The

Hydrogen Standard

RESEARCH & NEWS

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Issue 2 - January 2022

KUSTEC: THE WORLD OF HYDROGEN COOLING SYSTEMS

IF WE CAN SHARE CONCEPTS WE CAN SHARE OPPORTUNITIES

BIG OIL TO BIG HYDROGEN: ANALYSIS OF HYDROGEN ECONOMY PLANNING AT CHINA'S THREE BIG OIL MAJORS

GREEN HYDROGEN PRODUCTION: COULD IT CAUSE A SHORT-TERM RELIANCE ON FOSSIL FUELS?

The Hydrogen *Standard*

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Welcome to The Hydrogen Standard

When looking around in the world of decarbonisation, there is no lack of company announcements on new plans, mergers, or technological solutions that should get us closer to the net-zero target by 2050.

The recent COP26 in Glasgow showed us the ambitions of many governments to move towards a more sustainable future, particularly in regards to our energy needs. No lack of head-line grabbing announcements, even by the big economies. Despite some of them are a bit vague in regards to proper commitments, time-lines and plans for implementation, the intentions - at least - are there to move into the right direction.

In all of this, hydrogen will play a key role. The second issue of The Hydrogen Standard Magazine will further illustrate hydrogen's versatility in a more decarbonised world. It also demonstrates the diversity of companies involved offering a wide range of solutions to make the bold and ambitious targets set by our governments worldwide a reality.

This ranges from offering hydrogen cooling solution systems, to supporting clients with infrastructure requirements to decarbonise as well as offering and educating the world about alternative ways to generate green hydrogen through the thermal conversion process of waste.

As a courtesy we included some articles of our premium subscription product on China's Hydrogen and Fuel Cell Market too. After all, in all that is discussed regarding decarbonisation, it is the big economies that can significantly move the needle, although smaller nations can and already do lead by example too.

We hope you find our second issue insightful and informative. If you would like to feature in future issues of The Hydrogen Standard, feel free to get in touch. We'd love to hear from you.

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FEATURE

KUSTEC

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Company Focus: Hydrogen Cooling Systems

Interview with: Mohamed Koubassi and Florian Lechner, sales and project managers

Website: www.kustec.at

LinkedIn: KUSTEC

The World of Hydrogen Cooling Systems

Author: Dr. Quentin Meyer

Launched by Martin Schreiblehner in 2006 in Freundorf Austria, Kälte- und Systemtechnik GmbH, or KUSTEC for short, has positioned itself as the leader in customized cooling and refrigeration systems. Since a first project in 2008 with one of the largest industrial gas manufacturers in the world, KUSTEC has grown its activity towards hydrogen cooling, which currently occupies between 50 and 60% of the company activities. We sat down with two sales and project managers at KUSTEC, Mohamed Koubassi and Florian Lechner—to discuss this exciting technology, what makes KUSTEC unique in the field, and the future of this exciting hydrogen revolution.

Cooling systems can be an obscure field for many customers, who don't always understand their own needs. Led by Martin Schreiblehner's vision, KUSTEC has built its business model and core values around a focus on the customer.

Before accepting any project, KUSTEC's team confirms how much heat really needs to be removed from the customer's system, and how the company's technology can do it in the most energy- and cost-efficient way. In fact, KUSTEC's motto is "We are only satisfied when you are." As a result, KUSTEC quickly became one of the world leaders in custom cooling systems, with its team of engineers and technicians specialized in understanding the best solutions for their customers.

What exactly is hydrogen cooling?

“To begin with, hydrogen gas is stored at a very high pressure in large tanks in hydrogen refueling stations. Here, it’s used to fuel hydrogen fuel cell vehicles, such as cars, trucks, boats, and even trains or small planes,” Mohamed explains.

“As the hydrogen is fueled from the high-pressure storage tank to the vehicle, it experiences a pressure drop, targeting an end pressure of 700 bars for cars and 350 bars for buses. The gas enters the vehicle tank and experiences the Joule Thomson effect for hydrogen. Thus, overall a high amount of heat is produced. For the safety of the vehicle tank, the hydrogen must reach the SAE (Society of Automotive Engineers) Temperature Protocol within 30 seconds from the start of the fueling process and avoid the temperature in the tank exceeding 85 °C.”

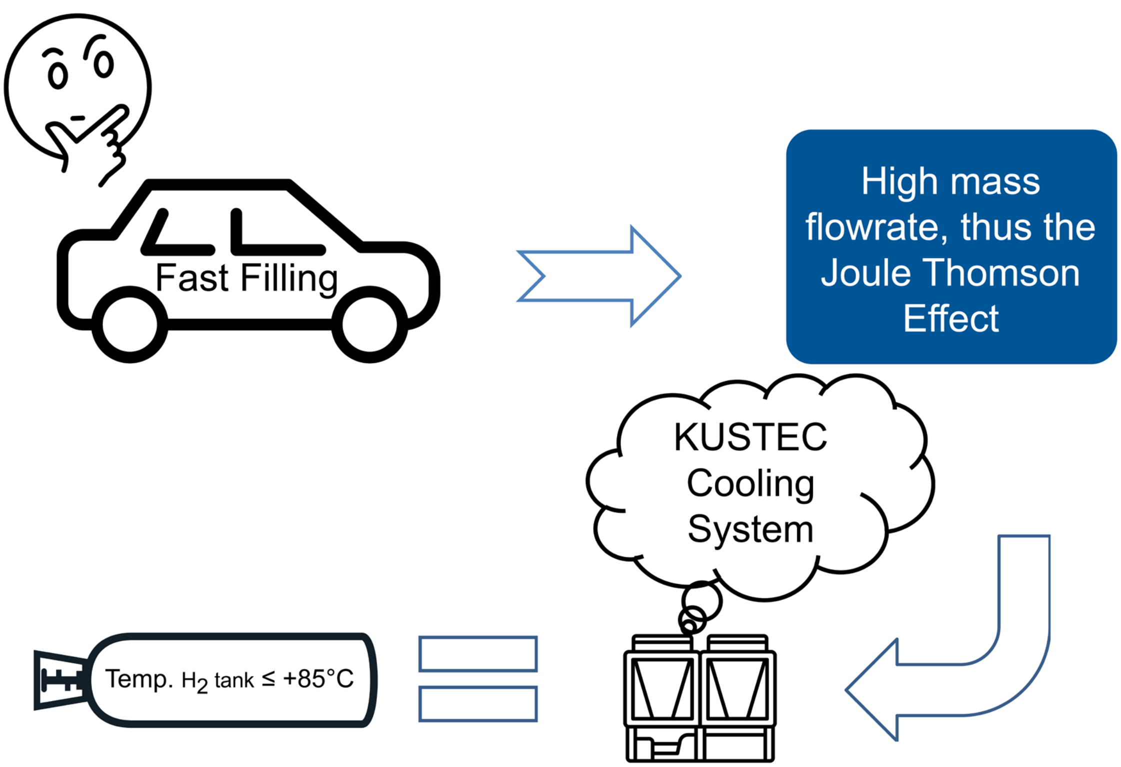
“Therefore, you need a hydrogen cooling system, integrating with the hydrogen flowline through a heat exchanger to cool down the hydrogen flowing from the storage tank to the vehicle. That’s what we do at KUSTEC.”

What makes KUSTEC unique in this field?

Hydrogen cooling began for KUSTEC when Martin Schreiblehner was approached by a world leading industrial gas manufacturer in 2008 to cool their hydrogen refueling station. Since then, KUSTEC has deployed over 250 hydrogen cooling systems worldwide. That’s about half of the world’s hydrogen refueling stations.

KUSTEC’s team of experts has designed rapid and high efficiency cooling systems to cool the hydrogen flow to the required SAE Temperature Protocol and ensure its temperature does not exceed 85 °C in the vehicle tank. These use a unique direct cooling

Image 1: Fast Filling Overview with KUSTEC Cooling System



"We are cleaning from every perspective, by consuming less electricity through our unique cooling systems, and by supporting hydrogen vehicles that capture air pollutants."

system, with the refrigerant in direct contact with the hydrogen in the heat exchanger, which reduces the energy consumption and increases the efficiency of the system significantly.

KUSTEC hydrogen cooling system has deepened its knowledge with CO2 refrigerant and optimized it for hydrogen cooling technology. With the rise of global warming, international regulations have been implemented to limit the global warming potential of refrigerants releasing harmful emissions. A difficult trade-off must be reached between using a refrigerant with a low global warming potential but requiring a lot of electricity to cool the system, and a refrigerant with a higher global warming potential but requiring less energy to cool, as Florian explains.

"As it turns out, when used a cooling gas, CO2 has a very low global warming potential compared to refrigerants such as R449A which have a global warming potential a thousand times greater. Therefore, using CO2 enables you to cut down the operating costs of the system, as it consumes less energy and achieves a higher efficiency."

All these exciting innovations have introduced KUSTEC as the world leader of this technology.

As Mohamed puts it, "we are cleaning from every perspective, by consuming less electricity through our unique cooling systems, and by supporting hydrogen vehicles that capture air pollutants".

Yet, alongside the technologies themselves, KUSTEC's strong focus on the customer is ideal for hydrogen cooling.

"As hydrogen refueling stations are an emerging market, every customer can have different requirements—a different refueling time, refueling temperature, refueling pressure, etc.," Mohamed continues. "More importantly, countries have different cooling system regulations. As such, a hydrogen cooling system deployed in the German market may not be compliant with the regulations in South Korea or vice versa."

