Touching Hydrogen Future. Tour around the globe

Jules Verne Style' stories on the role of Hydrogen in 2030s and 2040s

EDITOR: ERIK RAKHOU
CO-EDITOR: ROSA PUENTES

FULL AUTHORS' LIST INSIDE

VARIOUS AUTHORS

Touching Hydrogen Future. Tour around the globe

Jules Verne Style' stories on the role of Hydrogen in 2030s and 2040s

Cover design was inspired by Shutterstock.com gallery.

9th February 2022.

First edition

Editing by Erik Rakhou and Rosa Puentes

This book was professionally typeset on Reedsy.
Find out more at reedsy.com

Contents

Disclaimer

The opinions expressed herein are purely those of the authors and **in no case should they be construed as official positions of the associated organizations**.

The information presented in this book is based on publicly available information although the authors reserve the right to include additional fictional projects or features for the sole purpose of this book. In no way should it be considered a guarantee of what may or may not happen in the future. The reader in its capacity as professional individual or entity shall be responsible for seeking to verify the accurate and relevant information needed for its own assessment and decision and shall be responsible for use of the document or any part of it for any purpose other than that for which it is intended.

The story, all names, characters, and incidents portrayed in this production are fictitious. No identification with actual persons (living or deceased), places, buildings, and products is intended or should be inferred.

This publication and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Foreword

Author: Andris Piebalgs

Following previous 'hydrogen hypes' that came and passed in recent history, there is a growing consensus that this most recent groundswell of momentum will see renewable and low carbon hydrogen carve out a critical role in the drive to a carbon neutral economy. This has been borne out by the breadth and depth of hydrogen strategies and roadmaps that have emerged around the world in recent years, such as those to be explored in this book.

Aims for a clean hydrogen sector go well beyond decarbonisation, it also entails the development of supply chains, jobs, innovation, and an opportunity to redraw the global economics and geopolitics of the energy sector. For countries without fossil fuel resources, hydrogen could be an opportunity to reduce their dependence or even become energy exporters, whilst fossil fuel rich countries may be able to leverage hydrogen as part of a just transition to a more sustainable future. Hydrogen could help reduce the volatility of global energy markets and alleviate energy poverty through democratising the means of production, anchored in cheap and abundant renewable electricity. The International Renewable Energy Agency (IRENA) estimates hydrogen could cover up to 12% of global energy use by 2050, with strong demand development

in the mid-2030s.[1] There are immense opportunities for the global community in clean hydrogen development, with production potential far exceeding estimated global demand.

Nevertheless, we must take pause and acknowledge the difference between what we can envisage, and what we know and see. I can personally attest to this difference. In 2004, during my mandate in office, I stood in front of the European Parliament during Energy Commissioner's hearings and confirmed the importance of advancing hydrogen as a clean energy carrier. Subsequently, hydrogen was prioritised in the European Strategic Energy Technology Plan (SET-Plan) to accelerate the development and deployment of cost-effective low carbon technologies in Europe, leading to the creation of the European Hydrogen and Fuel Cell Technology Platform. Nevertheless, almost 20 years later clean hydrogen production remains incredibly scarce. This needs to change, and it will change. Many countries and companies around the globe are taking the initiative with new pioneering projects emerging all the time.

'Touching Hydrogen Future - tour across the globe', drafted and edited by Erik Rakhou and Rosa Puentes, together with 20+ authors from every corner of the world, provides a well-crafted and informative picture of the trajectory for the sector. Starting with the Netherlands and moving westwards, the reader is taken on a true tour of the 'hydrogen world', discovering the ambitions and key projects of different countries. It is done in a way that makes this 'journey' accessible and enjoyable not only for energy professionals but for anybody with a curiosity, and educational interest.

The reader learns from local experts about the moves of policy makers and industry, as well as significant technological

breakthroughs that will help deliver real action on hydrogen. The book allows us to understand the gravity and complexity of the task in hand, with each country bringing its own opportunities, constraints, and positionality. Although the transition will be far from simple, requiring unprecedented efforts from governments, industry, and citizens, the tour shows the reader the truly exciting opportunities hydrogen offers for all nations. It is not just a fuel replacement, it is a paradigm shift in the way we look at energy systems, with co-benefits across a number of Sustainable Development Goals.

Acknowledgment

Molecules flow. Electrons bump. Life flows and bumps, leading us always further sand wiser. So did a series of events that lead to writing this book in collaboration with so many great people. I and my co-editor Rosa are blessed with many friends, and great families, loving parents and are not ashamed to ask for help and to collaborate. We approached many of you, and apologies if we do not list all in this acknowledgment.

The idea for this book, in hindsight, may have started in 2017 in London, on an event 'role of natural gas' where Erik and 30+ energy executives from around Europe had a Chatham house rule discussion on decarbonizing gas markets. One of the ideas was to look at 'what about hydrogen'.

Then few years on in Amsterdam in 2019, a banking friend (she) gave a wonderful presentation 'Hydrogen or Hype'. Conclusion was, it could be both. In same event, deepsea cross-continent interconnection was discussed. Conclusion was, why not. The world longed for energy transition solutions urgently.

