrolysers and fuel cells. Currently, getting fuel cells back from the market for recycling is not well structured, and a new strategy will be needed. "Bringing end of life materials back into the loop will be a crucial aspect to manage the supply and has to be part of a raw material strategy for the hydrogen ramp up."

But Christian is confident.

"From our perspective, we are already well developed in managing the recycling of precious metals throughout the hydrogen value chain. We're excited to make it happen, for a more sustainable future."

05

Document #39 & China's FCEV Industry

The PRC is already the second-largest FCEV market in the world. The fuel cell electric vehicle (FCEV) industry in China is forecast to grow fast over the next few years, with total vehicles operating in the country expected to exceed 100,000 by 2025 and one million by 2030. Over 7,500 vehicles composed of over 400 different models are currently operating in China. Each model is a unique combination of auto OEM and fuel cell system integrator (FCSI). Despite these impressive numbers, the FCEV industry is much smaller than it could have been, thanks in part to a notorious policy released in late 2018 known in the industry as "Document #39."

Auto OEMs in China require separate production licenses for each type of vehicle, such as sedans, commercial vehicles, trucks, electric vehicles, and even FCEVs. During the Golden Age of FCEVs in China between 2017 and 2019 many small, struggling auto OEMs jumped on the hydrogen mobility concept, adding to the hype surrounding the industry, in the hopes of selling fleets of FCEVs at inflated prices and thus turning around a declining business. The ease of applying for production licenses meant that many otherwise ill-equipped auto OEMs could simply buy sets of batteries and fuel cell systems (FCS) and assemble a FCEV on a chassis in a matter of days. Needless to say, these "out of the box" FCEVs often did not perform as advertised.

The commercial vehicle segment in China is divided into three segments. Routes under 200 km are considered city driving and suited to EVs with charging times of around one to five hours. Routes between 200 and 300 km are considered short-distance and routes over 300 km are considered long-distance. According to the China Hydrogen Alliance, any route over 200 km is suited to FCEVs, with refueling times of less than 30 minutes. Within the commercial vehicle segment, FCEV market penetration is expected to reach 5% by 2025 and to exceed 40% by 2050 for buses, to exceed 10% by 2050 for trucks, and to reach about 10% by 2050 for heavy duty (HD) trucks.

Part of what began the hype cycle at the beginning of the FCEV Golden Age in 2017 in China that ultimately enticed many small, regional auto OEMs to enter the market was a series of industrial policies released by the China government. China hopes to promote mid- and heavy-duty trucks and buses through to 2025 after which the country plans to shift to promoting SUVs and long-distance buses through to 2030.

Numerous professionals in the industry in China have cited a mutually reinforcing relationship between successful - albeit small-scale - FCEV pilot projects and industrial policy; supportive policies drive projects and projects in turn encourage more policy support. Ultimately, China hopes to move the domestic FCEV industry from an "introductory phase" to a "scaled phase," according to the Ministry of Commerce (MOFCOM).

While only around 150 FCEVs were ultimately granted subsidy disbursements for fleet operations during the Golden Age of 2017 to 2019, the fleets operating after 2020 managed to achieve larger scale despite more stringent subsidy requirements. Over 438 million RMB were disbursed to 1,029 FCEVs operating after 2020, an average of 426,000 RMB per vehicle.

Furthermore, to avoid the embarrassingly low numbers of the Golden Age, the government appears to have limited applications in the first place, rather than limiting the number of successful applications. The number of successful applications was out of a total of 1,140 - a success rate of around 90%. The number of successful applications in the post 2020 period - following the implementation of the "subsidies-to-rewards" program - is in stark contrast to the small numbers during the Golden Age period.

Why were so many auto OEMs and FCSI firms unsuccessful in indexing and selling FCEVs during this early period?

General industrial policy in China assumes than a large pool of small firms has emerged in most industries following the country's Reform and Opening policies starting in the 1970s and after the country's admission to the World Trade Organization (WTO) in 2000. The auto industry in 2016 was a case in point; many regional firms sold to local markets and little technological diversity existed between vehicle models.

First released internally in 2017 and then officially released in 2018, "Document #39" drastically raised the commercial and technological bar for auto OEMs in China. Manufacturers had to meet minimum sales requirements in addition to enduring onerous process and safety checks. While nominally designed to root out so-called "zombie firms" – auto OEMs with very few sales and no innovation – Document #39 was actually designed to force small firms into mergers with large, state-owned auto OEMs in the hopes of creating "national champions" in the industry. Auto OEMs were given until July of 2019 to meet all the requirements enumerated in Document #39 - or close business.