While harmonization efforts have taken place recently, thanks to the SAE International standards, KUSTEC still needs to carry out slight modifications for each installation of the hydrogen cooling system. KUSTEC's personalized approach and huge flexibility in delivering this system is ideal.

Each hydrogen cooling system built by KUSTEC is first evaluated in their facility in Freundorf, Austria, then installed on site either by KUSTEC's team, or by their growing network of consultants and business partners in different countries (Australia, Belgium, England, France, Germany, South Korea, Spain, Sweden and United States of America), offering lifetime maintenance and support.

Where do you see the largest market growth for hydrogen refueling stations from your perspective?

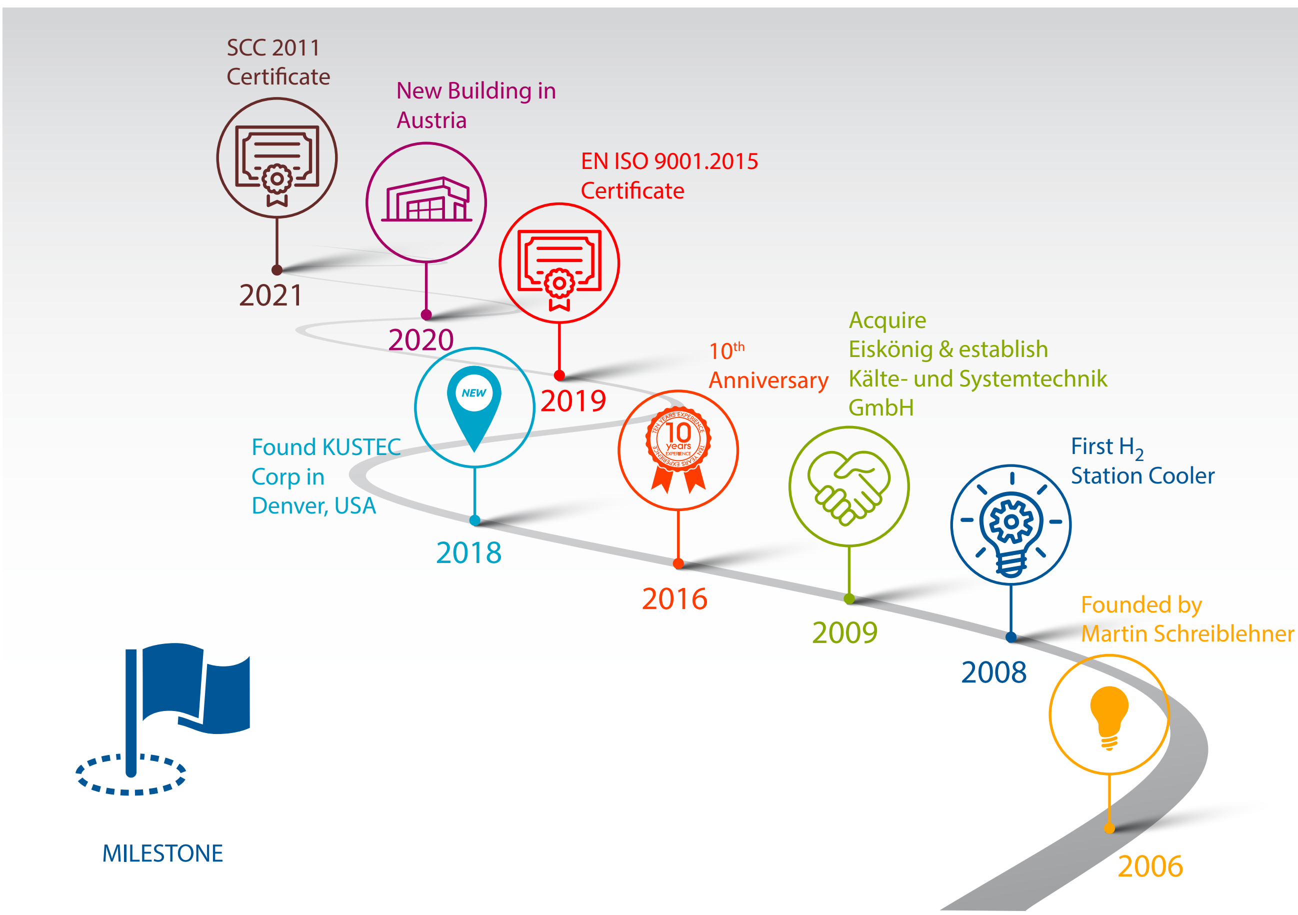
"Interesting question," Florian tells us. "While there is a lot of talk and excitement around hydrogen—and grand claims of covering countries with hydrogen refueling station—each hydrogen refueling project faces its own unique challenges. And that includes the best hydrogen supply chain, the design of the refueling station, and the hydrogen storage capacity. KUSTEC is proud to contribute to this hydrogen revolution, by supplying the much-needed hydrogen cooling systems.

"Right now, we have a constant baseline of projects for cars, which is excellent for business. We also see the bus and trucks market growing very fast, as well as some projects with forklifts, and we have interesting projects for trains. Overall, I would say that public transport in general seems to be moving towards hydrogen, and we expect many interesting projects appearing in the next few years based on what we see now. Also, we see increasingly interesting projects for heavy duty and high-power trucks, and high-power excavators.

"It's an exciting time for hydrogen, and we expect to see even more projects happening in the future."

HS

Image 2: KUSTEC Milestone Overview



FEATURE

GenComm

Key Features:

Company Focus: Community to promote development of sustainable energy

Interview with: Paul McCormack, innovation manager at Belfast Metropolitan College

Website: GenComm

Twitter: Interreg NWE

LinkedIn: Company Page

"If we can share concepts, we can share opportunities": A Conversation with GenComm's Paul McCormack

"It is the most universal element in the world, but hydrogen won't be universal in its use," says Paul McCormack, innovation manager at Belfast Metropolitan College and program manager at GenComm, a project that aims to validate, both financially and technically, the maturity of hydrogen technologies.

"Rather, each country will have to develop its own hydrogen typography based on their own energy needs and opportunities."

We sat down with Paul to discuss the green hydrogen transition, the need for local hydrogen solutions, and GenComm—or "GENerating energy secure COMMunities through Smart Renewable Hydrogen", to give it its full name.

GenComm is currently working to implement three pilot plants in northwest Europe, that will link three major renewable energy sources—namely solar, wind, and bioenergy—with energy storage and energetic demand—heat, power, and transportation. One plant in Northern Ireland will use wind energy to generate hydrogen for fuel cell buses. In the Scottish islands, biomass will generate fuel for transport and power for industry. And in Germany, a solar-powered refuelling station will provide hydrogen for passenger cars.

It's this diversity of hydrogen production and use that Paul refers to when he says that hydrogen cannot provide a single, universal solution across all contexts.

"Fossil fuels are generally a single fit for everyone," he says. "But a hydrogen system has to be different across countries. At root, using green hydrogen means integrating more renewable energy into the supply chain and thinking about how to optimise hydrogen in the energy mix. That solution can't be one-size-fits-all, but what we are showing with GenComm is that a variety of solutions are possible."

However, Paul tells us, changing the energy mix and reaching those different hydrogen solutions won't happen in a single step.

"That's fine at first," he says, "as long as we do use less-polluting fuels and take small steps toward green hydrogen. Hydrogen puts us on the right path. But the real question is, how can we pivot business to green hydrogen solutions?"

For Paul, things aren't as simple as having businesses and societies abruptly turn away from fossil fuels. That, he says, would spike energy prices in the way that we saw at the end of 2021. Instead, he suggests we need a slow transition, to minimise the economic shock and lessen the potential negative impacts for everyone."

To this end, Paul suggests a highly collaborative approach to driving hydrogen adoption.

"We'll need to work in tandem with industry—and we'll need to work both with existing and new industries to upscale green solutions and rescale existing polluting ones. But we also need to work across nations too—because if we can share concepts, we can share opportunities."

That brings us round to the work on which GenComm focuses: energy secure communities.

"Communities are really the end users of the energy grid," Paul explains, "and energy security is the foundation stone for secure communities. If the aim is to build a stable society into the future, energy security is a priority."

