HEROES OF HYDROGEN

Justin Jin for Hydrogen Europe

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Content

Prologue

History happens, every day. But some historical milestones are more significant than others, affecting countries, continents, and even all of humankind. History with a human impact is particularly significant, with great change brought on simply by the heroic commitment of everyday people.

This book tells the story of heroes making hydrogen the foundation of climate neutrality for many generations to come. They turn their energy and investment into something totally new and take the risk to exploit new challenges; aspiring to something that little children dream of accomplishing when they grow up. The heroes presented in our book try to do exactly that: save our planet earth.

The story is told in pictures and text by an extraordinarily talented photographer. Justin Jin is a British-Belgian international artist who has won a plethora of awards for his work. Justin tells stories with pictures each capable of saying far more than a thousand words, and then tops them with beautifully crafted written texts.

To achieve net zero hydrogen, we need lots of heroes. In this book we focus, amongst others, on four projects across Europe and beyond. Courageous entrepreneurs are putting their business soul into the development of renewably produced hydrogen for many different applications. The stories of our heroes show that history does not happen without catalysts, agents, human beings able to shape it. Hydrogen's human impact has much for which to thank these courageous minds.

If you are reading this and get inspired to contribute, don't hesitate. There are still plenty, plenty of opportunities to make hydrogen the centrepiece of our journey towards carbon neutrality. All we need are more heroes.

Jorgo Chatzimarkakis
CEO, Hydrogen Europe

Story 1

A Green Steel Revolution

Steel is one of the world's most pollutive industries, contributing to 8% of global CO2 emissions. A Swedish steelmaker is aiming at total decarbonisation.

Workers using remote control inject hot iron with carbon-enriched gas at SSAB's blast furnace in Luleå, releasing massive amounts of CO2.

Luleå, Sweden — Steel shines. Steel strengthens. Steel builds entire civilizations. This was the image lodged in Martin Pei's mind. An image so strong, the chief technology officer of SSAB, Sweden's biggest steelmaker company, devoted his entire life to it.

Martin first learnt about the world's most-used alloy growing up in China during the 1960s. As an eight-year-old he was awed by a black-and-white propaganda film, "The Steel Giant", that praised the Communist party's industrial plan. The message set him on the trajectory for a metallurgy degree at a Chinese university. A top student, Martin won the coveted national scholarship to Sweden, a global leader in high-end steel production.

Martin joined steelmaker SSAB in 2001 as research manager and became its CTO and vice president in 2007. In his two decades there, the revenue grew to EUR10 billion in 2021 from EUR2 billion in 2001, while net profits soared to EUR1.5 billion from EUR100 million. SSAB supplies high-strength, wear-resistant steel to companies around the world, from car makers and household appliance producers to the construction industry.

But steel also holds a dirty truth that has haunted the 60-year-old, now a Swedish citizen. The steel industry produces 8% of global CO2. The numbers get worse. At 10% of Sweden's national emissions, SSAB is the biggest polluter in a country particularly concerned with the troubling reality of climate change.

"The current industrial set-up worldwide was built when no one cared about CO2 emission, now we have learnt that is going to kill the planet if we don't change," Martin says.

The greenhouse gas is threatening the entire metals sector too. Clients are under pressure to decarbonise and expect their suppliers to make the transformation too. Carbon taxes are getting higher, and managers are checking environmental credentials when they pick stocks to invest in.

Portrait of Swedish steel-maker SSAB's CTO Martin Pei looking at steel production at a steel mill in Luleå, inside Sweden's polar region.

A steel slab rolls off a production line at SSAB's steel plant in Luleå, inside Sweden's polar region. The iron is melted to 1,500 degrees celcius.

Pollution

Steel is made primarily of iron, found in the earth's crust in the form of iron oxide. Fleets of diesel machines blast cavities in mines, bulldozers haul the crumbling rock to the plant, and more diesel guzzling machines grind them into ore.

A steelmaker such as SSAB using the blast furnace, a technology from the 14th century, melts the ore at around 1,500 degrees Celsius and mixes into it coke -- a grey, porous, carbon-rich material derived from coking coal -- that pulls oxygen out, leaving pure iron. Elements such as chromium, manganese, and carbon are added depending on the customers' needs for strength, anti-corrosiveness, and ductility.

The by-product, however, is a monstrous amount of carbon dioxide. For every tonne of steel made, some 1.8 tonnes of CO2 are released into the air. Each year, the global steel industry is estimated to release some three billion tonnes of greenhouse gas.

That's not all. SSAB buys the three million tonnes of coal its blast furnaces burn each year from the other side of the earth in Australia and USA, compounding the pollution.

"Imagine all these big ships and barges crossing the world's oceans and cruising along big rivers carrying coal to feed the steel industry," says Martin.

A train carrying molten iron leaves a blast furnace at SSAB's plant in Luleå.

Developing a Solution

For years, Martin has been searching for a way to decarbonise this so-called "hard-to-abate" sector where fossil fuel is not only used for energy, but a key ingredient in the chemical process.

Martin first considered the common ways to lower emissions. He tried switching from coal to natural gas, biofuel, and plasma. He also tested carbon capture and storage (CCS). But he couldn't manage to cut emissions by more than half. And even this unsatisfying approach would require prolonged new investments in outdated technology.

There was another method Martin had been researching, but it had never succeeded on a commercial scale.

The technique replaces carbon fuel with hydrogen, the world's smallest, lightest atom, in a process called direct reduction. Using so-called 'green hydrogen gas', produced with electricity from renewable sources, emits nothing but water.

The hydrogen technique has been known for decades, but has never been commercially viable since the infrastructure isn't in place to produce the volatile gas at scale using electrolysis. Green hydrogen also requires expensive renewable energy and until now little-produced machines called electrolysers.

Martin Pei tests an iron pellet inside HyBrit

Workers blast rocks using explosives in the LKAB iron ore mine in Arctic Sweden.

Decarbonising the Source

There was one big player missing. To create truly emission-free steel, they must clean up the entire value-chain, including the mining industry that produces the iron ore.