Shortly after the event, the deepsea interconnection relation asked me – 'do you know any Hydrogen industry relation in Germany'. I didn't – but it made me think again on Hydrogen and electrification (another vogue of these times) being interconnected.

Fast forward, Covid happened, and one learning from these intensive times, is that virtual collaboration and trust can work.

Through these times, I also observed a rising interest with clients and relations in hydrogen economy; loads of work started happening in this space, and me being part of it, learning.

Then, on a dark but cosy afternoon in Groningen of 'wind meets gas' in 2021, I spoke to a CEO of an energy utility - against the background of an ancient church, she shared her fear – we won't find enough people to build energy transition. We need to teach new talent soon.

Then through October 2021, as Covid persisted, the idea came – why not write a book that educates and enthuses on the underlighted part of the energy transition – futures of hydrogen. Hydrogen economy with its clean chance to be the new decarbonised replacement for oil, coal, natural gas at once – can be the beacon that can draw new people to the energy industry.

Then, magically – as sometimes good ideas need a little coincidence - on 27 October 2021, Rosa wrote me – I love the idea and could help. Well, we wrote the first article as test on Linked-in, got both happy and angry responses (negative attention is still attention.) We knew then, this is timely.

Once the article was out, it was natural to find great, smart and energy savvy collaborators to write specific chapters on global countries, which are considering hydrogen economy. Their names in alphabetical order are: **Andrey Bondar, Anne-Sophie Corbeau, Argun Karacay, Carlo Degli, Dan Shulman, David Sheipourri, Eric Ehrhardt, Gerhard Human, Giuseppe Grimaldi, Irina Gaida, Joachim von Scheele, John Baldwin, Katerina Sardi, Konstantin Lenz, Lavinia Tanase, Miguel Ballesteros, Nesma Aboshanab, Oghosa Erhahon, Pablo Ferragut, Petar Sofev, Robin Macpherson, Robin Mills, Rocío Salas, Sigrid Colnerud, Thomas Quer-**

rioux, Tom Baldwin.

Also thank you for honesty to those who, sometimes after weeks of thinking, let me know, they disapprove of the rationale hydrogen economy rise in their country, and hence cannot write on it. One of such countries we did not cover is South Korea - it is a very promising market, with loads of OEM-savvy players and ambitions to lead the global rise, for now heavily state funded and driving to its own energy security. Perhaps, in the 2nd edition, we will find a courageous writer to add.

Thank you to our first reader, **Andris Piebalgs**, who wrote an insightful foreword.

Finally, thank to team of **Luther Pendragon** for supporting the media attention around this book first release.

As we go closer to the release, also thank you in advance to you, the readers, for any of your feedback to this book – please let us know via LinkedIn – it can be both pros and cons.

Hydrogen is these days known to be a very popular part of the energy transition toolbox – this book will show some of it possibly becoming a reality, and some of it get delayed or failing. One thing is certain – in 2031, it would be our honour to host at least an online event to bring all authors together – to check how the hype, vogue hopium or simply realism turned reality (or maybe we will realise it just 'aged super badly'.) Will you join us?

We have a dream to have this book in each library of educational centers in the world in print – if you want to help us achieve this, please contact us.

Our goal has always been to inspire people around the world to learn about hydrogen, and challenge it when needed. As humans beings, we are born to learn, think and even innovate. 'Knowledge is power, ignorance is bliss. But curiosity, even if

it had killed the cat, is king' – an American writer once said. Fearing knowledge may sound non-sense, but from time to time, we may feel it. There are questions we do not want to know the answers to. We hope this book is the starting point of a journey that will encourage you to be more curious about the energy transition, the changes to come, fearless of the future and, hopefully, it will also help you to realise that the energy transition is not only about fuels switch, but about human changes, as well. And that is what will make the real difference.

#TouchingHydrogenFuture

Erik and Rosa.