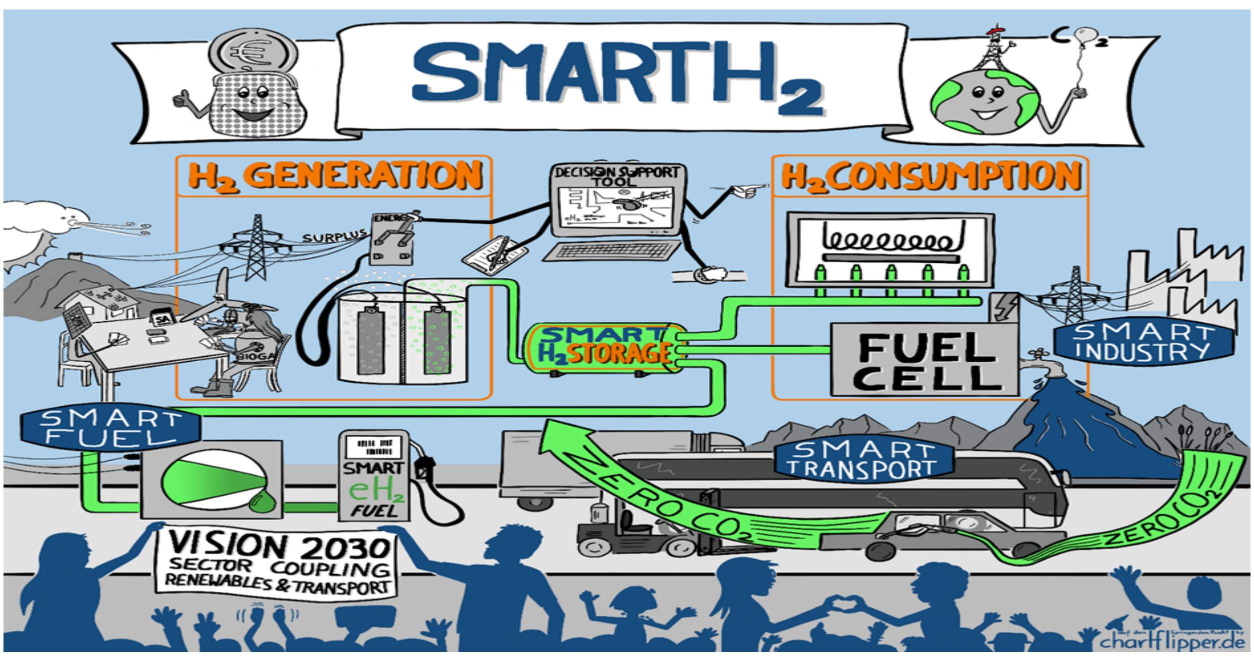
That's why Paul insists on making nations ensure that they are energy self-sufficient. Just because it is cheaper to import fuel, it doesn't mean that the resulting energy dependence is a good thing. Instead, energy should be produced locally, Paul affirms—to create new jobs, new opportunities, and new positive impacts. At the same time, every country should have the support to make this happen.

Yet it doesn't all need to be hydrogen. Instead, in Paul's words, the ideal scenario is "a broad menu" of energy opportunities based on local capabilities—and one that doesn't rob the planet of its natural resources.

But what can be done to make the transition a reality?

Start with "regulating, repurposing, redirecting", Paul says. Rather than building from scratch, we can use some of the existing assets that would otherwise go to waste. Oil tankers can be used for ammonia, oil pipelines for hydrogen transport. In fact, everything we use today needs to be modernised for a greener economy. And GenComm are helping to drive the technology to make that happen. HS

Image 1: GenComm Smart H2 Generation & Consumption Overview



FEATURE

Pennsaco

Key Features:

Company Focus: Converting waste to green hydrogen

Interview with: Robert Kelly, CEO and Amy McCrae Kessler, VP of environmental affairs

Website: pennsaco.com

LinkedIn: Pennsaco Technologies

Turning Biomass into Carbon-Negative Hydrogen

“Waste streams and biomass harbour untapped value. Effectively refining these materials can unlock vast resources—and turn them into valuable products.”

We’re talking to Robert Kelly, CEO at Pennsaco Technologies, and Amy McCrae Kessler, the company’s vice president of environmental affairs. The company’s work provides society access to the valuable resource that we conventionally know as waste—to produce green hydrogen, create carbon-negative energy, remove carbon dioxide from the atmosphere, and replenish soil and water health.

That happens with a patented system which, with advanced thermal conversion and carbon capture technology, recycles biomass, plastics, and municipal solid waste into renewable energy and biochar.

So, how have they made it happen?

The company started when CEO Robert Kelly developed a process to create a drop-in fuel similar to renewable gasoline—something that was already a well-developed technology at the time. Beside issues of price and demand fluctuating with developments in the oil market, there was a production problem that Robert faced. Biomass does not carry a lot of hydrogen—but it does contain a lot of carbon. And you have to burn that carbon to access the hydrogen.

“Pennsaco really took off when we found a way to make the hydrogen release more efficiently and less expensively,” Robert explains. “We discovered that we could make large volumes of high purity hydrogen in a proprietary process separate from syngas production. From that point, we decided to pivot away from biofuels and turn the biomass into carbon negative hydrogen.”

“Our approach to hydrogen production through thermal conversion is entirely differentiated from the rest of the industry. We are not producing our hydrogen from syngas, which typically contains low hydrogen yields and requires expensive clean up. Pennsaco’s process is so efficient that it allows

"Pennsaco's process produces 3x more hydrogen per ton of biomass than competitors, electricity to power the system, and excess electricity that's send to electrolysers for more h2 production."

us to produce three times more hydrogen per ton of biomass than competitors, enough electricity to power our system, and excess electricity that we send to electrolysers for additional hydrogen production capability. There is nothing producing more high purity, carbon negative, low-cost hydrogen on the market today."

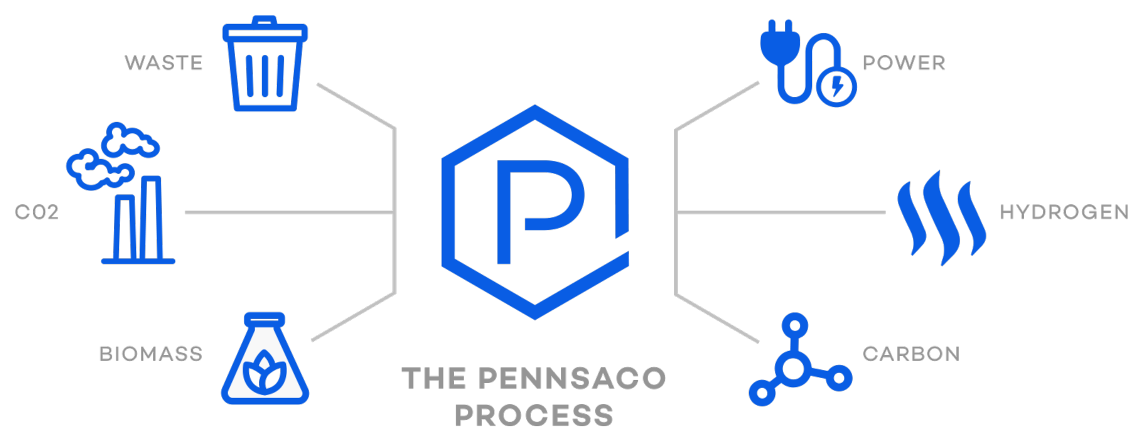
While Pennsaco's ability to produce large volumes of fuel cell quality renewable hydrogen at low-cost addresses renewable hydrogen industry scaling and cost concerns, the real breakthrough came with a solution to the problem of the carbon. One of Pennsaco's main assets now is its production of biochar— making it "a carbon negative hydrogen technology", Amy says.

"If you run biomass through our thermal conversion process you inevitably end up with a carbon product," Amy explains. "The original technology was designed to create a high-end activated carbon product, which could be used for air and water purification systems or in catalytic converters. To optimize the carbon negativity of our hydrogen, we decided to maximize the amount of carbon from biomass we could permanently capture in that highly activated carbon product and produce biochar - for use in regenerative agriculture and climate change mitigation."

As Amy and Robert explain, for every tonne of biochar, three tonnes of CO_2 are removed from the biogenic carbon cycle and permanently sequestered in the earth through agriculture. Biochar increases the carbon content of the soil, helping to improve crop yields and increasing water retention, while reducing the need for fertilisers and pest controls compared to conventional soils.

Most importantly, biochar enables the permanent removal of CO_2 from the atmosphere. And with companies such as Microsoft and Stripe buying biochar carbon removal credits for their carbon

Imgae 1: The Pennsaco Process



portfolios, Pennsaco's system offers a potentially lucrative model for a carbon negative industry.

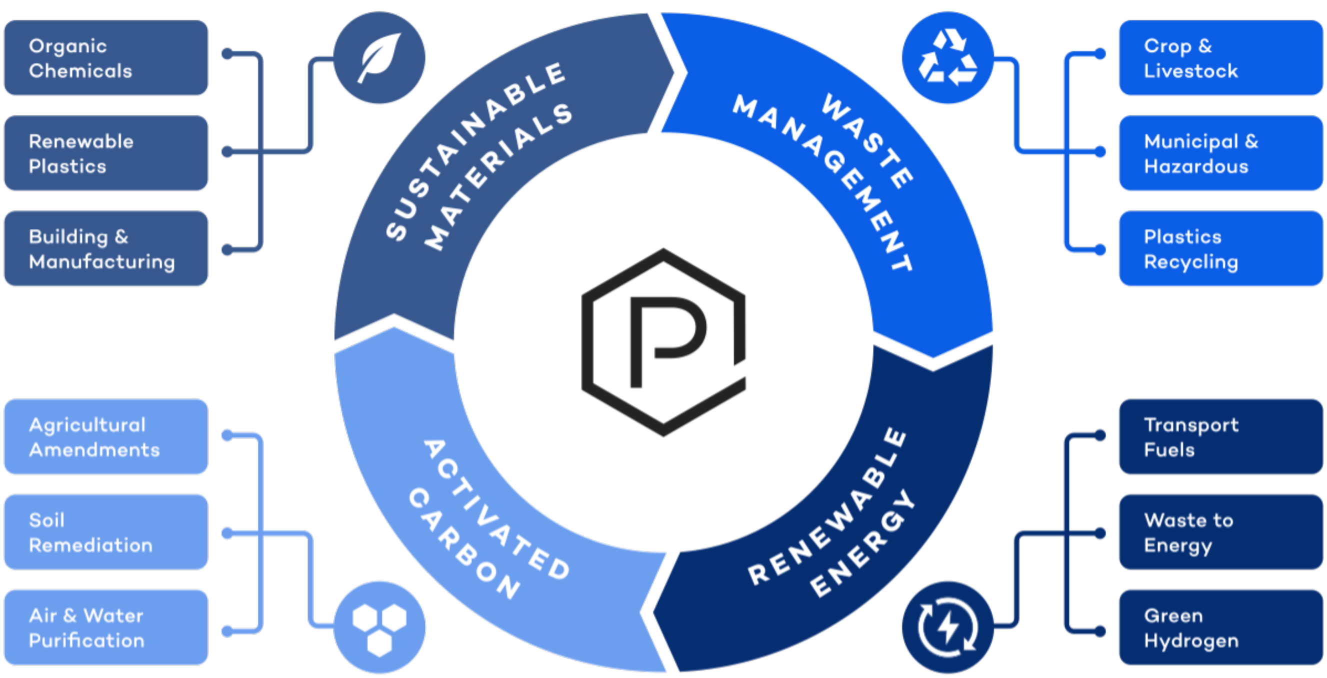
But what makes Pennsaco's technology stand out?