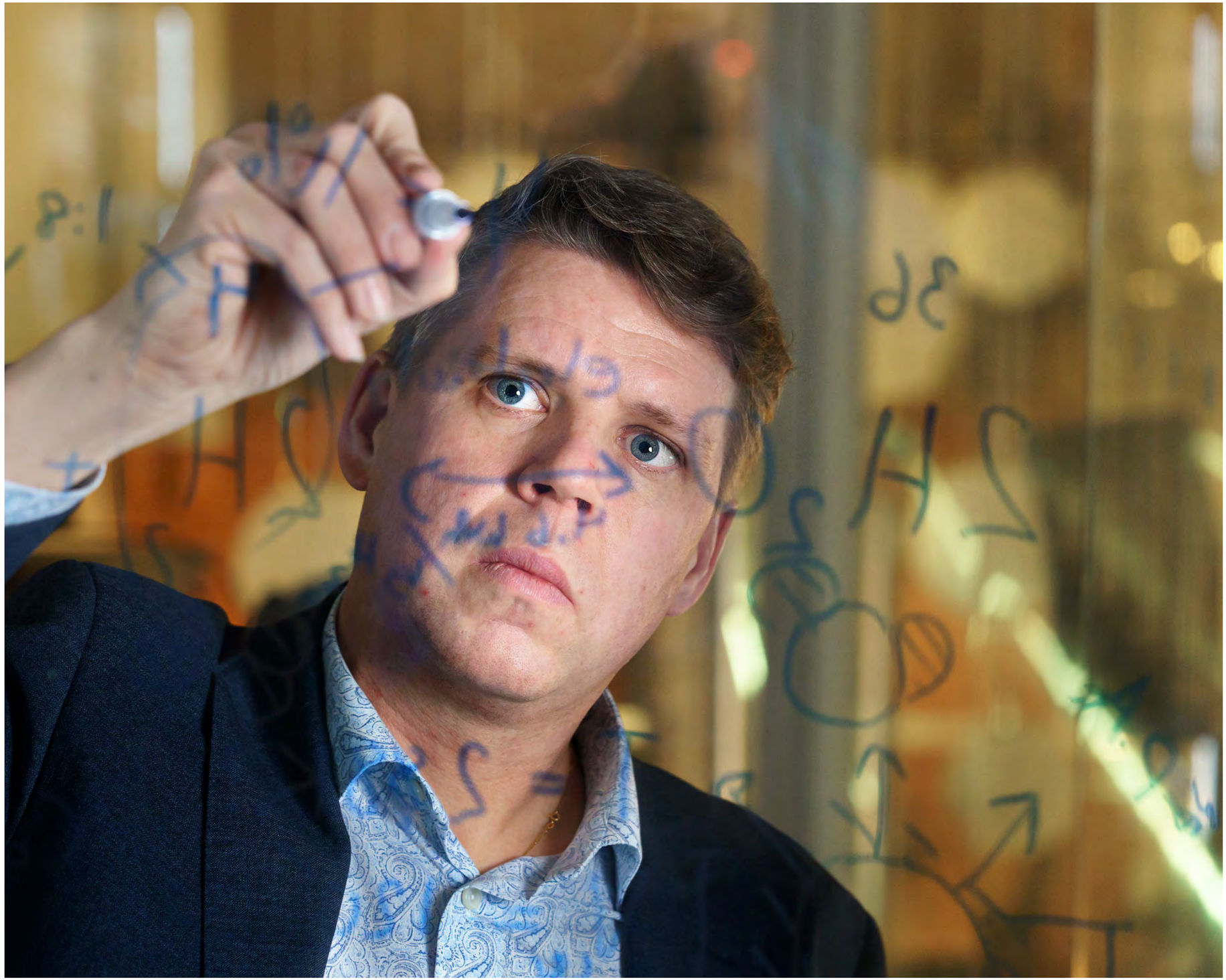
Fortunately, SSAB's mining supplier LKAB was hard at work at decarbonisation too.

The owner of the world's largest and deepest underground iron mine has already electrified much of its mining process.

LKAB, based in Kiruna, Sweden's Arctic north, was planning to further reduce its footprint by using natural gas to reduce iron, a process that produces less CO2 than coal. Then Martin came along.

"Natural gas was the process we saw for our future, but it would only solve 40% of the problem, so when Martin said let's go for hydrogen, it was the perfect match," says Susanne Rostmark, research director at LKAB.

Overview of LKAB's iron ore mine in Kiruna city in Arctic Sweden.



Powering the Experiment

Martin realised he needed an electricity provider. Unbeknownst to him, that partner was already waiting for him.

Over at Vattenfall, Sweden's state-owned electricity provider and one of Europe's largest, a team was quietly anticipating SSAB's electricity needs.

"I heard Martin Pei was planning to speak at a seminar about future technology, and I suspected he would talk about hydrogen, so I quickly made some calculations about how much extra electricity they would need," says Mikael Nordlander, Director of Industry Decarbonisation at Vattenfall.

Mikael, 45, was at that time leading part of the R&D department. He says he used "high-school chemistry" to come up with an analysis for SSAB.

"Your starting point is an iron oxide of 70 percent that you want and 30 percent that you don't want. So, you need a glue where the 30 percent you don't want can get stuck to. And the essence of the calculation is how much glue do you need. Coal is the glue of yesterday; and today it is hydrogen. If you know how much hydrogen you need, you can work out the electricity demand," says Mikael.

Mikael's hunch came true during the SSAB seminar.

"I went up to Martin pretending it was a spontaneous meeting and showed him my numbers," says Mikael with a laugh. Martin was impressed.

Within weeks, they had persuaded their respective CEOs to join forces.

Mikael Nordlander writes chemicial formulas related to the electrical needs of producing hydrogen at his office in Vattenfall's research centre in Sweden.

Mikael Nordlander (left) studies the flow of water past a plastic model dam with a colleague who is holding a speedometer at Vattenfall's research centre in Sweden.

Sweden's oldest river dam stands near Vattenfall's research centre in Sweden.

This is the electrolyser that powers the HYBRIT Fossil-Free Green Steel Pilot Plant, the site that produced the world's first batch of fossil-free sponge iron.

A Star is Born

SSAB, LKAB and Vattenfall started pre-feasibility studies within weeks of getting together in 2016. By 2017, they formed HYBRIT (Hydrogen Breakthrough Ironmaking Technology) with an investment of approximately EUR200 million by 2023. The amount is split among four parties: the three companies plus the Swedish Energy Agency.

It was critical for HYBRIT to be located near a large electricity source. Converting SSAB's blast furnaces to hydrogen DRI needs 15 TWh, while the eventual transformation of LKAB's iron ore production to HYBRIT sponge iron on a commercial scale would need a combined total of 55 TWh, more than a third of the country's current demand.

Mikael says electricity production is not a problem since Sweden's electricity production is close to 100% fossil-free and had a surplus of more than 25 TWh last year. More wind farms are on the way. But they must plan well.

In the south, especially around Stockholm where SSAB is headquartered, the grid's bottleneck limits electricity transmission. HYBRIT built its pilot plant in Luleå city next to SSAB's existing blast furnace to tap the abundance of green energy in the sparse Arctic region.

It appointed a CEO, hired around 40 employees, and linked up with numerous local and international sub-contractors. The plant started working in 2020.

Martin says they are re-studying everything about steelmaking with hydrogen that produces only water as a by-product because everything has to be re-invented from scratch. Electrolysis is still a new technology in the steel industry and there is limited knowledge in handling large hydrogen volumes.

"We need to create a new ecosystem because nothing is there," says Martin.

At the moment, HYBRIT's plant produces a tiny amount of hydrogen-reduced sponge iron, just one tonne per hour. The few dozen staff are a football club compared to SSAB's army of 14,000. But if the trials here prove successful — and so far they are — large-scale production should start in Gällivare, near LKAB's iron ore mines, in 2026.

Martin aims to reach production of 300 tonnes an hour, or around 2.7 million tonnes per year — equivalent to current Luleå production -- by 2030. SSAB could then shut down all its blast furnaces in Sweden and Finland, reducing CO_2 emissions by 10% and 7% in each country respectively.

Swedish mining giant LKAB's Research director Susanne Rostmark tests fossil-free iron pellets at her lab in Arctic Sweden.

HYBRIT Success

HYBRIT's announcement in June 2021 of its production of the world's first "Fossil-Free Sponge Iron" grabbed global headlines. The level of metallisation is higher than fossil produced sponge iron, which means a stronger and more reliable final product.

LKAB's Susanne attributed HYBRIT's success to Martin: *"Martin is really the father of this project. He was the initiator who saw now the time is right to move to hydrogen"*.

The uptake came quickly. By October 2021, Volvo Group unveiled the world's first vehicle made using HYBRIT's steel. Other brands are following suit.

"This shows that the whole value chain works," says Martin.

The European Union this yezar gave HYBRIT EUR143 million to support commercial-scale development under the Innovation Fund.