Rather than close quietly many auto OEMs scrambled to find new technologies in hope of securing quick sales before the July deadline. By coincidence, another set of industrial policies in China was promoting FCEVs around this same time. Many smaller auto OEMs latched on to FCEV technology, throwing together vehicles with very little testing – "out of the box" FCEVs. These auto OEMs also convinced many fuel cell system integrator (FCSI) firms to sell-on-credit on the promise of payment after subsidies were paid. However, as described above, the number of subsidies actually disbursed during this period was very small. Overdue or bad debts from auto OEMs may even have interrupted one FCSI firm's stock market listing in 2021.

While the effectiveness of Document #39 in producing national champions in China's auto sector is still disputed, the policy had the perverse effect of increasing the hype already surrounding FCEVs during the Golden Age from 2017 to 2019 - adding "oil to the fire," according to the Chinese expression. This effect only exacerbated the collapse of orders in 2020. However, the industry appears to have found new life after the Beijing Winter Olympics of 2022, with orders of special vehicles, such as street sweepers and garbage trucks, from municipal governments rising steadily.

Document #39 marked a dividing point in the China FCEV industry. Before Document #39 the industry was characterized by high hype and few orders; after Document #39 - and into the present-day - the industry appears to have toned down the hype and yet increased orders at the same time. Document #39 may not have had the desired effect of central planners in Beijing, but China's FCEV industry does appear to have become healthier after the publication of this notorious policy document.

06

Overview of China's Energy Industry: From Coal to Renewables… to Hydrogen!

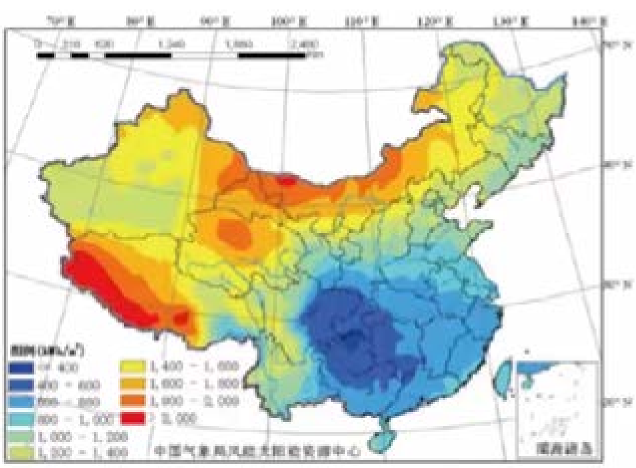
The recurring refrain describing the energy industry in China is "rich in coal, poor in oil, and with a little natural gas." Fully 70% of oil burned in China is imported. While the country has deposits of natural gas in the southwest, large amount of natural gas, especially LNG, are imported to heat China's coastal megacities. Accordingly, industrial policy in China is designed to develop new, clean fuels to both reduce reliance on imports - improve energy security - and also to reduce pollution. Intermittent renewable energy (IRE) has traditionally been seen in China as the solution to moving away from coal while at the same time reducing energy imports.

China has led the world in annual installed capacity of wind energy for 12 years in a row. China accounted for about 50% of all installed wind and solar energy in 2021. In that year the country installed around 300 GW of wind energy, an increase of 25% over just a year earlier. Graphing solar installation by year for the European Union (EU) and China shows the former with a convex curve - starting high, but decreasing over time - and the latter with a concave curve - starting low, but increasing over time. Annual solar production in Germany, for example, has remained static at around 40 TWh since 2014. China, in contrast, doubled installed solar capacity from 50 TWh to 100 TWh from 2015 to 2017.

Despite installing nearly an entire exajoule of intermittent renewable energy (IRE) in 2021, China still generated vast amounts of CO2 pollution from burning coal. Indeed, about 75% of all China's CO2 emissions are due to burning coal alone. While coal dropped as a percentage of total energy production in China to around 65% in 2018 the fuel is simply too cheap and abundant and, as a result, resists being phased out. The economies of some provinces in northern China, such as Shanxi to the northwest of Beijing, are also dependent on coal mines for revenue. World coal consumption fell by about 4% in 2021, yet consumption actually rose by a small amount in China. The political importance of coal to northern provinces like Shanxi as well as abundance and cheap prices continue to make coal the fuel of choice for most power plants in China.

Unlike coal, oil in China is imported, mostly from the Middle East, with Africa, Russia, and the Americas accounting for around 15% each of China's production. Within the Middle East, China's largest oil supplier is Saudi Arabia; the country alone supplies 16% of all China's oil imports. Despite being generally considered cleaner than coal, natural gas is still a fossil fuel and emits pollution when burned.

Consumption of natural gas fell in most countries in the world in 2021 but actually rose in China by more than 5%. It is likely that consumption of fossil fuels had started to decline in China but that the post-COVID economic recovery caused a surge in demand that temporarily reversed this downward trend. China's "Carbon Peak 2030, Carbon Neutral 2060," industrial policy, colloquially known as the "Double Carbon" goals, should in the long run ultimately depress coal and oil consumption.