"That's simple. We do what we do with a 30% greater efficiency than similar technologies, capture 95% of feedstock BTU, produce three times more hydrogen per ton of feedstock, and do it at a much lower price. We also address scaling, cost, and speed of deployment challenges faced by green hydrogen from wind or solar to electrolysis: we produce four times the hydrogen yield per megawatt at a fraction of the price, we aren't constrained by electrolyser capacity, cost, or availability to scale, we have a compact footprint, use a third of the water, and don't require hundreds of millions of dollars in infrastructure costs to produce industrial and utility scale volumes of renewable hydrogen," Robert tells us. "Meanwhile, a single site can convert hundreds of thousands of tonnes of waste and CO2 that would otherwise end up as landfill or greenhouse gases into millions of kilograms of carbon negative hydrogen for the transportation, energy, and industrial decarbonisation sectors and tens of thousands of tonnes of biochar for carbon removal and regenerative agriculture annually."

"Our job now is to show the world the benefits of this technology. Right now, there is an overwhelming preference for using electrolysis to create hydrogen—and so much investment is going into scaling the world's electrolysis capacity. But using renewable energy such as wind and solar to generate green hydrogen through electrolysis costs six times as much as making hydrogen through Pennsaco's thermal conversion technology, will never have carbon removal capability, must compete for wind and solar resources allocated to decarbonising the electric grid by governments around the world, will take decades to scale, and does nothing to address the tens of millions of tons of CO2 we need to be removing annually from the atmosphere between now and 2050 to meet global goals of limiting climate change to 1.5C."

"Really, our established technology could do a lot to change the world." HS

Image 2: The Operation Model



Key Features:

Company Focus: Community to support low-carbon **technologies Interview with:** Erik Steeb, senior technical leader of technology innovation

Website: Www.LowCarbonLCRI.com

Twitter: @LowCarbonLCRI

LinkedIn: Low-Carbon Resources Initiative

FEATURE

EPRI

Electric Power Research Institute: Driving Research into Electric Power

Author: Christina Abou Char

The Electric Power Research Institute (EPRI) is a non-profit research and development (R&D) organisation that is celebrating its 50th year in 2022. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe.

We sat down with Erik Steeb, senior technical leader of technology innovation at EPRI, to understand more about the organization, its Low Carbon Hydrogen Accelerator (LCHA) project, and its deep decarbonisation goals for 2030 and beyond.

So, let's start from the top. How can we describe EPRI's work?

"EPRI produces research into the electricity value chain, from production, through transmission and distribution, to end-use," Steeb tells us. "In other words, we focus on how energy is produced, moved and used." "Our work is by necessity highly collaborative, working with stakeholders around the world to ensure our electric power system continues to meet the needs of society."

Decarbonisation in the electric power industry is an important aspect of our R&D in looking at opportunities to increase zero-carbon supply, while ensuring the electricity grid remains reliable, efficient, affordable, and flexible enough to support large and intermittent loads.

Yet, research into and changes in power production and the electricity grid won't be enough to meet the world's decarbonisation goals all by itself, Steeb says. "We're also working to help decarbonise other sectors around the economy as well. Much of the work we do in the energy end use area is focused on the electrification of buildings, transportation, and commercial and industrial processes."

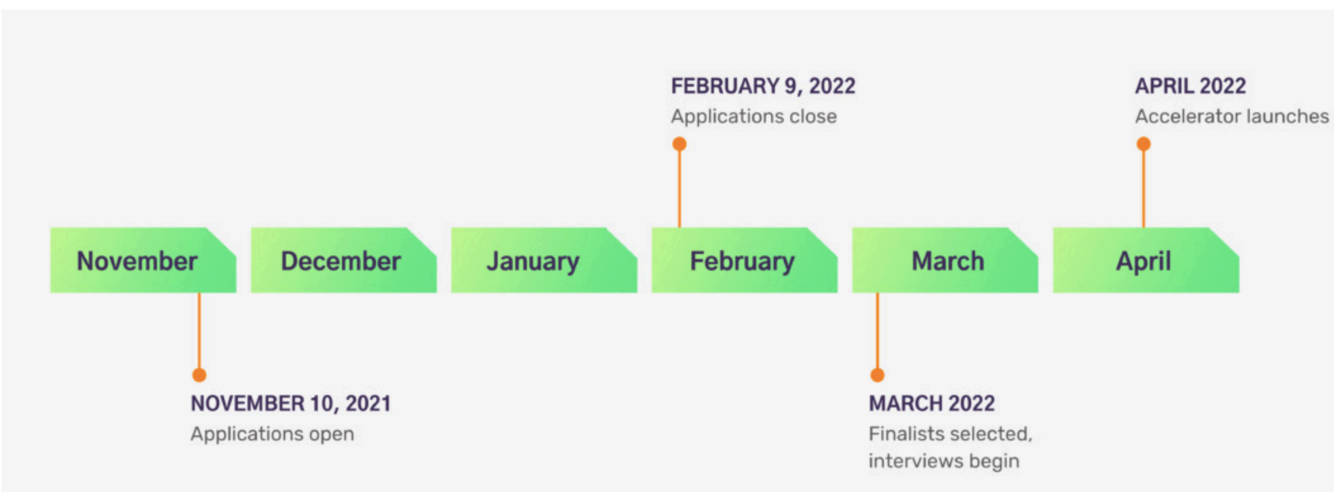
"The trouble is, Steeb adds, "that some sectors of the economy are really difficult to electrify and will require low-carbon fuels like hydrogen and ammonia."

"EPRI's Low Carbon Resources Initiative (LCRI), launched in 2020, is a multi-year collaboration across the electricity and gas sectors to enable such solutions. With more than 50 sponsors so far, the initiative is bringing together investor-owned utilities, municipal utilities, original equipment manufacturers and more to accelerate the deployment of low-carbon technologies. While much of this innovation will come from existing industry leaders, it's important that we also engage the startup community. That's where the LCHA comes in."

So, what is the LCHA? It's collaborative effort between EPRI, Shell, and the City of Houston (the hydrogen capital of the world)—alongside Greentown Labs and the Urban Future Lab (UFL) at the NYU Tandon School of Engineering. The LCHA is an initiative intended to facilitate innovation and support startups creating solutions that enable hydrogen as a low-carbon energy source.

"This group represents an unparalleled mix of talent and resources. As incubators, Greentown Labs and the UFL lead startup outreach and coordinate the program," he explains. "EPRI brings our research and development capabilities and utility connections to support the test and demonstration of promising solutions and Shell brings industry leading R&D, partnership opportunities, and a global reach to help carry promising energy

Image 1: Timeline Overview



solutions and products to scale to enable a leading position in hydrogen."

"It's an amazing blend of resources and together, we offer startups support with technology validation and demonstration—with access to testing facilities, technical experts, and demonstration sites that help create pathways to scale."

"For our first year, we plan to engage six to eight startups with a focus on low-cost green hydrogen generation, storage and distribution, digital solutions, and new business models that enable hydrogen adoption," he adds. "We're working closely with Shell to understand which companies would benefit most from the pool of resources available within the accelerator."

Ultimately, for Steeb and his colleagues at EPRI, the emphasis regarding decarbonisation should remain on collaboration:

"There's a tremendous amount of work to be done to hit the net zero goals by 2050," he says. "And the reality is that no single organization will be able to achieve this by themselves. But that's exactly the value of projects like the LCHA and our collaboration with Shell, Greentown Lab, UFL, and the City of Houston—and that's part of why we're so proud to be part of it." HS

FEATURE

PROTIUM

Key Features:

Company Focus: Facilitating hydrogen infrastructure

Interview with: Chris Jackson, Co-Fouinder and CEO

Website: Protium.green

Twitter: @Protium18

LinkedIn: Company Profile

Facilitating Green Hydrogen Infrastructure on the Road to a Zero-Carbon World

Chris Jackson set up Protium to build green hydrogen infrastructure for companies in heating, transport, and other industries—for people and the planet.

"Businesses across the world and up and down the value chain are aiming to be net zero by 2050—but this will pose a big challenge for so many of them. To make it a reality, businesses need a structure that is commercially viable and technically proven. That's where we at Protium can help."