A worker holds fossil-free iron pellets at the HYBRIT Pilot Plant.

World's First Hydrogen Cave

Fossil fuels can be stored and used when required, meeting the 24/7 energy needs of the steel industry. But the renewable energy that makes green hydrogen is more finicky, with supplies surging when the sun shines or the wind blows and dwindling at other times.

HYBRIT needed a buffer to smooth out changing weather conditions in the form of a hydrogen storage tank.

"It would cost a fortune to build tanks, so we came up with a crazy idea, blasting a dome in the underground rock bed and letting geology do the job," says Mikael.

On the sweltering afternoon of June 14, 2022, the HYBRIT team and board members gather to unveil what Mikael calls "the world's first hydrogen storage facility using the lined rock cavern technology". Engineers had dug 30 meters underground, filled out the walls with concrete, and covered it with sealant. The resulting cavern is 100 cubic metres, the size of a living room.

"This hydrogen storage system is the last puzzle piece to make the technology commercially competitive," says Martin.

In the coming two years, the HYBRIT team will fill the cavern with hydrogen at around 250 bars for testing. They will study how to fill the storage, how to take the gas out — and how the mountain reacts to the rising and diminishing pressures.

LKAB is expected to take the findings to build storage capacity large enough to supply a full-size sponge iron plant for around four days, says Lars Ydreskog, Senior Vice President Strategic Projects at LKAB and a board member of HYBRIT.

By 2048 when LKAB turns fully net-zero, the miner expects to produce and use 15 gigawatts of hydrogen, says Lars. Putting that in perspective, 15 billion watts of energy can light up 3 billion LED light bulbs of 5 watts each.

The minister of energy and digitalisation, Khashayar Farmanbar, waxed enthusiastically about HYBRIT's contribution to the local economy and the world at large.

"Sweden will create new jobs by leading the climate change transition," says the minister. *"Hydrogen will be one of the most crucial new energy carriers."*

Mikael Nordlander (centre) talks with workers building the hydrogen cavern at the HYBRIT Fossil-Free Green Steel Pilot Plant, joint Swedish invest, iron ore miner LKAB Vattenfall.

Opening ceremony of the hydrogen cavern at the HYBRIT Fossil-Free Green Steel Pilot Plant.

Benefitting the World

On the evening flight back home to Stockholm after the inauguration, Martin looks content as he leans back at his window seat to marvel at the midnight sun.

"The world needs a solution and we are taking the first steps to make it happen," he says.

Martin believes other manufacturers will follow suit, now that HYBRIT is proving not only an environmental reason for hydrogen green steel, but a business case.

HYBRIT will make available its knowledge and know-how to other companies on a licensing basis perhaps as early as the end of the decade, says Martin.

"Everyone, even our competitors, will be able to use our technology, because together we can make a real climate impact," says Martin. *"And we can profit from our IP too."*

Martin has become The Steel Giant of his childhood dreams. One that can transform the world too.

Susanne Rostmark (Left), Research Director at LKAB, Martin Pei (centre), CTO of SSAB, and Mikael Nordlander (right), Decarbonisation Director at Vattenfall.

Story 2

Building a Solar System

A French energy entrepreneur plans to connect Africa and Europe to create the world's biggest green hydrogen value chain.

When Thierry Lepercq flew into Mauritania in the dead of the night, the Parisian energy pioneer did not know whom he would meet in the African country he had never visited. He only knew the desert nation set in one of the world's most volatile regions was now touting the ambition to be the Saudi Arabia of green hydrogen.

Inside the rucksack of the chairman of one of the world's biggest sustainable hydrogen projects was a plastic folder containing a business proposal worth EUR100 billion.

The next morning the silver-haired entrepreneur drew the curtain open after four hours of sleep. Harsh sunlight flooded his hotel suite, and he knew he was in the right place.

Mauritania is twice the size of France, but with only 4.7 million inhabitants, most of whom live below the poverty line. Nearly all of its land - 99.5 percent - is arid and unsuitable for growing anything. The world's longest train trundles through the Sahara Desert in a 24-hour, 704-kilometre journey, carrying black iron ore from the national mine to a port in the Atlantic coast, from where the resource is shipped around the world. Desert nomads hop on for the reverse route, often sleeping on the soft ore, to bring back fish to the desert.

The train itself is quite safe despite not having any seats or handles, but the danger lies outside. The three-kilometre train travels through the Sahel region, known as one of the most dangerous in the world as a base for Al Qaeda and other warring groups.

Thierry wants something that has long been a curse of the desert: scorching sunlight. A world-leading creator of renewable energy projects, he calculates that covering 1,500 square kilometres, or 0.15 percent of Mauritania, with photovoltaic panels could capture enough energy to make five million tons of green hydrogen a year. This would cover 2 percent of energy consumption in Europe, or 20 percent of its import of Russian gas that the continent is trying to wean off.

With this urgency to find alternative fuels as a backdrop, European entrepreneurs are innovating on a massive scale to produce hydrogen. This oldest and most abundant element in the universe produces plentiful energy when combined with oxygen, leaving only water as a by-product. The "fuel of the future" is rapidly becoming a present reality as the global drive to decarbonise is accelerated by geo-political risks tied to fossil fuels, especially Russian gas.

Thierry views solar panels outside Nouakchott.

Gijón, Asturias.

Solar Beginning

Born in Toulon in the south of France in 1962, Thierry's lineage is in energy exploration. His grandfather was a hydro-electricity engineer; his father managed search teams for off-shore oil companies, after cutting his teeth as an underwater de-miner. On thousands of perilous deep sea dives the elder Lepercq neutralised ocean explosives for the French navy. A young Thierry dreamt of following their footsteps and travelling the world.

After graduating from HEC Paris, France's top business school, Thierry joined the military service as aide to the commanding officer of a helicopter carrier that went around the distant seas - a "floating embassy of France".

His early career in banking specialised in project finance - in other words, raising the money to achieve greater things. This experience gave him his first entrepreneurial success.

In 2006 Thierry founded Solairedirect with a capital of EUR20,000 to build solar parks around industrial areas.

Within 18 months, his company had raised EUR26 million in a challenging environment. In the late 2000s, building solar parks was a difficult business with high costs and uncertain demand. Thierry aggressively cut costs by sourcing photovoltaic suppliers from China, building big projects for economy of scale, and using his project financing skills to borrow money at low interest rates.

Now with seven partners and around 300 employees, Solairedirect became a market leader in France.

In 2015, just 9 years after its founding, Thierry and his partners sold the company to Engie, France's largest electricity provider, for EUR250 million, a full 12,500 times his founding capital. Engie retained him as Executive Vice President to run its R&D and innovation.

While at Engie, Thierry asked his team to conduct a study about new energy. They came back with scientific proof that hydrogen is the game-changing solution.

"This is the biggest tipping point since oil 150 years ago. Here we are talking about something that will replace everything," Thierry says.

After leaving Engie, Thierry published the book "Hydrogen is the New Oil." to forge a path to hydrogen development.

Building a System

While hydrogen looks promising as the ideal replacement for fossil fuels, it has made little business sense to date due to its high production cost. A kilogram of so-called green hydrogen — hydrogen made by electricity from renewable sources such as solar and wind — typically costs around EUR 5 / kg. To beat oil and gas, the cost needs to drop below two euros.

Thierry started his new project in Spain, the sunniest country in the European Union with 40% more solar resources than France. He brought together upstream producers, midstream carriers, and downstream off-taker buyers, all of whom want to move into hydrogen but can't do it on their own.