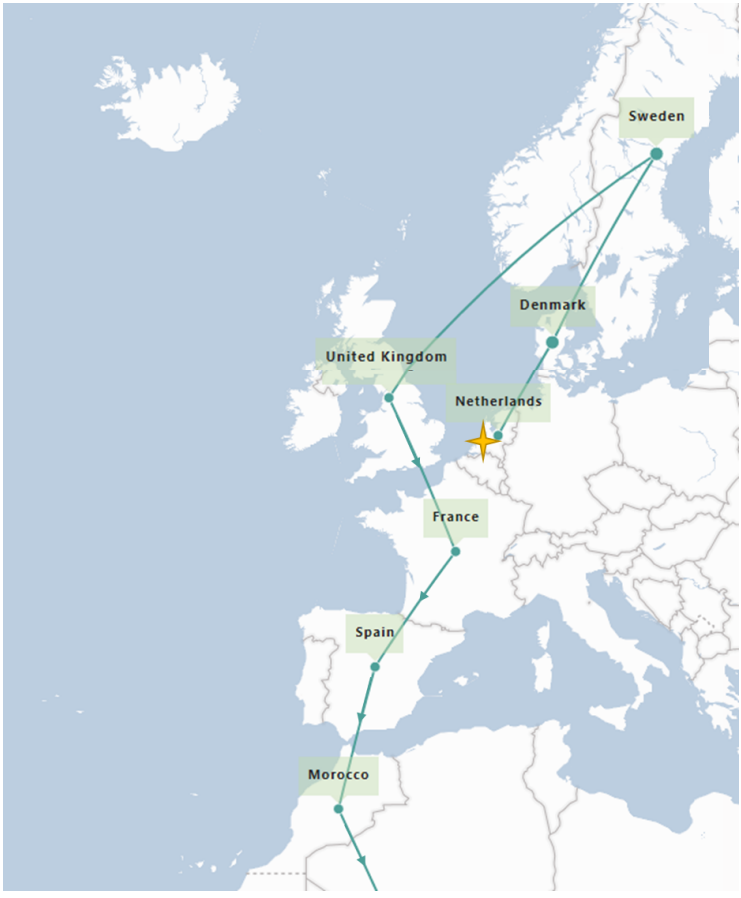
The journey on the map

We will visit 27 countries along all the continents of the world.

Starting in The Netherlands and finalising in Germany, the countries are visited following a specific and deliberated order that allows the reader (i.e., the traveller) to go in a tour around the world as she/he would do in real life, without discontinuations.

Illustration of countries visited along the book. Source: Google and editors

The journey starts by visiting Northern Europe (Denmark and Sweden), followed by UK, France, and Spain.



ap visualising part of the journey. Source: google and editors

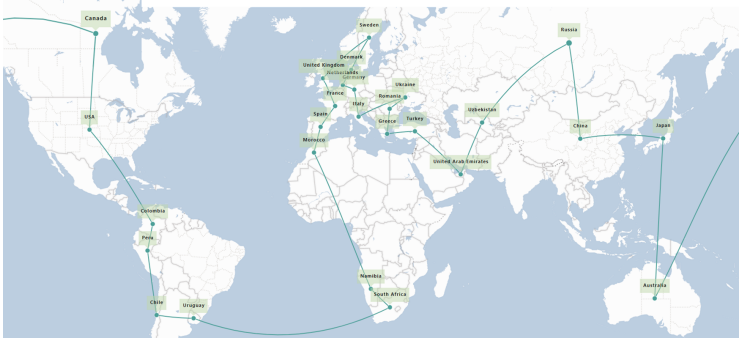
From Spain to Africa: First Morocco and then Namibia and South Africa. Later, we move to South America to visit Uruguay, Chile, Peru and Colombia. Then, North America: USA and Canada.

Map visualising part of the journey. Source: google and editors

The journey continues connecting Canada and Australia. Then, Japan, China and Russia follow. From Russia we move to Uzbekistan, United Arab Emirates, Turkey and back to Europe, this time the East part of the continent. The journey ends by visiting Greece, Romania, Ukraine, Italy and, finally, Germany.

Map visualising part of the journey. Source: google and editors

See the complete journey below:



Map illustrating the whole journey. Source: google and editors

For an interactive experience, visit this website.

Note: The maps included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

About the authors

28 people contributed to this book. In order of appearance:

Netherlands
Erik Rakhou
Denmark
Petar Sofev
Sweden
Sigrid Granström
United Kingdom
Tom Baldwin and John Baldwin
France
Thomas Querrioux
Spain
Rosa Puentes Fernández
Morocco
Nesma Aboshanab
Namibia
Oghosa Erhahon
South Africa
Gerhard Human
Uruguay
Pablo Ignacio Ferragut Varela
Chile
Eric Ehrhardt
Peru

Rocío Salas
Colombia
Miguel Ballesteros
USA
Anne-Sophie Corbeau
Canada
Robin Macpherson
Australia
David Sheipouri
Japan
Dan Shulman
China
Joachim von Scheele
Russia
Irina Gaida
Uzbekistan
Giuseppe Grimaldi
United Arab Emirates
Robin Mills
Turkey
Argun Karacay
Ukraine
Andrey Bondar
Romania
Lavinia Tanase
Greece
Katerina Sardi
Italy
Carlo Degli Esposti
Germany
Konstantin Lenz

The Beginning

All good things come to a start. In 1874, the French science fiction writer, Jules Verne envisioned a hydrogen dream. In his book *The Mysterious Island*, Verne imagined:

> "A world where water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable."[2]

The same Jules Verne loved to picture global travel and helped to show how one could cross the world in 80 days. From the time of Verne's "*around the world in 80 days*", the world has become more dependent on energy. We have learned that affordable, clean and secure delivery of energy is a societal cornerstone. Hydrogen holds part of the global answer, if scaled up - and countries across the globe have started recognising this.

In the meantime, as a world we have moved from putting fossil fuel industries on a pedestal last century to admiring climate change risk savvy investors in the modern day. In the late 2020s and 2030s there will be a new respectable and cool job - enter any room in the world as a hydrogen professional

and you may well be the star of the birthday party. This book will help you as a reader to decide if you want to become part of building a future based on hydrogen.