Chris Jackson is the managing director at Protium, a green hydrogen energy service company (HESCO) that helps industries to reach net zero. Protium does this by building green hydrogen infrastructure at all stages of the hydrogen production chain—from production to storage and use. In practice, that means designing, developing, and operating green hydrogen solutions so companies can achieve net zero emissions.

"If Protium is not having a material impact on reducing CO2, then we are just wasting our time," Chris says with a certain frankness. "We want our clients to achieve their sustainability targets—but it's our aim to decarbonise at least one million tonnes of CO2 per year in each of the markets we work in too."

For a company with 26 employees over two office spaces, this now feels achievable for Protium. Yet the company has grown fast since 2015, when Chris was a student at SAIS John Hopkins University in Bologna, Italy.

There he was taught by Professor Marco dell'Aquila, an adjunct professor in renewable energy project finance. After university, Chris then wrote a paper on decarbonising the mining sector with hydrogen—and soon managed to persuade the World Bank, where he was working, to provide funding for green hydrogen research.

Throughout his research, what Chris came to realise was that the challenges of decarbonisation were not due to a lack of technology. Rather, the problem was that the various components required to decarbonise businesses needed to be pulled together. What was required was a company that was willing to take the risk offering these holistic solutions.

Chris got back in touch with Marco, pitched the idea of Protium, and together they set to work. Now, the company still works in the two industries in which Chris wrote his original paper:

"We work primarily on consumer facing industrials, whose usual peak demand is industrial grade heat and commercial transport. There, hydrogen use has always been a little controversial, but we think it can really make a big difference to the day-to-day lives of end consumers. Then there's transport, where we're contributing to net-zero by using green hydrogen in things like trucks."

But while playing a big role in the HESCO space, Chris is not interested in using hydrogen in these industries just because.

"In whichever industry you are working in, or whatever use case you are exploring," he explains, "you have to ask the question: does hydrogen provide the best solution to this problem? In some cases, batteries can offer better solutions to problems, but in others hydrogen simply does the job better. Ultimately, the energy transition is about how people can improve their quality of life, living standards and environment. It's not just a fuel-switching exercise."

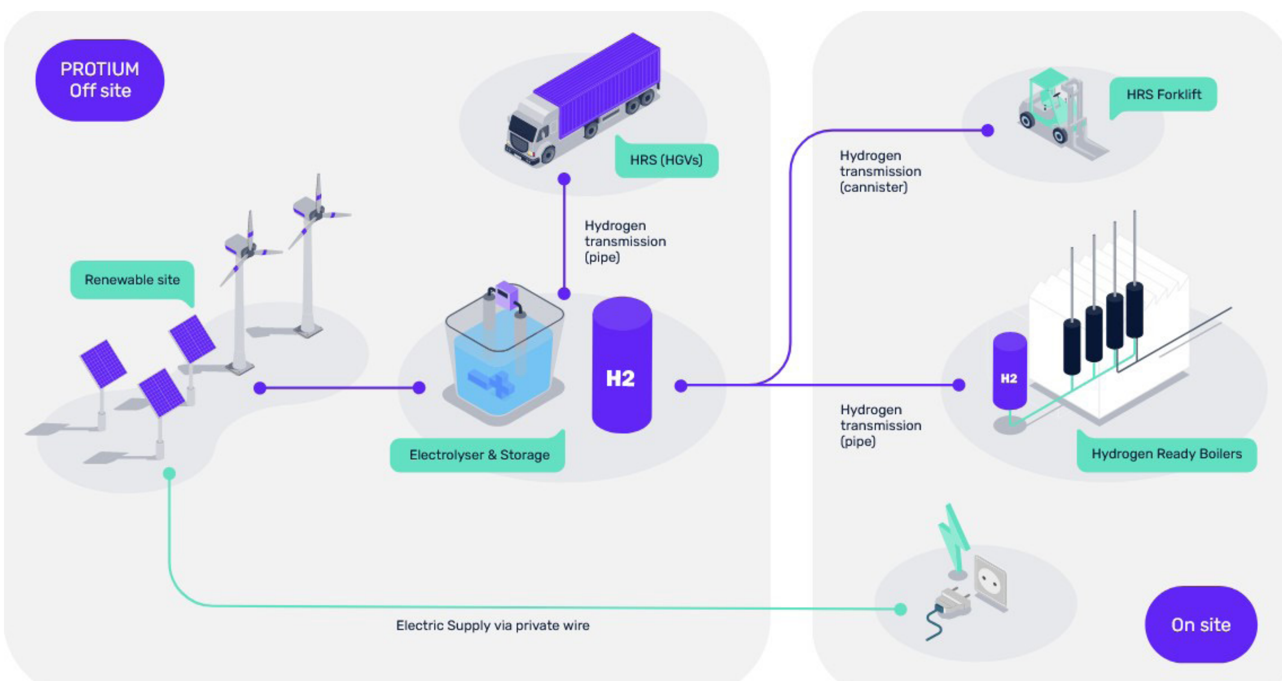
Instead, Chris suggests three crucial factors in any decarbonisation strategy: consumer awareness, a level regulatory playing field across all energy companies, and realism about the world's current capabilities.

"Business need more help to educate their consumers of the value of using green hydrogen, but the whole industry is being held back by different regulations across countries," Chris explains. "Right now, we need to scale manageable projects in bitesize chunks to minimise risk and encourage investment. Later on, we can all step up to much bigger projects."

For Chris, ultimately, the energy transition is about more than just markets:

"It's about people," he says. "I want to encourage the young to avoid the temptation to go into high-paying finance roles. Instead, they should join us in the efforts to decarbonise industries, in order to generate a more sustainable future society."

Image 1: Overview of HESCO: Transforming Energy Services with Hydrogen



Green Hydrogen Production: Could It Cause a Short-Term Reliance on Fossil Fuels?

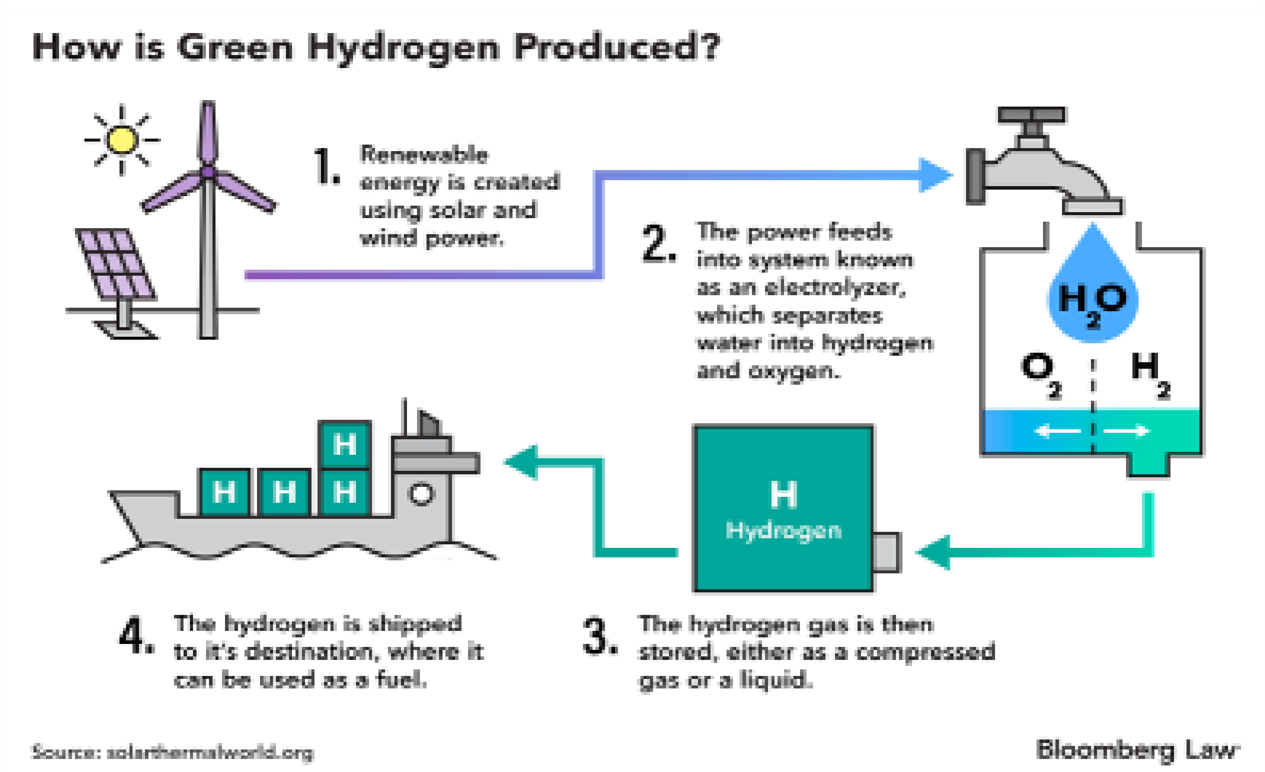
Athor: Afriyie Ankamah

As the world moves towards cleaner and more renewable energy in the bid to decarbonise, the current renewable electricity supply may not be enough (at least in the short term) for all competing end uses. With transportation, industry, and domestic users all demanding clean energy, there might not be enough supply to keep up. This is argued by a group of researchers at the Potsdam Institute for Climate Impact Research (PIK) in Germany, led by Dr. Falko Ueckerdt.