He made them a high-stake conditional promise: if every party followed his plan in lock-steps, he could create a low-cost hydrogen system that smashes the energy paradigm for the benefit of all. If one party messes up, the whole thing might fall apart.

His plan required a big leap-of-faith: hydrogen producers signed long-term contracts with off-takers so they could use the future cash flow to invest in scale now, thus driving expected production cost below two euros; off-takers with the promise of a fantastically cheap hydrogen supply would transition to hydrogen technology to buy the hydrogen; and the midstream carriers would build hydrogen transmission infrastructure believing there are customers on both sides for decades to come.

"The first thing is to inspire trust by having trustworthy people. The trust reverberates," Thierry says.

It's a highly complex arrangement with 30 something members ranging from nimble technology start-ups to national gas behemoths with different decision speeds, financial health, and ownership structures. Thierry must get them to make fast and firm collective decisions, no matter how divisive the subject is.

Once he had all the agreements signed, Thierry brandished the contracts to banks and equity markets to raise extra funds.

On the upstream side he partnered with hydrogen developer DH2 Energy to locate some 12,000 hectares of sparsely populated plain in Castilla y Leon with a solar capacity of around 500 - 1000 MW per project.

For mid-stream transmission capacity, Spanish national energy provider Enagás will provide 1,000 km of hydrogen pipeline laid alongside existing natural gas lines.

The biggest rabbit Thierry pulled out of his hat are the off takers, in this case anchor customers that would not only sign multi-year hydrogen contracts with him but also be one of the key investors.

At a HyDeal board meeting at the headquarters of Enagas in Madrid, Spain. Sitting next to him is Fertiberia's CEO Javier Goñi.

The Spanish Off takers

ArcelorMittal, currently the world's second largest steelmaker producing 10% of the world's steel, operates in more than 60 countries with Europe its main base. While steelmakers create the stuff that builds modern civilisations — from cars and buildings to cutlery and computers — they also have a disastrous carbon footprint, contributing to around 8% of global emissions.

In Spain, the company with 5,000 employees is based in Asturias, a northern coal region associated with pollution and decline. It currently produces 4.5 million tons of crude iron.

Smoke of sickly shades hangs above the sprawling compound. It burns two million tons of imported coal as a reduction agent to turn what is essentially iron oxide into iron.

ArcelorMittal discharges 6.5 million tons of CO_2 per year in Spain alone. With carbon taxes becoming an increasing burden on offenders, it was set to replace coal with natural gas, which is cleaner but still highly pollutive.

Then Thierry came along.

"In all my life I never worked with hydrogen. But when I read Thierry's book and worked with him, I immediately became a believer," says ArcelorMittal Spain's Chairman José Manuel Arias.

ArcelorMittal has pledged to invest EUR1 billion in hydrogen technology to produce green steel, with production starting in 2025, producing around 2.2 million tons a year. By 2030, it aims to have reduced emissions by 50%.

Suddenly people who were afraid of losing their jobs are at the forefront of this change.

"Asturias is a coal-fired region, you can argue it's a place that should die, it has highly pollutive manufacturing of steel, fertiliser, and the rest. But they are now totally turning around this backwardness and putting themselves in the forefront," says Thierry.

Smoke belches out of the ArcelorMittal plant in Gijón.

Thierry visits an experimental furnace using a mix of hydrogen gas to reduce iron ore at ArcelorMittal's R&D department.

ArcelorMittal's blast furnace.

A natural gas depot in Gijón.

Green Fertiliser

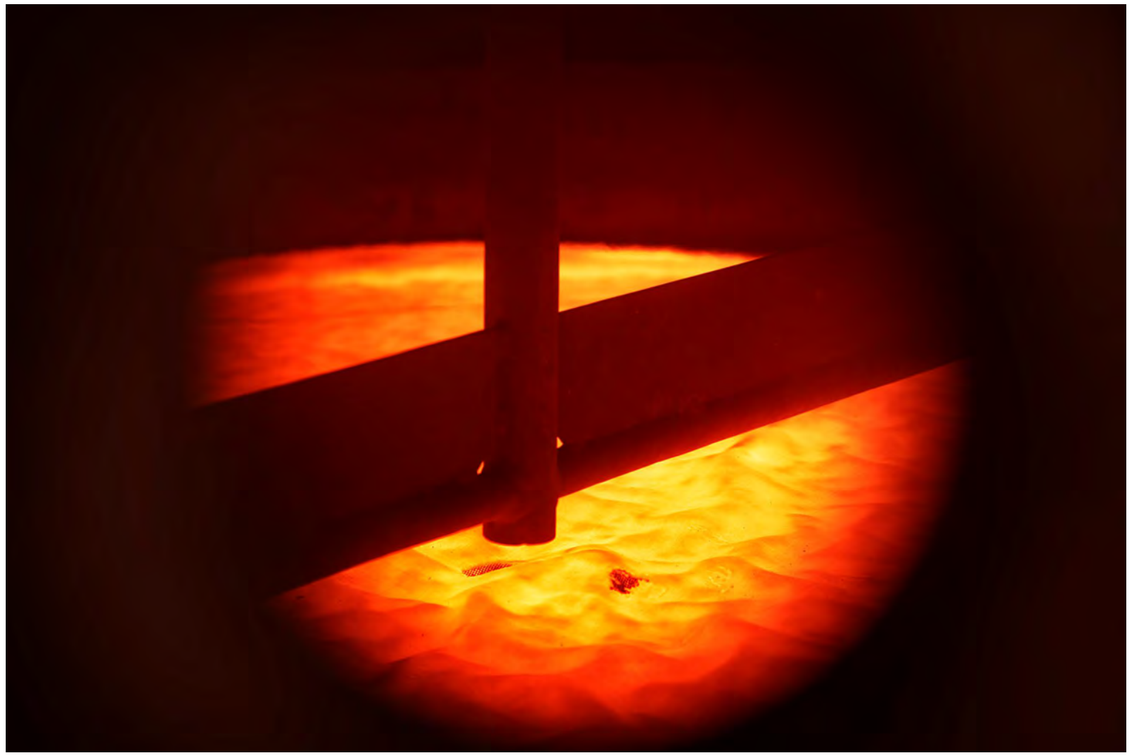
A few hundred metres away from ArcelorMittal's factory in Avilés town is Fertiberia, Spain's largest fertiliser maker — and one of its main polluters too.

In its ageing, crusty factory, Fertiberia uses natural gas to make ammonia, the chief ingredient of fertilisers and the second most produced chemical in the world.

But ammonia takes a lot of energy to manufacture. Most of that energy comes from burning fossil fuels like coal and methane gas, which give off greenhouse gas. Ammonia manufacturing today contributes between 1% and 2% of worldwide carbon dioxide emissions. By using green hydrogen, Fertiberia's ammonia production will be carbon-free.

"Right now ours is a grey factory, but by 2026 it will be fully green," says Fertiberia's factory head Alberto Saez Sanchez.

This has a massive implication for the world. By making a business case for zero-carbon ammonia, Thierry's project is helping to decarbonise the food we eat.



Making fertiliser at Fertiberia in Avilés.

At Fertiberia's R&D lab in Seville.

Fertiberia in Avilés.

World's Biggest

The complete hydrogen system is now called "HyDeal Ambition", with "HyDeal España" being the actual industrial implementation in Spain and Portugal with a projected production of 330,000 tonnes of hydrogen.