Hydrogen energy is an important component of the Double Carbon goals, according to a recent interview with China Energy Department Director Zhang. The Fourteenth Five Year Plan (14FYP) specifically mentions encouraging the development of a hydrogen energy value chain, including generation, storage, transportation, and off-take. The China Technology Department wants to promote hydrogen energy across three pillars: industry, academic, and research.

While China has yet to announce a national hydrogen strategy along the lines of Japan and Korea, the 2020 Domestic Economy Development Plan calls for a "Three Segments-One Line" policy, with focus in promoting hydrogen energy concentrated in the three "segments" of petrochemicals, general chemicals, and steel production and the "line" of high-quality heat (greater than 400˚C) from hydrogen blended with natural gas. China's collection of hydrogen energy promotion programs appear to be focused on transitioning the economy away from coal and oil by promoting blending with natural gas. Such a blending strategy will "level up" China's residential heating needs without requiring new infrastructure.

A series of recent, high-profile political projects show the integration of hydrogen energy technology into China's energy industry. An example of an upstream project is a MW-level PEM electrolyzer designed by China State Shipbuilding Corporation (CSSC) Institute #718, based in the city of Handan in Hebei Province. Inst. #718 develops and manufactures technologies for military and civilian applications. Inst. #718 also developed China's first sled-mounted hydrogen membrane compressor. The institute currently has about 65% market share in China and also sells overseas, especially to Europe.

An example of a mid-stream pilot project is the development of a containerized "smart" hydrogen refueling station (HRS) by Furise Hydrogen, based in the city of Zhangjiagang in Jiangsu Province. This HRS project, funded by SinoPec, was the first in China to operate at 70 MPa, twice the pressure of what is commonly available in China. Furise also builds hydrogen supply systems (HSS) for fuel cell electric vehicles (FCEV) in addition to HRS. Furise has sold around 4,000 HSS in China since 2016 and recently started construction on a new facility in late 2021 to increase capacity. Most recently, Furise supplied 70 MPa hydrogen dispensers to a HRS based in the city of Chongli in Hebei Province.

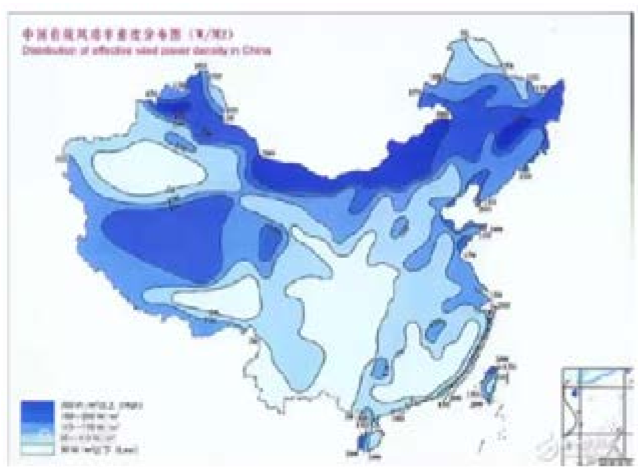
A final example is a down-stream PEM "power generator" project for fuel cell system (FCS) installed in Shanghai's petrochemical district. This FCS has rated power of 300 kW and is designed to produce both electricity and heat as a combined heat and power (CHP) installation. ReFire, based in Shanghai, specializes in the core components and engineering of fuel cells and has extensive experience in FCS design, control, modeling, assembly, and safety.

Indeed, safety may become a problem holding back the development of the hydrogen energy industry in China. According to a survey of industry professionals in late 2021 the lack of comprehensive safety standards for different hydrogen storage technologies and pressures was considered the primary roadblock in the industry.

Another problem is commercial, rather than technical. There is a lack of diversity in the hydrogen energy and fuel cell development programs in different provinces in China. Each province has a unique endowment of natural resources as well as different off-take - "end-user" - industries. However, recent industrial policy bemoaned the "low-level repetition" common between provinces with hydrogen technology parks; everybody has a local fuel cell system champion, but nobody apparently has a membrane manufacturer, to cite one example. Rather than build on unique natural resource endowments, provinces are building low-level technology parks and integration firms; from a national standpoint, such low level redundancy is a waste of resources, according to the China Hydrogen Association.

The association also predicts that hydrogen energy will make up 10% of China's energy industry by 2050 - up from a negligible value today. The association ties China's hydrogen production to the country's expanding IRE production capacity; according to the association, 70% of the 60 million tons of hydrogen that will be produced by 2050 will come from electrolysis powered by IRE. These predictions help explain why so many cities in China today are encouraging electrolyzer firms to increase research and production activities – at the risk of yet more "low-level redundancy."