Figure 1 below provides a simple explanation on how green hydrogen is produced from renewable energy sources.

Before we delve more into the discussion, let's check out some numbers on primary energy consumption (which is essentially the total energy demand). This information is for 2020 and provides a perspective of the percentage shares in the energy mix per sources.

Figure 1. Green hydrogen production from renewable energy sources



On the global stage:

- Renewables accounted for less than **6%** share of the world's primary energy consumption.
- Fossil fuels, on the other hand, occupied over **80%**, with oil as the largest contributor followed by coal and natural gas.
- The Middle East was the region with the highest reliance on fossil fuels, which made up over 95% of their energy mix.
- Europe and South and Central America led the share of **renewables** with both regions having slightly over **10%** each.

In the UK:

- According to BPs Statistical Review of World Energy, the UK's share of renewables in the primary energy consumption was 17% while that of fossil fuels were over 76%.
- The share of the energy sources in electricity consumption changes across the 24-hour daily period based on the demand, with renewables reaching peaks of 40%.

The percentage of renewables and fossil fuels in the energy consumption mix varies based on demand. It also shows that currently, the amount of renewable energy in the consumption mix is very small—just 6% globally. This is the same pool of electricity from which green hydrogen will be tapped.

Could there be any issues with the overall decarbonisation when the push for green hydrogen production speeds up?

Issues with the massive push for green hydrogen production:

Right now, demand is heavily supported by fossil-fuels, as renewable capacities are still not sufficient to entirely decarbonise the grid as argued by the International Energy Agency (IEA).

According to the IEA, achieving net zero by 2050 requires over 300 million tonnes of green hydrogen each year. This will require about 14,500TWh of electricity, or 20% of the global electricity supply.

The Guardian newspaper quotes Dr. Falko Ueckerdt saying, "If we cling to combustion technologies and hope to feed them with hydrogen-based fuels, and these turn out to be too costly and scarce, then we will end up burning further oil and gas".

The introduction of new end uses such as green hydrogen without a similar pattern of renewable electricity generation is likely to put a strain on current renewable electricity supplies. At the same time, the pace required by the net-zero emissions scenario may be limited by inadequate renewable electricity generation.

If 20% of the global electricity supply is diverted to hydrogen production, this will result in very much needed renewable electricity being diverted from the grid to power these electrolysers for hydrogen production.

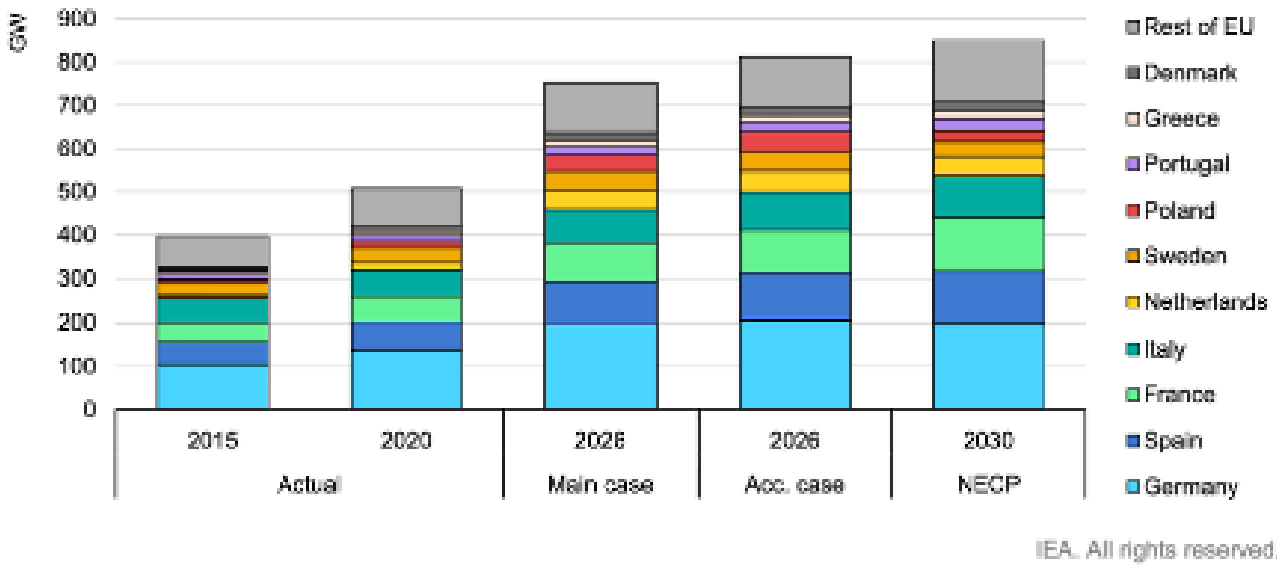
The push for green hydrogen production can jeopardise the quantity of renewable electricity to the grid, causing a reliance on fossil power in the short term.

The Push for Green Hydrogen

But it is not all *doom* and *gloom*:

To decarbonise the grid and other sectors while supporting green hydrogen production, there should be enough renewable electricity generation capacity installed.

Figure 2. Installed renewable capacity and capacity expected in 2030.



Note: Acc. case = accelerated case, NECPs = National Energy and Climate Plans
Source: IEA analysis based on NECPs.

International Renewable Energy Agency (IRENA) recommends adequate renewable electricity should be made available for both hydrogen production and for other end uses.

Similarly, IRENA has recommended targets to be set for electrolyser capacities as part of policy support for green hydrogen production. An example of such is the 80GW target to be achieved by 2030 set by the European Union.

They argue this approach should be similar to the one used for incentivising investments like the renewable energy targets.

Key Takeaways
If the rapid push for green hydrogen production is not strategically aligned with the supply of adequate renewable electricity, the amount of electricity available for other electrification sectors will diminish.

This will create a scenario where fossil-based electricity will have to be relied on to meet the electricity demand.

Green hydrogen production targets should be strategically set alongside renewable electricity generation targets to create a healthy balance in supply and demand of renewable electricity.

Specific areas with over supply of renewable electricity could be a focus when choosing a location for electrolysers for green hydrogen production.

This will help to mitigate losses from the curtailment of renewable electricity in these areas while at the same time the excess electricity generated is diverted to produce green hydrogen.

The development of renewable electricity capacity should be an important focus for policy makers and ambitious targets should be set for these projects.

Big Oil to Big Hydrogen: Analysis of Hydrogen Economy Planning at China's Three Big Oil Majors

This is a free article from the China Hydrogen & Fuel Cell Monitor. Available HERE

China has three big state-owned enterprises (SOE) in the oil and gas sector, colloquially known as the "Three Barrels of Oil." The three are: China National Offshore Oil Corporation (CNOOC), PetroChina, and SinoPec. All three have plans for the hydrogen economy with an emphasis on hydrogen production and the operation of hydrogen refueling stations (HRS) for fuel cell electric vehicles (FCEV).

The Hydrogen Economy and the Three Barrels

Of the "Three Barrels," CNOOC has the lowest level of activity in the hydrogen energy sector, with an apparent exclusive focus on generating green hydrogen by electrolysis of water powered by offshore wind. CNOOC focuses on offshore oil exploration and extraction so a focus on green hydrogen from offshore wind is in-line with the firm's resources and mission. CNOOC created a clean energy subsidiary in February of this year to focus on hydrogen and e-fuel production. Green hydrogen produced in this way has also been written into CNOOC's corporate strategy, as announced in September of this year.

The middle-ranking in terms of activity level in the hydrogen economy is PetroChina. Though the firm plans to build fifty HRS in the coming years PetroChina's focus is on north China, notwithstanding individual HRS projects in Wuhan, Shanghai, and Guangzhou. These individual projects, all of which took place over the past few years, were probably designed to trial key technologies, such as: 700 bar HRS equipment, joint petrol-hydrogen stations, and blue hydrogen production using green hydrogen and CCS technology. PetroChina recently established a hydrogen technologies research center thus showing a focus on key technology breakthroughs as opposed to market share.

Figure 1. Brands of the Three Oil Majors in China

CNOOC is limited by mission; PetroChina is limited to north China and technology R&D; in contrast, SinoPec has made the transition from grey to green hydrogen a core part of the firm's corporate strategy. Indeed, while CNOOC's hydrogen production is the smallest of the three and PetroChina produces around 2.6 million tons a year, SinoPec produces 3.5 million tons a year, making the firm the largest producer of hydrogen in China. Unlike PetroChina, SinoPec is investing in hydrogen production - especially in Inner Mongolia and Xinjiang, in the far northwest - not as simply another oil by-product but as a potential oil replacement. Of the Three Barrels of Oil SinoPec has the grandest plans both for hydrogen production and for large-scale HRS roll-out in China.