In two short years, Thierry has put together what the renewable energy agency IRENA ranks as the biggest hydrogen project in the world based on projected capacity.

Scaling up, as HyDeal does, makes it possible to aim for EUR1.5 / kg of hydrogen production price, says Thierry. This means zero-emissions aside, green hydrogen can be chosen for bottom line alone.

"It's going to make immediate business sense," Thierry says. The buyer agrees.

"We cannot continue to produce steel the traditional way because there will be no longer economic rationale for it," says José Manuel from ArcelorMittal, a prominent conglomerate on the Fortune 500 list.

With 20-year contracts worth EUR10 billion in committed cash flow, Thierry is ready to do what he is best at: raising external money for the project.

HyDeal is seeking to finance half of the total investment with debt and equity from banks and infrastructure funds.

"We don't need subsidies because we will be making a lot of money," says Thierry.

The HyDeal board visits Enagas's control room.

The Mauritania iron ore train snakes across the Sahara desert.

Desert nomads ride the train atop the iron ore to the coast to collect fish.

Connecting Africa

With the Spanish model showing success, Thierry is extending the project to an even bigger goal: supplying the whole of Europe with solar energy.

While Spain has plenty of sunshine, its solar output is limited by its population density. Thierry estimates Spain's total potential output can cover the country's own energy needs but doesn't leave much for the rest of the continent.

"Europe simply cannot do it without Africa," Thierry says.

To provide Europe with African sun, Thierry wants to implement the HyDeal model and connect suppliers in North Africa with off-takers in Europe.

"I'm going to be immodest and say this is probably the biggest project that's ever been done by anybody, not even Rockefeller 150 years ago," Thierry says.

Thierry studied a dozen countries. Mauritania has a vast amount of unused space for solar panels. It has a coast, critical for water supply even though it has to be first desalinated.

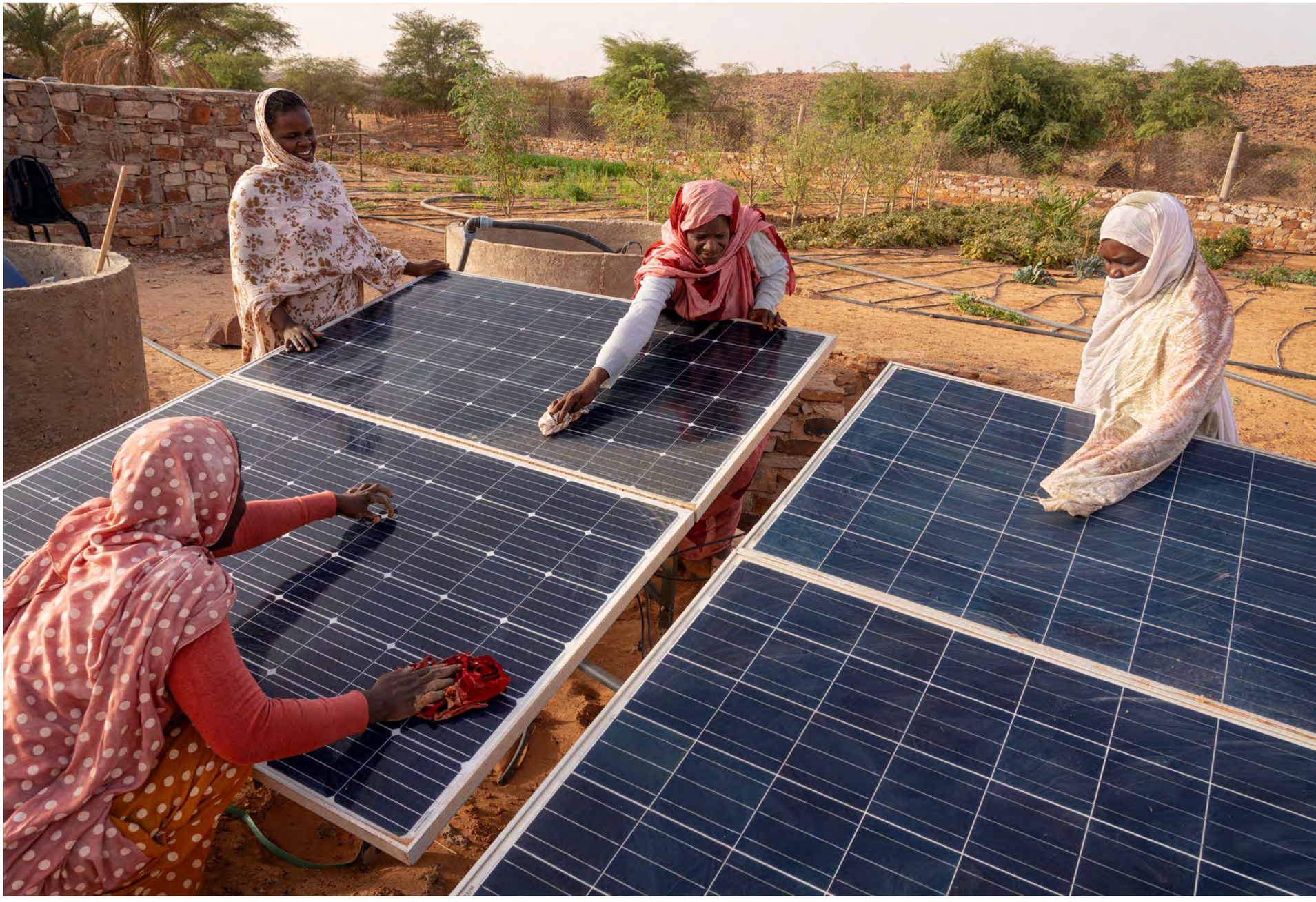
And most interesting to Thierry, it is often overlooked and welcomes investment. He bets that he would have more chances here. Once Mauritania joins his project, other countries might follow.

Thierry plans to install 150 GW of electrolysers with a total investment that amounts to around 10 years of Mauritania's GDP.

Thierry's blank schedule suddenly became very full when prominent businessmen and politicians heard he was in town. He now bounced between meetings with them, culminating with an audience with Mauritania's energy minister, Abdessalam Ould Mohamed Saleh.

The minister, however, seemed initially uninterested. Thierry leaned forward to make his pitch: to work long term as an equal partner in a multinational system with guaranteed buyers of Mauritania's hydrogen for decades.

"I have the customers, and I have among my group members people who build pipes, and that's what you want. You've got the land, you've got the sunshine, water can be desalinated, you just need a system," Thierry said. The minister reached for his paper presentation to study it.



Women in a Sahara oasis use solar panels to take water out of the well behind them for irrigation.

Long Term Partnership

Thierry further sweetened his offer by showing his group is ready to do business with Mauritania on a broad basis.

ArcelorMittal was already preparing a memorandum of understanding with SNIM, the national mining company that operates the iron ore train, for the production of 2.5 million tons of green steel a year from the hydrogen production to make emission-free sponge iron. This would significantly upgrade Mauritania's export economy -- and put the Sahara on the world map as a pioneering location for fossil-free steel.

"We are not just coming in to get your natural resources," Thierry says. He figures desalinated water will be 2-3 % of his output, from which he could offer 5-10% to Mauritania.

"Hydrogen is not just energy or jobs, it's also water that changes the landscapes," says Thierry.

Thierry wants the local community to benefit from his system, which he expects to be around for 30 or 50 years. And this is not just PR talk, *"it's pragmatic"*. In a region beset by insurgency, he needs stability and long-term cooperation for good business.