How would that hydrogen future feel and be to live in? We combine Jules Verne's ideas about hydrogen's promise and travelling as proof. Join us on a rapid tour around the globe in the 2030s and 2040s, covering more than 100 locations. We visit 27 countries with hydrogen ambitions, turning the PowerPoints of the 2020s into reality in 2030 and 2040. Through the eyes of today's *passionados*, we show you how the hydrogen world will feel and invite you to join in building it.

Imagining the future is delivering it.

Let's go!

Netherlands, 2029

Author: Erik Rakhou

The red light on the wing was flickering, as he slowly started waking up, seeing his plane approaching 1 of the extended Dutch airports and losing height. It was 3 November 2029, 8 years onwards from Glasgow COP26. In his quick dream, he vividly remembered his trip to 1 of the Glasgow side-events, dedicated to huge steps needed to curb the rise of global warming and climate crisis – the somewhat inefficient tornado of then combined announced pledges to launch the shot at hydrogen at 1 USD/kg at the time did trigger the rapid becoming of "clean hydrogen"[3] the most cited energy word, like "fossil oil" in the decades before.

The plane suddenly started rising again, having to take a detour. The pilot announced: *"Dear passengers, apologies, we have to circle across the North sea, as the airport is inaccessible, due to power in airport terminal, having been cut due to a temporary local black-out caused by power grid problems.*[4] *We are using the opportunity to showcast how the hydrogen used by our airline is produced, and will fly over the energy island, where so-called SOUTH2,*[5] *successor of NorthH2,*[6] *is turning windmill power to split water into hydrogen and oxygen."* The structure has been inspired

by very famous Dutch architect, who became world known for having designed the first 200 MW electrolyser factory in Rotterdam, some of his early work (pictured below), floated as a memory in front of his eyes:

Design of the first 200 MW electrolyser factory in Rotterdam. Source

Meanwhile, looking at the giant structure of the offshore green hydrogen factory, flickering with green led lights to signify it having been labelled "Green hydrogen taxonomy"[7] he quickly remembered reading that the 15 billion euro project has just recently been commissioned,[8] and included a small modular nuclear reactor, enabling in hours that wind was not blowing, to keep using electrolysers, and thus lowering overall energy system costs. The project enabled artificial intelligence, provided by Spectrazon,[9] to steer the clean power towards the Dutch and other North sea grids, when the grid

needed power over hydrogen to keep the stability and avoid now common rolling commercially accepted black-outs. The hydrogen production had been in part sold long term to various Dutch energy buyers – airlines, logistics providers, steel plant, and shipping fuel producers. Part of the production had been reserved for short term sales to stimulate rise of new users, being able to enter the market and allow transparent price evolvement.

"Blast", he sweared – his digital watch signalled the micro-hydrogen futures he has bought for Rotterdam delivered clean hydrogen via HyExchange[10] to hedge his home use of hydrogen for his camping trailer, were pushing him for a small margin call.[11] He ordered from the plane stewards one of those trendy "Air vodka's"[12] now seen as acceptable way to offset some of the emissions from the past, and logically trendy as carbon has moved on from being seen as a burden in early 2020s to being recycled to make sustainable products.

The plane continued circling, and his mind wandered again. Using hydrogen in flying for Netherlands has become the new normal since 2024 Rotterdam airport showed it can be done.[13] A good friend of his, who casually jumped out of planes as if drinking tea, now regularly checked with him on his views on supply dynamics of price of global hydrogen, because his flying club finally bought themselves a hydrogen fuelled plane. He heard Airbus was making good progress for long haul flights using hydrogen based fuels.[14] Amazing how things have moved on.

Out of the plane windows he spotted a couple of huge Maersk ships starting the turn for port of Rotterdam; those ships operated on Methanol,[15] a volume efficient way to use hydrogen based Methanol[16] as fuel for shipping.

"Blast", he sweared again, he remembered in 2020 he made a bet for a case of Barolo with a CEO of one of Benelux shipping firms, that nuclear energy would be gone in Benelux by 2030. Who could have thought in 2020 that nuclear energy, as a source of stable hydrogen production at scale for global shipping, would have made a renaissance by 2030. Yet, it was true – he remembered attending a meeting in London Royal Automobile club chaired by Amber Rudd, which proved prophetic with release of a study paving the way to nuclear energy and hydrogen marriage in policy debate.[17]

His watch bleeped again – his hydrogen fuelled next generation of Toyota taxi – called Dutch HYPE after a few successful Paris projects[18] – was reporting to wait for him at the airport. Amazing how things moved on here, he vividly remembered his debate with a TESLA taxi driver in Amsterdam, who happened to be an expert back in early 2020s on pros and cons of electrical vehicles versus hydrogen cars and trucks; here is a bit of a transcript of that conversation that appeared in my mind bringing back memories of early 2020s thinking:

Me: *"So what do you think about hydrogen and cars, trucks?"*

Him (the TESLA taxi driver): *"It's feasible but not sensible. Can't compete with battery electric, too energy consuming, distribution of hydrogen near prohibitively expensive, and delays getting rid of grey hydrogen in existing sectors of use like fertiliser and refining.*[19] *Hydrogen is a problem we just started to solve, not a solution, which justifies expanding the market for it - effort is better used finding ways of making it competitive in existing sectors where hydrogen is used. I'm all for green hydrogen for ammonia in fertiliser industry, and methanol production. Not much else"*.