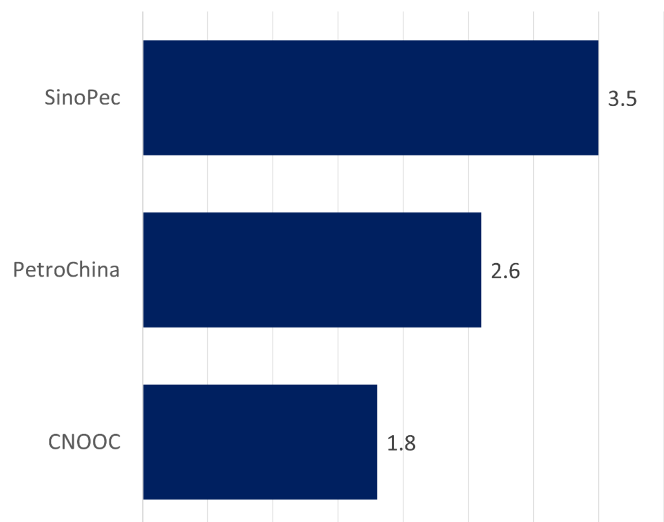
Upstream Hydrogen Production

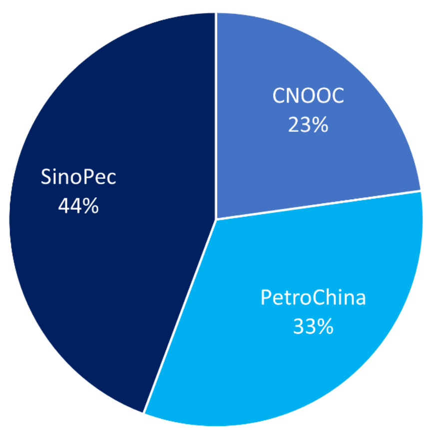
PetroChina North China Corp., a division of the larger company, is developing twenty hydrogen purification projects in north China as part of a larger goal to create "blue" hydrogen and e-fuels such as methanol and ammonia from "white" by-product hydrogen and CO2 obtained from carbon capture and storage (CCS) technology. Though PetroChina signed a hydrogen supply agreement with SinoHyKey, a membrane electrode assembly (MEA) manufacturer in Guangzhou, and JZY propane dehydrogenation (PDH) in Dongguan, the firm's focus is squarely on north China, especially two new markets: Xiong'an New District, a new Beijing suburb, and the Zhangjiakou Winter Olympics, scheduled for 2022.

SinoPec may be China's largest hydrogen supplier - but most of that hydrogen is "grey" hydrogen, or hydrogen reformed from coal and natural gas with carbon pollution. At 3.5 million tons of hydrogen per year, SinoPec may be China's largest single producer but still only produces 14% of the total in the country, thus showing the decentralized nature of hydrogen production in China.

Earlier this year SinoPec announced two green hydrogen projects - like PetroChina, also in Inner Mongolia and Xinjiang - to be online by 2022 and powered by 510 MW of solar. Consider that worldwide electrolyzer capacity in 2020 was just 200 MW; SinoPec's planned installation would more than double world green hydrogen capacity. And if this initial announcement was not stunning enough, SinoPec recently updated the timeline for the Xinjiang facility - with the new expected date of completion in October of this year - and expanded

Figure 2: Estimated Million Tonnes of Hydrogen Production (LHS) and MArket Share (RHS) Among the Three Oil Majors in China





capacity from 510 MW to 1000 MW – or one GW – of power to operate electrolyzers with capacity to produce 20,000 tons of hydrogen per year. SinoPec's "super-project" in Xinjiang may be the world's largest green hydrogen production venture by a very large margin.

Further evidence of SinoPec's commitment to green hydrogen was evident at a signing ceremony in Beijing in July of this year where the firm announced projects with firms as diverse as State Power Investment Corporation (SPIC), China Mobile, Dongfang Electric Corporation (DEC), and China Guangdong Nuclear (CGN), among others. SinoPec's stated strategic goal is to not only implement China's "Carbon Peak 2030, Carbon Neutral 2060" industrial policy goal but also to implement the firm's own "One Base, Two Arms, Three New Developments" program. In this program, SinoPec is the "base," energy resources and clean and modern oil and chemical products are the "arms," and new energy, new materials, and new economy are "new developments."

Downstream Hydrogen Applications

PetroChina built pilot hydrogen refueling stations (HRS) in Wuhan in 2018 and in Beijing in 2019 and 2020 but didn't operate the actual stations. However, earlier this year, PetroChina both built and announced the operation of the Zhangjiakou City Taizi City Service Area HRS, colloquially known as the Taizi HRS. This facility is located in the Chongli Winter Olympics Games District, a satellite site for the 2022 Winter Olympics. Unlike previous HRS this facility will be operated by PetroChina to serve a local fleet of 50 FCEV buses. In the future PetroChina plans to build only around 50 HRS, mostly concentrated in northern China.

In contrast to PetroChina, SinoPec began work on 27 HRS in 2020 alone, mostly concentrated in eastern and southern China. A representative SinoPec HRS in Shanghai supplied more than 200 tons of hydrogen over two years to FCEVs operating in Jiading District. As part of the firm's long-term strategy to replace oil with hydrogen, SinoPec estimated the 200 tons of hydrogen in Jiading displaced about 660 tons of Diesel fuel. In addition to the 27 HRS announced in 2020, SinoPec plans to build 30 HRS in Shanghai and 20 in Guangzhou; one source claimed SinoPec could ultimately build more than 1000 HRS or petrol-hydrogen joint stations around China.

Big Oil to Big Hydrogen

China's Three Barrels of Oil have each shown both different levels of commitment to the hydrogen economy and also different focus areas. CNOOC has shown the lowest level of interest and appears focused on ocean-based wind-to-green hydrogen; PetroChina has shown medium interest and appears jointly focused on the north China region and also on "blue" hydrogen; finally, SinoPec has shown the greatest interest in the hydrogen economy and is focusing on the transition from grey to green hydrogen. In terms of downstream applications, while CNOOC has not announced any HRS, PetroChina has announced more than 50 nationwide and SinoPec more than 30 in Shanghai alone with future planning having, evidently, only the sky as the limit. HS

State of the MEA Industry in China

This is a free article from the China Hydrogen & Fuel Cell Monitor. Available HERE

Part I: Markets & Production

Recent calls for "self-sufficiency" in the fuel cell industry in China have become almost shrill regarding the perceived need to localize production of membrane electrode assemblies (MEAs). An outside observer might make the observation that such calls for "home-made" MEAs indicate that China lacks the facilities or experience to make what is often considered a key component for fuel cells.

In fact, firms in China have been manufacturing MEAs for export since the early 2000s. Wuhan University of Technology (WUT), now owned by Shenzhen Vision, made MEAs for small, US-based fuel cell firms that were later acquired by PlugPower. To cite another example, Dongyue Membranes built MEAs for the Automotive Fuel Cell Corporation (AFCC). As with many industries in China, there is not a gulf between "national" and "foreign" capabilities but rather a disconnect between China's world-class "built-for-export" industry and its developing "domestic consumption" industry; the fuel cell sector seems to be no exception.

This disconnect is evident in figures for MEA use in FCEVs operating in China. According to data updated in February of 2021, around 70% of MEAs installed in China were imported. Multiple sources claim the MEA market in China will reach a value of more than 80 billion RMB by 2035. Understandably, China wants to encourage domestic producers to increase market share to benefit from this developing market.

Now owned by Shenzhen Vision, the MEA production facilities at the Wuhan University of Technology (WUT) are notable for a very fast production line, claiming a pace of 5 m/min. WUT also claims to have built the first catalyst-coated membrane (CCM) production line in China, probably in 2012, though WUT has been producing MEAs for export since 2006.

Dongyue Membranes (DY) started exporting MEAs as early as 2008 and claims energy density of 1.2 W/cm2. (See part II: Technology Development).

A notable new player is Shanghai Tangfeng, a spin-out from Shanghai Traffic University, specializing in low-Pt MEAs. Like all MEA manufacturers, Tangfeng claims high energy density, around 1.5 W/cm2 and lifetime of 10,000 hrs. Tangfeng recently received more than 100 million RMB in a B-round of investment.

Shanghai FTXT, a fuel cell manufacturer owned by Great Wall Motors (GWM), recently installed a roll-to-roll production line for MEAs and appears to be preparing for volume production, probably to supply FCEV sedans built by the GWM group. FTXT also owns 10% of a MEA production facility in Dalian, which may be associated with the Dalian Institute of Chemical Physics (DICP), a traditional leader in the fuel cell industry in China.

DICP claims to have developed a novel, low-Pt, nanofiber MEA that enables current density of 1.5 A/cm2 even at low pressures (0.2 MPa). MEA R&D at DICP is focused on water management and chemical stability.

SHPT, also in Shanghai, claims to have the world's largest roll-to-roll MEA production line, which includes materials mixing, coating, etc. and can produce a complete 7-layer MEA. SHPT is focused on volume production (with a rate of 5 m/min) and production accuracy.

The last major MEA producer in China is Hydrogine (not to be confused with "hydrogen"), based in Suzhou, and invested in by the Shenneng Group, based in Shanghai. Hydrogine claims to have lowered Pt use by 75% from market standard. Hydrogine MEAs may be installed in fuel cell systems (FCS) in as many as 200 vehicles currently on the road.

Other firms interested in the potentially lucrative MEA industry include Na'er, based in Shanghai, which specializes in digitally controlled spraying for printing materials. Na'er has also invested in a CCM production line.

Dongfang Electric Corporation (DEC), a major, national-level state-owned enterprise (SOE) based in Chengdu, recently announced a new MEA production facility in Beijing. DEC also has fuel cell stack and system production facilities. The investment in Beijing shows how some fuel cell firms in China are responding to calls to localize MEA production - and thus keep more of the value-chain in China - by moving to replace foreign suppliers with in-house components.