Upon hearing all this, the energy minister instructed his team to start planning with HyDeal without delay.

Thierry delightedly headed back to the hotel to check out.

"Now I just have to convince my partners back home to sink EUR100 billion into an unknown place surrounded by failed states." he muttered as we drove to catch the red-eye to Paris.

Four weeks later on May 24, 2022, with HyDeal's board's backing, Thierry again landed in the dark in Nouakchott at the invitation of the energy minister to start pre-feasibility talks.

This time he had someone to meet: 500 government and business leaders who listened to him during an energy seminar.

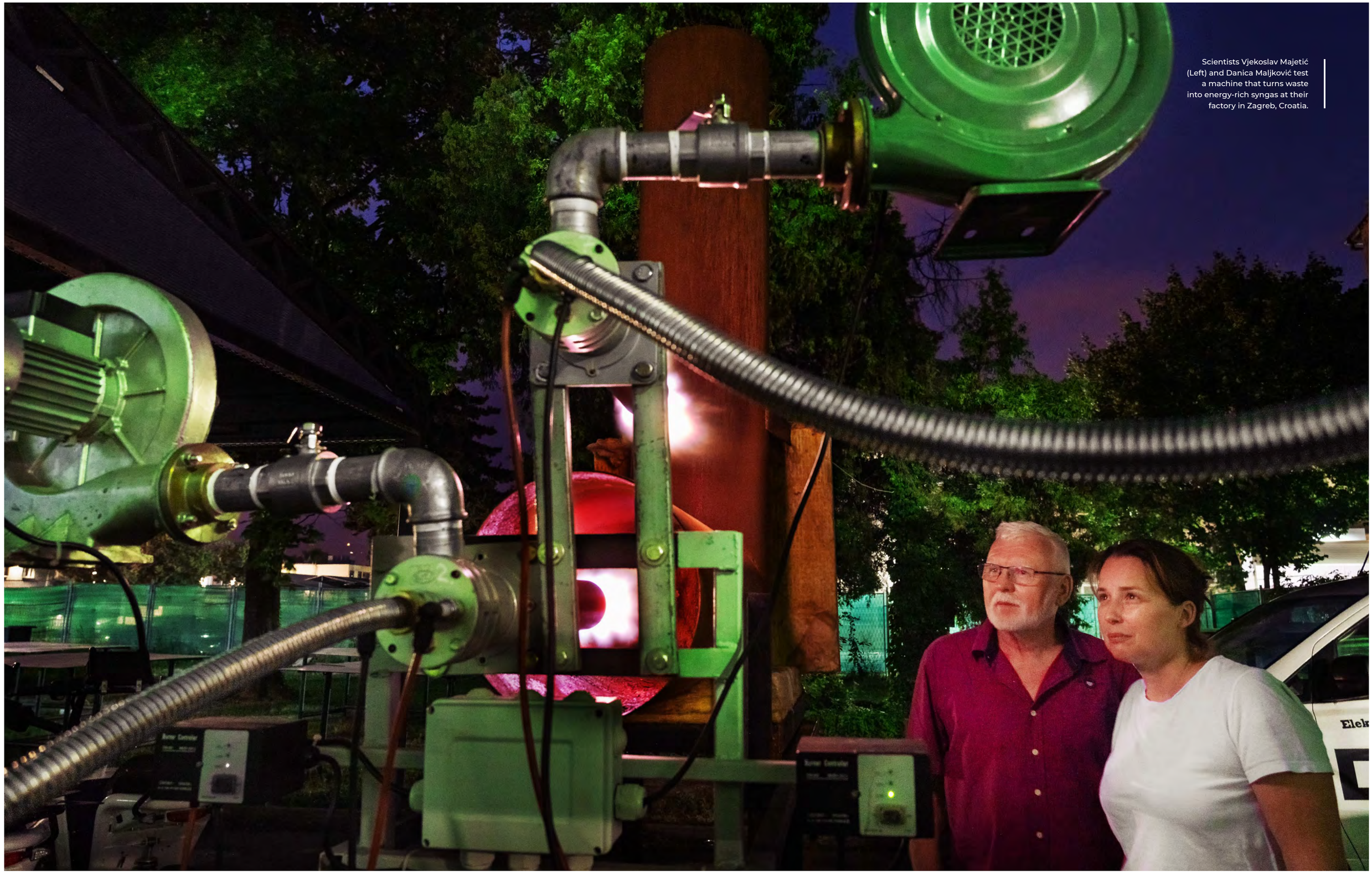
Thierry chats with his business contact Mohamed El Hamed at his home in Nouakchott.

A family looks out at fishing boats moored on the Atlantic shore of Nouakchott.

Story 3

Extracting Every Joule

A Croatian team invents a machine that turns faeces and other wastes into hydrogen-rich gas.



Scientists Vjekoslav Majetić (Left) and Danica Maljković test a machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

Zagreb -- On a cold afternoon in early 2020, a star consultant at an energy think tank in Zagreb was debating district heating with Croatian government officials keen to boost efficiency in the EU's youngest member.

Drawing on her expertise on machine learning modelling, Dr Danica Maljković was just getting to the technical details when her cell phone rang.

Danica came back promptly after stepping out to answer the call, but her mind never returned. It was from a man she had seen turning weird ideas into meaningful reality in the last two decades.

He had invented a machine that would turn human faeces into hydrogen-rich gas, and he asked if she would join his new start-up as the CEO.

Back to the Future

While at university in Zagreb in 1999, a fellow mechanical engineering student invited Danica home. As she walked through the front porch she gazed into the garage and saw her friend's father soldering, welding, and screwing parts together, all the while drawing blueprints using a giant computer screen.

"He looked like a mad scientist with a lot of drawings and the biggest computer monitor I had ever seen," says Danica, now 42.

The scientist was Vjekoslav Majetić, then in his forties. He was developing a de-mining vehicle that would go on to rip up millions of landmines around the world's war zones, starting in the Balkans and going on to many parts of the Middle East, Africa and former Soviet sphere. The effectiveness of his machines in clearing mines brought him hundreds of awards -- and a fortune too. DOK-ING, his group of companies, currently employs 160 people in Croatia with a turnover of EUR25 million in 2021.

But Slavko, as Majetić is often called, never stops inventing.

Scientists Vjekoslav Majetić works at home in Zagreb, Croatia, with a computer 3D drawing of his demining machine in the foreground.

A welder build a machine that turns waste into energy-rich syngas at his factory in Zagreb, Croatia.

Inventor Vjekoslav Majetić (Left) discusses with scientist Danica Maljković the machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

On a balmy night in the summer of 2019, he saw on the evening news how the capital city of 800,000 people is producing more human waste than the municipal system can handle.

Open trucks carrying stinking faecal sludge race from the central treatment plant to landfills along Croatia's magnificent coast, a world-renowned magnet for tourists seeking emerald waters, beautiful islands, and ancient fort towns.

An even bigger headache for the government is a directive from the European Union to limit cities to using landfills for no more than 10% of their waste by 2035.

There's no way Zagreb could meet that, Slavko thought.

"But we had the knowledge, science and power to solve the waste problem," says Slavko, now 67.

That week he drove with a colleague to the processing plant to collect a sludge sample. Back at his factory, he heated up the dried faeces to around 800 degrees Celsius, at which it turns into gas.

The resulting so-called syngas was around 50% carbon and 50% hydrogen, a highly explosive element gaining traction in the energy world as the emission-free "fuel of the future".