Me: *"*H*mmm....I do see some industrial scale-ups going into hydrogen trucks - Hyzon,*[20] *Nikola,*[21] *Daimler, Quantron,*[22] *Hyundai,*[23]

Tevva,[24] *Gaussin & Plug Power*[25]*..."*

Him: *"Does not make it right if strong and innovative players do it. Most of the world's hydrogen is made from methane and coal in a dirty energy consuming process. Any expansion of that market shouldn't be allowed today. I can put it into perspective. Do you like math? Here are some quick numbers for you. The current wind generation in this country is about let's say 1x. Converting the trucks and car fleets from diesel to green hydrogen would require another 1.5x in comparison with 0.5x fully electric conversion of fleets. There are illustrative ball parc figures I based on Volkswagen research which shows huge conversion losses from renewable energy down to using hydrogen in fuel cells in comparison to direct use of renewable power* [26] *– feel free to challenge, I know this assumes current state of technology. So now, there is no reason to even attempt to do that. It would benefit only the current fossil industry - using tax payers' money probably. It would be insanely expensive, and still not solve the current decarbonisation problem."*

Me: *"So if we looked at building all renewable energy just here in Europe, I would agree. There are global trade value chains emerging where hydrogen helps to bring stranded renewable power to end-users on different continents.*[27] *And what about other decision factors. In your experience, are your cars and trucks solutions able to cover - Rotterdam to Munich, say 800 km distance?"*

Him: *"I don't drive trucks, so it's a mental exercise. But if you are hinting to hydrogen being superior to battery electric in terms of range, you're wrong. Range is similar in my view. Limitation for hydrogen is weight and volume, with emphasis on volume. Limitation for battery electric is also weight and volume with emphasis on weight. In reality there is no real difference at present. I'm aware of the dreams of storing the hydrogen in liquid form on the trucks, which is possible, and will provide +1000 km range, but*

paying for that kind of hydrogen distribution is foolish in my view. Only benefit for hydrogen trucks over battery is filling time, which is a perceived benefit rather than a real one. There is no problem charging a 44 tons truck with 400 km of range in well under an hour. 400 km is roughly what's required to cover the allowed time for driving intervals under European rules for taking breaks. More or less all you need to know to realise that hydrogen for (cars and) trucks is a dead end. Unfortunately because it would be good for business. And moreover, hydrogen refuelling stations would face challenges equal to electrical charge stations of requiring huge grids expansion."

Me: *"If range is indeed manageable (400 km), in Europe hydrogen in trucks will face strong electric competition. It will come down to who manages supply of hydrogen and storage versus electrons and storage better. Nikola's and Shell/Daimler concept which appear to copy Tesla's approach of fuel plus vehicle is a good one. If same is offered in electric, hydrogen trucks will face competition indeed. The electric storage is not trivial - assuming now current fuel stations get depleted every 2nd day, one needs by analogue to hold day or 2 worth of power - battery solutions, don't yet match required duration, so one needs grid power. Grids may be slow to ramp up. As hydrogen value chain though gets developed for other industries, then its supply chain could get reused for cars and trucks with hydrogen fuel cells, just in time to compete with electric cars and trucks ...?"*

Him: *"All those things matter but in the end 3 main arguments should put a stop to any tax-money being poured into subsidizing hydrogen for vehicle use:*

1) It's still a monumental task to get rid of the existing grey hydrogen, which is most of the hydrogen production now. Expanding the market to trucks will only be an expensive distraction in that effort until grey hydrogen is greened first.

2) H2 trucks and cars need 2 to 3 times more energy as input due to energy conversion losses versus electric solutions - why would taxpayers want to pay for that fuel production?

3) We are talking about the fruits hanging highest in the tree for CO2-reduction in transport. All efforts of transport decarbonisation should be focused on the lowest hanging fruits where electrification is another-no-brainer. I'm sure there will be shipping industry or aviation industry firms, which struggle for alternatives to decarbonise, hence more than happy to pay top dollar for fuels derived from green Hydrogen, and pay for their special properties as molecules – hence there's no reason to waste green Hydrogen in trucks or cars, just yet."

He then continued to say, "*well thanks for the conversation, we arrived."*

* * *

My mind circled back to present (2029=, the taxi driver was quite right, aviation and shipping came first, but because of scale, hydrogen in cars and trucks came second simply because power grid operators, including visionary firms like TenneT realised power grids alone would not deliver the energy transition timely for carbon to become a non-issue.[28]

The plane finally started descent….yet he was still dreaming further, taken on a global tour of hydrogen future…

Denmark, 2030

Author: Petar Sofev

31 December 2030, what a fantastic year this was.

Introduction

Like many others, when a year comes to an end I sit down in quiet and spend some time reflecting. Today is slightly different as this year was perhaps the most eventful since I came to Denmark back in 2015, as the first step in my career change. What attracted me then as a student and still attracts me today is the country's green ambitions, social system, and high ranking in the good country index,[29] to name but a few. It was not always a smooth *voyage* but I've witnessed and hope to have contributed even a little to what has been a significant green transformation of Denmark and the rest of the world.