Yet another example of a fuel cell manufacturer developing MEA capabilities is Pearl Hydrogen, based in Shanghai. Pearl built a new facility in Fuyang City with MEA production capacity of more than 350,000 m2. Pearl expects to specialize in extra-wide, precision-coating MEA production.

In addition to the above dedicated MEA producers and fuel cell firms investing in MEA production several smaller firms have focused on research and technical breakthroughs. The Guangdong Institute of Energy Conversion (GIEC) recently tested an MEA with current density of 3 A/cm2. Two firms associated with Nanjing University - Sang-Lai-Te in Kunshan and Dongyi in Nanjing - have a long history in MEA development. Also in that part of Jiangsu Province is ThinkRe, based in Suzhou, with the memorable website: bestpem.com.

The image is an overview of current and future production in the MEA market in China as well as an introduction of major players, new entrants, and leading researchers in the industry.

Part II: Technology Development

Membrane electrode assemblies (MEAs) would seem to be limited by an apparent paradox of design: the thinner the actual membrane, the lower the voltage loss, the higher the efficiency; however, at the same time, the thinner the membrane the higher the gas diffusion from the anode (hydrogen) side to the cathode (air) side. MEA designers are thus faced with the challenge of making the membranes very thin and efficient, but not likely to last very long, or thick and durable, but relatively inefficient.

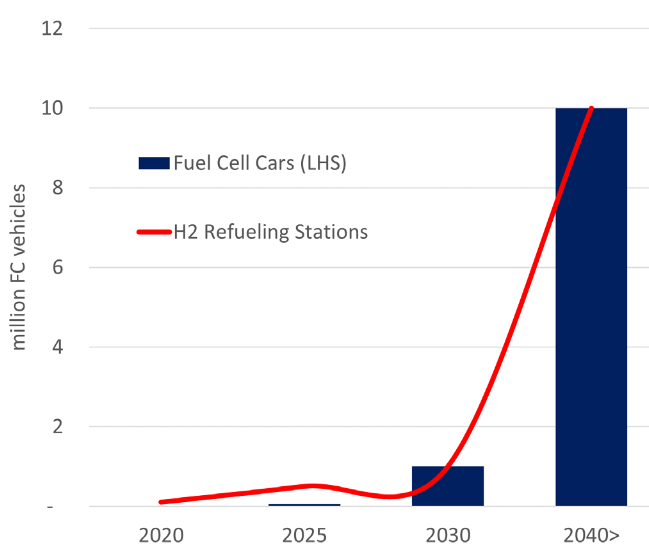
In China the MEA is often understood as the actual proton exchange membrane (PEM) coated on either side by a catalyst which is then coated by a gas diffusion layer (GDL), usually in the form of carbon paper. The total structure of the MEA therefore is 1 + 2 + 2 = 5, also known as a 5-layer MEA. Adding a final layer of framing to strengthen the MEA creates a 5 + 2 = 7, or 7-layer MEA.

Key design requirements for MEA manufacturers looking to enter the fuel cell market in China include: extended reversal tolerance, high ion conductivity, chemical stability (especially against caustic base chemicals and oxidation), high thermal stability, high technical strength, low gas diffusion from anode to cathode sides, and of course low price.

Many firms in China believe the key component of the MEA is the CCM and that the key component in the CCM is the catalyst, most often platinum (Pt). A few R&D laboratories in China are trying to lower cathode-side Pt concentrations to
≤ 0.12 g/kW, in-line with figures reported from the Toyota Mirai. However, even Toyota only recently lowered Pt content from 0.18 g/kW to 0.13 g/kW, showing that the 0.12 figure is a reach even for the world's leading FCEV manufacturer; it is unlikely domestic firms will meet such a figure in the near-term. Despite efforts to lower Pt loading while maintaining high efficiency, most firms in the fuel cell industry in China believe that the Pt loading cut-off point is ≈ 0.50 g/kW, above which point are domestic suppliers and below which are foreign suppliers.

Platinum is the most commonly used catalyst for MEAs for the fuel cell industry; it is also a precious metal and expensive. Therefore the ideal fuel cell uses less platinum for a higher power. Lowering platinum loading, however, can increase proton movement polarization at high currents, cause membrane deterioration at high electric potentials, and limit reaction of hydrogen protons with oxygen during fluctuating load profiles. The FCEV application, in particular, is known for fluctuating load profiles.

Figure 1: Planned Fuel Cell Car Sales and Hydrogen Refuelling Stations in China



A rule of thumb in China is that the MEA forms half of the stack cost and the stack forms half of the system cost. The average price of MEAs in China is around 400 RMB/piece, though scale production has recently lowered this price to as low as 300. Power density of MEAs in China averages between 0.75 ~ 1.00 W/cm2 at 0.6 V.

Major foreign MEA suppliers to the China fuel cell industry include Johnson Matthey (JM), 3M, Toray - the new owner of Greenerity - and Gore. The latter especially has drawn attention in China with claims of high durability at MEA thicknesses reduced from 18 to ≈ 8 μm.

The fuel cell market in China will continue to demand MEA products with long lifetime, high durability, low membrane degradation rate, and of course low prices. HS

This is a free article from the China Hydrogen & Fuel Cell Monitor. Available HERE

Industry Focus: Near-Term Sources of Hydrogen for Direct Reduction of Iron (DRI) Steelmaking in China

This is a free article from the China Hydrogen & Fuel Cell Monitor. Available HERE

The direct reduction of iron (DRI) process for steelmaking requires a hydrogen-rich syngas. In countries with cheap natural gas methane can be used directly in the DRI process; in countries with expensive, integrated renewables green hydrogen from electrolysis can be used as the DRI fuel.

China however, though possessed of a large renewable base, nevertheless has very few large-scale, grid-connected electrolyzers and also has very expensive natural gas, though unconventional natural gas is available in small quantities in the country. As a result, a recent study by the China International Steel Research Institute (CISRI) recommends that DRI projects make use of syngas extracted from a resource China has in abundance: coal.

The study from CISRI recommended three coal-based routes to producing syngas for use as a reducing agent in the DRI process: direct gasification of coal, coke oven gas (COG), and enriching of low-grade coal (LGC).

Direct coal gasification, while not as clean as producing coke, is still relatively cleaner than simply burning the coal for heat. Gasifying the coal results in a hydrogen-rich syngas. Many of the impurities in the syngas, such as carbon monoxide (CO), can be converted into either more hydrogen by injecting steam (H_2O) into the process, increasing the richness of the syngas, or into carbon dioxide (CO_2), a less dangerous emission gas.

In addition to the water-gas shift reaction - also common in methanol reforming hydrogen generators - the coal gasification process also includes a step to extract hydrogen sulfide (H_2S) using a pressure-swing adsorption (PSA) purifier as well as equipment to recapture purge gas. The resulting hydrogen-rich syngas can be used directly in vertical blast furnaces for DRI. Coal gasification is already the most common source of hydrogen in China today.

Baking coal removes gases and other impurities and results in "coke," a dense, carbon-rich fuel that burns hotter and with less smoke than the original coal. Of the off gases released during this "carbonization" of coal 60% is hydrogen with 25% of the remainder methane (CH_4). This methane can be further reformed to produce more hydrogen.

Producing hydrogen from coke oven gas (COG) is a well-understood and mature process in China, according to CISRI. Like direct gasification described above, COG also has impurities that must be removed. In addition to H_2S the COG often has ammonia (NH_3) which can be captured and used in other industrial processes. While co-locating steel plants using DRI technology with coking plants with COG represents a near-term opportunity to use the off-gas as a reducing agent in the steel plant, CISRI warns that, in the long-term, coke production - and thus COG production - will decrease in China as a result of de-carbonization of many energy-intensive industries, such as steelmaking.

Direct gasification of coal and COG may seem like similar processes. Indeed, both remove H2S and result in hydrogen-rich syngas. However, where direct gasification is a continuous process, COG removes methane before separately creating more hydrogen in a reforming reaction. Direct gasification also removes the H2S after the water-gas shift reaction yet COG removes the H2S before the reaction. According to CISRI, the volume of COG required to supply the reducing heat to create one ton of steel is about 620 cubic meters; in contrast, the amount of coal gas required is only 320 cubic meters. Coal gas may be more efficient, but is also more polluting.

A third and final opportunity for utilizing coal to create hydrogen-rich syngas is the enriching of low-grade coal (LGC) with COG. Using LGC to provide heat in thermal power plants is inefficient and releases relatively more pollutants. CISRI suggests high-temperature, pyrogenic decomposition of LGC and COG to produce a more hydrogen-rich syngas.

Why use LGC? China has a greater amount of LGC than of any other type of coal. Furthermore, using extracted syngas from LGC makes high-grade coal available for other purposes. Improving LGC with COG is a near-term way to efficiently use China's coal resources to produce the hydrogen needed for the DRI steel-making process.

The report from CISRI recommends pursuing COG, LGC enrichment, and direct gasification - in that order. The report also mentioned unconventional natural gas - such as from shales - as well as biomass pyrolysis as other ways to extract the hydrogen needed to heat the DRI steelmaking process.

Despite China's large investments in renewables, lack of grid-connectivity, transmission lines, and grid-connected electrolyzers means more investment in infrastructure is needed before China can turn its green power into green hydrogen. For the steelmaking industry, under pressure to decarbonize, hydrogen from coal - by a variety of processes - may be the best, near-term solution to implementing large-scale DRI.

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Figure 1: Steel Making in China

The
Hydrogen
Standard