The idea for a business was born.

Inventor Vjekoslav Majetić (in purple) discusses with his team the machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

Terminator

Slavko drew a 3D model of a reactor on the computer and proceeded to directly build the prototype, which he called "Terminator 1", in an old factory building that he bought from a brewery.

The machine uses a rotating oven to gasify sludge at 2.5 metric tonnes per day, heated by electricity. Jets of water pummel the gas in a cylindrical washer, giving out purified syngas.

Slavko needed more resources to back him up. He had spent "a few million euros" of his own money to purchase materials and equipment. He resuscitated a dormant company and injected assets into the empty structure.

The core mission of DOK-ING is to develop and create solutions that will help to save and protect human lives and property, says Slavko.

"This new innovation is contributing to a cleaner and healthier environment and thus directly influencing our lives on the planet," he says.

He now needed a team, especially a manager who could wear the hats of scientist, business developer, and project manager - preferably one who understands energy and government bureaucracy too.

He asked his daughter, Ana, to call Danica, who by then was Deputy Head of Department at the Energy Institute Hrvoje Požar, providing consulting service to both the private and public energy sectors.

After the short call, Danica, who holds a PhD in energy efficiency modelling, walked back to her ministry meeting dazed by the prospect of ending a comfortable 15-year career at the institute to join a venture no one had heard of.

"This was a rare opportunity to develop a possible ground-breaking energy technology," says Danica, whose life mission is to use every joule.

"I knew I must not miss it".

That night, she called back. *"Yes."*

Inventor Vjekoslav Majetić (Left) discusses with scientist Danica Maljković the machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

Scientists Vjekoslav Majetić (Left), Danica Maljković (right), and their research director collect a sample of fecal sludge at Zagreb's municopal waste facility to test how their machine perform in turning human waste into energy-rich syngas.

A technician makes experimental bricks out of clay mixed with carbon ash from gasifiying faeces.

A worker pours fecal sludge into a machine that turns human waste into energy-rich syngas at his factory in Zagreb, Croatia.

Prototyping

Danica's first role at the then unnamed start-up was to help build a scaled-up prototype. Slavko wanted a Terminator 2 that can process 25 tonnes per day to cater for the 120 tonnes of sludge that Zagreb produces daily.

Swapping her smart office wear for jeans and t-shirts, Danica followed Slavko's and his engineer's construction with real-time calculations.

Terminator 2 turned out to be a huge metal beast that did not use energy efficiently. Even with external heat supply, it could not reach the desired temperature of 850°C - 1,000° C.

They dismantled that and worked on the current version, Terminator 3, a 10-tonne / day model that is self-sufficient, using the energy it creates to heat the waste.

While Slavko's interest is about waste management, Danica's focus is more on energy extraction.

"Every material has energy, the question is how to take it out," says Danica.

Danica Maljković heats sludge to turn it into a gas to test its energy content at a university laboratory in Zagreb, Croatia.

Testing Textiles

With the speed that once made her captain of the national junior basketball team, Danica wasted no time in testing materials and applications with her team of 11 at the company now called Indeloop. They found the energy content of plastics and textiles is as high as brown coal.

The syngas contains two elements: hydrogen and carbon. Each tonne of waste contains 0.5 MW energy and can produce one kilogram of hydrogen which can be used for heating, electricity production, and as a chemical stock.

The other 50% of the Syngas is carbon, a usual element for the fertiliser, construction, aircraft, and paint industries.

To test the application in the real world, Danica fans out across the country to discover potential user cases.

One of her first stops is Regeneracija, one of Croatia's biggest textile recycling companies with an annual turnover of EUR10 million.

Here 40 kilometres north of Zagreb, she meets the managers of a dusty factory that shreds 8,000 tonnes of textile waste a year and discharges 800 tonnes of dust.

That dust currently is driven to incinerating plants in neighbouring Bosnia, causing CO2 and toxic wastes.

A 2.5-tonne Indeloop machine could take care of the dust and produce energy for the factory that uses some 400KW per day, says Branko Zbodulja, Regeneracija's Head of Production.

"We are hoping to use Indeloop's machine to get rid of our dust and make clean energy because our plant is in the middle of town and we need good relationships with the local community," says Zboudulja.

Textile waste at Regeneracija.

A worker shreds textile waste at Regeneracija.

Danica Maljković examines textile waste at Regeneracija, to see what material she can use to turn into energy-rich syngas at her factory in Zagreb, Croatia.

Preserving Nature

Danica also visits islands on the Adriatic coast famed for their beauty -- and nowadays also for trash pollution.

Every year, south winter winds bring hundreds of tonnes of plastic waste from neighbouring countries to the islands, littering them just as the lucrative tourist season starts. Teams of volunteers and rangers roam the beaches collecting the garbage.

Until now, on some islands such as Miljet, municipal workers collect the waste and ship them across the Adriatic Sea to a landfill on the Croatian mainland. On other islands, such as Vis, they are just left in makeshift landfills.

"At the moment we are depositing the waste in the mainland, so we are just transporting the waste from one place to another," laments Ivan Sršen, Director of the Miljet National Park.

He has been discussing with Danica using a one tonne / day Indeloop machine to eradicate the plastic waste forever and produce hydrogen, potentially for a fleet of non-pollutive hydrogen cars.

"It's very important for us to be clean, but we don't want to make another place dirty," Sršen says.

Seagulls feed on a garbage dump on a tourist island in Croatia.

A volunteer cleans a polluted beach on the island of Miljet in Croatia.

Divers clean a polluted beach on the island of Miljet in Croatia.

Each year, currents in the sea brings plastic wastes from other countries to Croatia's Adriatic Coast.

Garbage workers clean a polluted beach on the island of Miljet.

Extracting Every Joule

Encouraged by the strong interest across different industries, Danica and Slavko are planning to make a range of machines with daily capacities of 1, 2.5, 10 and 25 tonnes of waste.

They hope production will start in 2024, with first deliveries by around 2026. They are looking to ramp up production capacity in Croatia to 24-30 machines a year when orders come, which they expect will first be from within the European Union where environmental standards are high.

For now, the machines will produce Syngas, pending customer orders for hydrogen separators that would allow the units to further refine the product to the element that powers our sun.

"There's no such thing as waste, everything can be a material," says Danica. *"We want a machine that will squeeze the last drop of energy out of every material."*

"And hydrogen is our ultimate goal."

Divers clean a polluted beach on the island of Miljet in Croatia.

Story 4

The multi-fuel fuelling station founded by Edward Doorten.

Heavenn on Earth

Lessons from Europe's first Hydrogen Valley in the Netherlands.

Patrick Cnubben at the Eemshaven.

Groningen - A hydrogen refuelling station; a seaport built for renewable energy; schools teaching fuel cell technology. These are the components that make up Europe's first Hydrogen Valley, founded in the Netherlands in 2018.

These, plus Patrick Cnubben. Cnubben, 56, is the director of hydrogen strategy at the New Energy Coalition. He is considered the "architect" of HEAVENN (H2 Energy Applications in Valley Environments for Northern Netherlands).

For years the New Energy Coalition has been seeking ways to help the northern provinces of Groningen and Drenthe - which have been rocked by earthquakes induced by gas extraction - to find alternative ways to power the economy.

"It fit like a glove," Patrick says, explaining how a hydrogen network could be built on existing gas infrastructure.

The first earthquake induced by a natural gas field hit the region in 1986. Since then, gas extraction in Europe's largest natural gas reserve has led to more than a thousand recorded tremors.