The following paragraphs look back at the elapsed year, during which so many, but not all, of the 2030 pledges were finally reached. It was interesting to observe how we sometimes waited for the very last minute to meet this very important deadline. I am only thankful that climate change proved more patient than anticipated and we somehow managed to avoid

the worst of it, so far.

Winter 2030

It was a cold January morning and I was on my way to the Danish island of Bornholm[30], which in the past got into the spotlight due to the Nord Stream 1, and mostly Nord Stream 2 gas pipeline,[31] but today is one of the two major Danish energy islands. Initially, 2GW[32] of offshore wind from the Baltic Sea was planned. Today the capacity has reached 5GW. The island is connected to the power grids of Denmark, Sweden, Germany, and Poland.[33] For this trip, I was however more interested in the hydrogen production that via the Port of Roenne has been supplying more than 60,000 passing ships with liquid hydrogen and ammonia from as early as 2025.[34]

I live in a suburban town only 20km from Copenhagen but far enough that I need to rely on regional trains to get to the main station or the airport. Today, I was looking forward to flying for the very first time on a hybrid-electric plane that was completing the trip from Copenhagen to Bornholm in less than 40 minutes. I cannot get my head around the fact of how quickly Denmark managed to meet its goal to have all domestic flights be zero emissions by 2030[35]. Copenhagen airport alone has fully developed the announced back in 2020 IPCEI[36] project "Green Fuels for Denmark" and today produces more than 250,000 tones of sustainable fuels for transport, including e-kerosene for aviation[37] from its 1.3GW of electrolysers. Most of the electricity comes from Bornholm's wind but the electrolysers are in the Copenhagen area. It is also worth a mention that most flights in Scandinavia are today close to zero emissions.

Planes get you to your destination fast, but of all forms of transport, I like trains the most. Especially these days they are very comfortable and mostly reliable. I say mostly with a bit of bitterness as today, of all days, there were severe train delays. I hesitate a little whether I should hope for the best and wait for a train and run the risk of further delays, or grab a taxi. I didn't want to miss my first hybrid-electric flight, and the meetings that were scheduled in Bornholm, so I've decided to just grab a taxi. To somehow compensate for my early sweats, I was treated to a brand new and somewhat luxurious Toyota Mirai cab. It was one of 500 hydrogen taxis that were roaming the streets of Copenhagen as part of a partnership that in retrospect proved essential for developing the refueling infrastructure for hydrogen vehicles in the capital region.[38]

Twenty minutes later I arrived at Copenhagen Airport with little time to spare. After a swift progress through the terminal (steady running towards the gate) I finally boarded a short-haul hybrid-electric plane that according to the brochure in the front seat can carry 80 passengers in comfort mostly relying on solid-state batteries and a small e-kerosene generator, which for today's short flight will serve only as a back-up.[39]

The flight was surprisingly silent and relaxing, but I was perhaps too excited to get the intended benefit from it. I was also excited to once again visit Bornholm. Today, I had a few meetings in the port of Roenne, to discuss their role as an energy hub and their outlook for the future. My fascination with Bornholm as the first energy island, I believe in the world, goes back to late 2021 when together with some students we visited the Technical University of Denmark (DTU) Power Lab[40], where they have a small model of the island but more impressively, a control room that is a physical duplicate and

fully connected to the control room on the island. Back then it looked like something that belongs in NASA.

Spring 2030

In early spring, together with some colleagues, we visited the second Danish energy island located in the North Sea[41]. The artificial island located 80 km from the small Danish coastal town of Thorsminde took 9 years to develop and continues to expand.[42] The island today harnesses 3 GW of offshore wind and is on track to expand its capacity to 10 GW.[43] These days almost everything that gets in the headlines is on the gigawatt scale….The island looks and seems to operate just like a small industrial port. In addition, it has P2X production and storage facility, warehouses, accommodation, and a decent restaurant. When back in the day you would probably need a special permission to get to the island, now it is as simple as taking a ferry. The island also hosts an information center with lecture and exhibition halls. A lot of students and foreign visitors come here to learn more about the cool concept and operations of an artificial energy island. Please see below for an impression of a future energy island in the North Sea.

Snapshot from the visualisation of the VindØ project, credit the VindØ consortium

Summer 2030

In June, I decided to visit relatives in neighboring Norway and couldn't think of a better way to get there than the fairly new hydrogen-powered ferry that replaced the old sister cruise ferries connecting Copenhagen and Oslo.[44] Stepping onto the top deck I had a *déjà vu* from the first time I took the overnight ferry. The only difference is that there were no exhaust chimneys that, despite the very low sulfur fuel used back then, still managed to "stink everything up." There were also no engine vibrations, which improved the passenger comfort but reduced the "drama" of a big ship that some people nostalgically remember (myself included.)