However, the potential profits - and tax revenues - to be made as China transitions away from dirty coal and imported oil and gas to domestically-produced, green hydrogen have attracted large volumes of investment. China clearly hopes to transition from "rich in coal, poor in oil, and with a little natural gas," to "blue, gasified coal, high-quality oil products, and lots of hydrogen."



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Torus Cooling

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Torus Cooling implements innovative systems and holds seven proprietary patents in the field of modern refrigeration technology.

Key Features

Focus: Refrigeration Technology
CEO: Steven Zweegers
LinkedIn: TORUS Cooling

Ingenuity in Cooling Systems that Provide Huge Efficiency Gains in Hydrogen Fuelling

With a history in food technology, Torus Cooling now deploys its patented heat exchangers in the hydrogen industry too. We spoke to Antoon Martens and Niels Govers to understand Torus's cooling technology—and the brand's plans for the future.

Torus Cooling may now be powering some of the most important technological developments in hydrogen cooling. But the story of the brand has a perhaps surprising beginning.

The founder of Torus, Wim Schoonen, initially launched a company known as Cool Food Ideas. His focus at the time was to invent and patent solutions and sell them to third parties in the food industry. Yet Wim soon had a breakthrough that would change the course of the company forever.

He invented a heat exchanger—in the unique form of a doughnut. "This device has an distinctive shape and the heat exchange enables very long surface areas between hydrogen and refrigerant. Combined with the inner tube layout, this area facilities fast temperature drops (on hydrogen side) as well as low ΔT between refrigerant and hydrogen out temperature (< 1 K is possible). For use in refueling stations these properties translate into fast cooling capacity reaction and low energy consumption. A cold-storage buffer is no longer required. Consequently, cooling is done in-line and on demand, making back-to-back refueling capability available," Niels explains.

This incredibly versatile product became known as the Torus, and its potential went far beyond the food industry. As a result, alongside three other shareholders, he founded Torus Cooling to market the product more widely.

"Today, we're still active in the food industry, where we use the technology to cool beer on-demand, as well as to cool milk in agricultural contexts," Antoon Martens, Torus's general manager, tells us.

"But a large part of what we do is now in the hydrogen industry."

While food to hydrogen may sound surprising, the decision made a lot of sense. A couple of years ago, Torus reached out to Resato, a Dutch company specialising in high pressure technology. Both brands were investigating the hydrogen market—and they found an opportunity to work together.

"Resato builds pressure pipes, to compress hydrogen up to 1000 bar. And, at Torus, we integrate our heat exchangers into their technology to deliver precise benefits to customers," Niels Govers, manager product development at Torus, explains.

"For example, we purchase Resato pipes and bend them into the doughnut form. This helps to prevent any loss of pressure, stop any blockages of micro crystals, and ensure that no thermal storage of hydrogen is required. Of course, this makes the whole process much more efficient."

As a result of these efficiencies, Torus's technologies are now selling hugely well. The brand's H2cool solution, for example, is one of the most widely used. It's a cooling device with four heat exchangers that can fuel vehicles with up to eight kilograms of compressed hydrogen. The H2Cool is a dual use cooling unit. Not only does it provide in-line and on-demand cooling for refuelling, it also cools hydrogen that is being compressed for storage modules. This so called interstage cooling helps hydrogen compression to be more efficient.

H2cool uses a novel method to achieve this. Rather than cooling the hydrogen from 40°C to -40° in a single stage, Torus Cooling splits the process into two stages—cooling from 40°C to -20° and then from -20° to -40°. This way, it's much more efficient, often by more than twice as much. Efficiency in cooling helps to lower energy consumption during refuelling. The kWh per H2 kg is reduced by as much as 30%.

“This makes refuelling hydrogen vehicles much quicker,” Niels explains. “But there's a lot more that needs to go into that process. So far, we have ten tank stations across Europe. We focus on temperature regulation, and work on the fuelling systems with partners who manage the hydrogen flow valves and piping systems.”

Currently, Torus is focusing on solutions for small commercial vehicles and passenger cars—the only vehicles currently covered by global regulation—the SAE26. However, Torus is hoping to go much further.

A hydrogen solution for heavy duty vehicles, for example, is the biggest priority for Wim, Niels, and Anton right now. Yet a lack of standardisation makes this difficult. For example, Volvo has plans to fuel its vehicles at a pressure of 700 bar, while other truck manufacturers are aiming for 350 bar. With different pressures, different levels of cooling are required, and this means that Torus need to build flexibility into the heart of their solution.

From the food industry to hydrogen, Torus has big ambitions. With the team's passion for experimentation, they are determined to make it a success.

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