Cracks that appeared on the walls clawed through some houses as thousands of buildings were damaged, including some of the region's rich stock of mediaeval churches. Patrick quotes figures saying at least 200,000 people have been impacted by the "gas-quakes".

Protests have led the government to gradually wind down extraction and promise to stop it completely in the coming years. While this would address the communities' environmental and safety concerns, it also risks economic uncertainty.

This interview taps Patrick's experience in bringing the public and private sectors together to realise a plan to boost the northern Netherlands' economy using hydrogen as what he calls the "growth diamond".

Gasunie's Zuidwending natural gas site also houses a green hydrogen pilot

Workers test the feasibility of converting an underground "salt-dome" used for storing natural gas to hold hydrogen at Gasunie's Zuidwending site.

Workers test the feasibility of converting an underground "salt-dome" used for storing natural gas to hold hydrogen at Gasunie's Zuidwending site.

An electrolyser at a pilot project in Zuidwending.

What problems did your region face looking for a solution out of the gas-quakes?

Some 20.000 people were employed directly and indirectly in the northern natural gas and related sector, and there were long periods of fights and disagreements between locals and the energy company responsible for the extraction. Stopping gas extraction would create a big, big problem for the regional economy, potentially causing an 8-10% drop in gross regional product.

What options did you consider?

For years we were looking for new opportunities from energy - especially green energy - as a driver for economic growth. A region needs business. We worked on all kinds of solutions: green gas, system integration, LNG (liquified natural gas) and Bio-LNG. We found green hydrogen works perfectly thanks to the repurposing of the natural gas system, not to mention the quality of zero emissions that hydrogen brings.

How did the idea of Hydrogen Valley start?

I heard about the concept of Hydrogen Valley from Bart Biebuyck [Executive Director of the Clean Hydrogen Partnership] at an event in 2018 in Ljubljana, Slovenia. There, we were presenting our hydrogen bus that we brought from the Netherlands. We had to transport the zero-emission bus on a diesel trailer because there were no hydrogen fuelling stops on the way. Bart was impressed with the attention we got, and we made an appointment at his office in Brussels to discuss acquiring more buses with his support.

A few weeks later when we got to Brussels, he said, 'sorry, there are no buses left, but I've got another idea for you: a Hydrogen Valley.' It was a prize open for bidding. We made a successful pitch with energy as the driver of employment.

What is a Hydrogen Valley?

A Hydrogen Valley is a defined region that takes steps to decarbonise and grow a new economy, creating a new value chain based on green hydrogen. Everything has to be done in parallel. This includes building industry parks, wind parks, power cables, gas pipes, electrolysers and hydrogen storage facilities, and public applications such as refuelling stations.

There are also educational institutions solving practical issues, such as training blue collar workers and bringing up a generation of engineers to not only build but also maintain the systems.

What are the advantages of a Hydrogen Valley?

A Hydrogen Valley is regionally organised, so the number of actors is overseeable, and the variation in interest is manageable. Lines of contact are shorter, rather going back and forth to HQs, you can solve issues fairly quickly. And the public authorities are very engaged and involved, making a Hydrogen Valley a regional public private cooperation.

When you have a defined plan, you understand where to get investments from, where to build, and how to get authorisation. If no one did that, then there would be mismatches: the entrepreneur wants a factory or a refuelling station, the utilities want to supply the clean and canned energy in the form of hydrogen, and the government thinks about permits. They think they know what they are doing and know what the other party needs, but they don't. It is all about aligning communications between the public and private interests.

How did it get going?

At the beginning, there was a lot of scepticism about hydrogen. It was a Catch 22: no one would buy a hydrogen car if there was no refuelling station, and no one would invest in refuelling if there were no cars. So Dutch entrepreneur Edward Doorten, the founder of a multi-fuel refuelling station in our region, took a chance and installed hydrogen in his station with support from EU funding. Everybody has a car, so anyone who fuels there sees that a hydrogen car works.

Qbuzz, our regional bus service provider, was instrumental. They drive hydrogen buses between cities, and they transport people, making this transition a people's business. The industry took a long time to become a hydrogen player, but following our success with mobility, they are now taking off.

What challenges are you experiencing?

The biggest challenge is the state aid regulations. Actually, there are too many rules and these are old rules. Instead of aiding, they hinder and delay. Industries are ready to invest but they are holding back because of lazy and ineffective bureaucracy. Once a government decides to go ahead with hydrogen, they need to create efficient legislation. If rules are in the way, get rid of them!

Besides that, sometimes new buses don't work, a fuel station is down, installations, or components are not available due to logistical backlogs. Things take time.

Why do you have a hydrogen car and a gasoline car? When do you think you can just use one fuel?

I indeed have a hydrogen and a diesel car. In the future, my cars will be electric for the shorter distances and hydrogen for the longer distances. I generally would like to step over to hydrogen because of the ease of refuelling: three minutes and I am up for another 450 km or more. To do that, we would need a hydrogen refuelling station at every existing refuelling station. But that will take some time.

At home I want to step over to hydrogen for heating. I strongly believe that hydrogen can replace natural gas from the existing housing stock.

How has your Hydrogen Valley been received?

President von der Leyen specifically referred to HEAVENN in her opening speech at the European Hydrogen Week in 2021. She said the Groningen area has shown how we can accelerate the hydrogen economy on a local scale towards a European hydrogen economy as a whole.

Need I say more?

Why do some push for large scale development to drive down prices while Hydrogen Valley proponents advocate a collaborative approach?

You need to do both in parallel. Large-scale development is upstream, Hydrogen Valley is downstream. The large-scale industrial projects must be connected to large-scale off takers, using for instance dedicated big pipeline connections, these are usually one on one connections, whereas Hydrogen Valleys are addressing multiple producers with multiple off takers. Connecting the two systems creates the desired offtake and deep penetration of green hydrogen in society.

A boat carrying turbine blades cruise into Eemshaven.

What is the role of the small players – Small Medium Enterprises (SMEs) or start-up - in your Hydrogen Valley plan?

In HEAVENN there are a good number of SMEs. They are very agile in taking decisions and acting on opportunities.

In the development of Hydrogen Valleys, SMEs must take a prominent position because of the jobs they create, which in turn stimulate education and improve prosperity.

What are your next steps?

Now we are creating cross-border Hydrogen Valleys to connect markets. We need to share in order to multiply!

Enercon uses a Dutch-invented "climbing crane" to build a wind turbine.

A supply ship loads up with wind turbines at Eemshaven.

Patrick Cnubben speaks with Michel van der Mark, communications director at Qbuzz in Groningen.

Bus driver Gea Bakker, 60, drives a hydrogen bus.

Patrick discusses with executives of Groningen airport, which will replace diesel-fueled electricity supply machines with ones powered by hydrogen.

Students learn about hydrogen fuel cells during a model car racing competition held in Groningen.

An element of the Hydrogen Valley is to train up future H2 engineers and blue collar workers.

Wind turbines at Eemshaven wait to be loaded onto supply boats heading for off-shore wind parks in the North Sea.

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Justin Jin is an independent photographer, writer and explorer regularly publishing photo and text stories in the world's leading magazines including the National Geographic and GEO. His reportage on the turmoils in his birth city Hong Kong won the coveted Hansel-Mieth journalism prize in Germany in 2021 in both the writing and photography categories; his previous project on Russian gas was shown around the globe and won multiple awards including the Magnum grant. His current work focuses on new energy's impact on the environment, geo-politics and development.

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