The two new ferries have a similar capacity as the old ladies – 1,800 passengers, 120 trucks/380 passenger cars. They use compressed hydrogen in a 23 MW PEM fuel cell system[45] – a real technical feat when they first set sails back in

2027. The cool thing if you are making the *voyag*e with your car/camper/motorcycle is that your vehicle whether hydrogen or battery electric will get fully recharged for free during the passage. Yes, that is correct, there are 380 hybrid charging points in the car decks plus a few dozen for electric bicycles. We now take them for granted, but it took a very long time to sort out the technical standards.

Despite my best hopes, I was treated to another rough sea voyage to Oslo. Trying to ease my seasickness I headed to the outside decks as early as the first sun rays were emerging on the horizon. *"There could be no better occasion to check on the latest hydrogen-related news"*, I said to myself. We were halfway through 2030 and taking stock of the many, climate, energy, hydrogen (most commonly known in Denmark as P2X projects) will probably be as long as the remainder of the journey to Oslo. I had nothing better to do anyway.

Before hitting the summer holidays, Denmark announced that it has reached its goal of at least 70% CO_2e (CO_2 and other GHG emissions such as methane) and that wind and P2X[46] have played a significant role in achieving this (as originally intended.)[47] In 2030, Denmark has around 10GW of P2X facilities in operation. The green hydrogen hub between the towns of Hobro and Vibor has doubled its 2025 capacity to a 700MW electrolyzer plant and 400,000 MWh underground hydrogen storage.[48] The HySynergy project is another IPCEI that has expanded to 1GW electrolyzer capacity to produce green hydrogen for heavy road transport in Fredericia.[49] Green CCU Hub Aalborg produces 20 million liters of e-methanol with half being utilised as a petrol additive for passenger cars[50]. A large portion is also used as a marine fuel.[51] I am probably missing something, there are so many projects in the country…

Autumn 2030

Autumn is perhaps not the best time to visit a port, especially in what is considered as one of the windiest cities in Denmark (hence the world), but after the gloomy morning, that Thursday afternoon provided us with nothing but sunshine and a gentle breeze. We were paying a visit to Esbjerg in South Denmark where a number of projects were underway.[52] The city has an interesting story and has been through several transformations so it can today call itself an Energy Metropolis.

Most of the offshore power and hydrogen flow through the port of Esbjerg, which is today a major energy hub in the North Sea. The hydrogen pipeline that connects Denmark and Germany also starts from Esbjerg and the green gas flows through Hamburg into the German gas grid. At full capacity, the pipeline can meet up to 25% of the German hydrogen demand. I think today it is only around 8%.[53]

The port of Esbjerg utilizes renewable energy and hydrogen for its own uses and has also been providing 100% green shore power to ships from 2022.[54,55] Since 2025 a 1 GW electrolyzer[56] has been in operation in the Port of Esbjerg. Due to high demand, expanding off-shore wind capacity, it has recently doubled its capacity. The produced hydrogen is used for heavy road traffic (e.g. trucks that refuel directly at the port) and for several regional train routes (there is a pipeline connecting the port and the train station.)

Esbjerg is also the home of one of the first large-scale ammonia production facilities in the world, the Høst project. With an electrolyzer capacity of 1GW, the plant has been supplying ammonia to the agricultural industry and to ships calling at the port of Esbjerg since 2027.[57] Large quantities of

liquified ammonia are shipped to Hamburg and other European ports via Esbjeg. In addition, a by-product of the Haber-Bosch process is large quantities of water with a temperature of 70°C, which is perfect for heating people's radiators at home. With its large capacity, the plant can supply half the city of Esbjerg with zero-emissions and "guilty-free" district heating.

Hydrogen projects in Esbjerg are now a strong part of the local economy and community and directly employ more than 500 people in the region[58]. However, the two larger projects were delayed by more than a year each. It took a really, really long time to win public acceptance for hydrogen and ammonia. Today we see them as no riskier than natural gas, but back in the day, we were hesitant to have them in our backyard. We knew that this could be an issue but still underestimated its impact. I remember back in 2021 I asked a room filled with P2X *aficionados* how many will be happy to have an ammonia plant in their neighbourhood… No one raised their hand, including myself.

After this reflection, it seems that we in Denmark are truly very lucky to have so many world-class and sometimes world's first projects that are so easily accessible. It seems to me that Denmark more than ever wants to share its know-how with the world. After all, this is what true green leadership is all about.

Sweden, 2048

Author: Sigrid Granström

June 6, 2048

So, I find myself waiting for the ferry to take me to Gotland[59], this island in the Baltic sea where I have my own little paradise. A large stone house right by the sea at the southernmost tip of the island. It's been in the family for decades and we've been gently renovating it step by step. With solar panels on the roof of the big barn, we're basically self-sufficient most of the year. It's even enough for charging an EV, both our own and our neighbours. This time, I'm on my own and without car. That's however not a problem anymore. But we'll get to that.

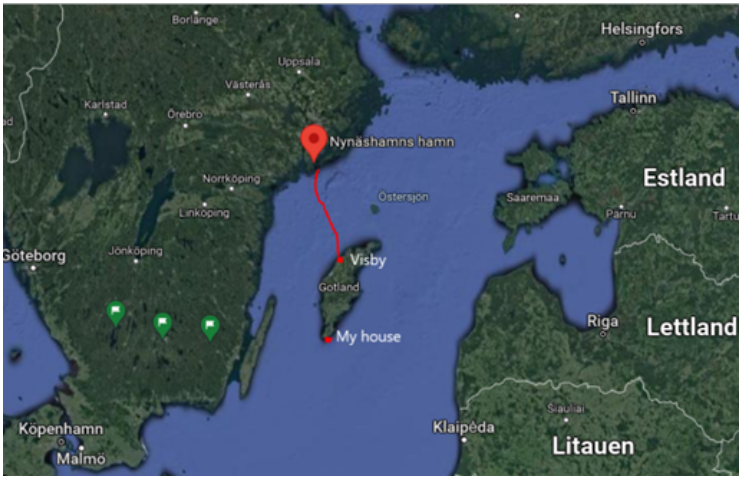
As I stand by the port waiting, I look at the old large natural gas tanks. Not too long ago, this was the main cargo port for natural gas import. It came by diesel motored ships, was unloaded and stored until further transport by fossil fuelled trucks.[60] Today, two of the tanks are transformed to a super cool, futuristic hotel with a seaside restaurant and a stage hosting theatres and concerts (the roof can be removed on warm summer nights) and a climbing centre.[61] The other tanks, with refurbishment, are now used as storage for liquid hydrogen.

Ships at this harbour are fuelled only by hydrogen. Of course.

Sweden set a goal some twenty-five years ago, in 2020s, that by today at least an equivalent of 84 TWh electricity would come from electrolyser capacity[62]. This was then said by some to be optimistic rather than realistic, by others to be naïve and imbecile. And here we are, producing far more hydrogen than we use and now we're one of Europe's leading exporters. As a result, national emissions have been cut by more than 40 percent.[63]

The cargo port still remains, but with a new purpose. Nowadays, it's a hub for CCS, carbon capture and storage. As the seabed around Gotland is mostly limestone, it's indeed suitable for storage of captured carbon dioxide. There also a site for carbon capture and use, where the carbon dioxide is used as a raw material for the production of electro fuels, e.g. e-methanol.

But here comes the ferry – let's go onboard! See figure below for my planned trip:



Overview route to Gotland. Source: google maps augmented with author's indications.

Visby, the medieval (and only) city on Gotland

Leaving the ferry by foot, appreciating the nonexistence of the sound of car engines embarking the ferry. Since a few years, the city is fossil fuel free meaning that all fossil fuelled vehicles are banned (no exemptions). Hence, if taking the car, you either have to have an EV or you need to leave your fossil fuelled beast parked in the harbour. You are still allowed to use a non-EV outside the city, but petrol stations are already scarce, and everyone will know you're not a local.

Gotland. Source: Lonely Planet

Gotland was the first large scale off grid community in Sweden. With only one cable connecting the island with mainland, it's always been a vulnerable spot on the transmission network. It all started back in 2019 when it was decided to make Gotland a pilot for a sustainable and fossil fuel free energy system. It then also became part of the EU Initiative Clean Energy for EU Islands.[64] The pilot succeeded, and Gotland became the role model for the rest of the country. Looking back, it feels so strange that we actually managed our energy system in such a short term, and unsustainable manner!

Now, there are windmills all over. On shore, mostly on pastureland for sheep. There are solar panels on fields with corn, buck wheat, and other crops as it has been shown to actually increase harvest. The shadow it brings does more good than harm nowadays as the sun burns harder and rain is more unreliable.[65] A vast majority of windmills are however offshore.

They're beautiful, like immense Nordic flamingos out in the ocean. The total installed capacity just around the island is an impressing 30,000 MW (30 GW), with material production. That's three times more than the entire country had just 25 years ago. But it's a bit unfair to compare output now and then as the technical development increasing efficiency of each windmill has been faster than Road Runner (for those who remember the old cartoon by Chuck Jones.)[66]

When there's a regional net production surplus, the excess power is used for hydrogen production. In that way, the volatile power production from wind can be stored. There are large subterranean hydrogen storages, just like the hydropower dams in northern Sweden, but below surface instead of above. It was said by sceptics that large scale hydrogen production would be unlikely due to lack of fossil fuels free electricity, as the process is energy intense. They were proved to be wrong. The efficiency of the electrolyser is still to be improved but compared to an efficiency level of about 65 percent back in 2020[67], it has improved indeed. And the excess heat that comes out of the process is taken care of and used e.g. for heating of green houses during the colder part of the year to prolong growth and harvest.

Combined with emission free electricity production and hydrogen storages, there's of course a need for user flexibility. With decentralized solutions at our regional level here at Gotland combined with centralized – national and European – solutions, this works. It took quite some time to get collaborations work and fair enough, at European level there are still some bumpy roads to be travelled. Nevertheless, those three components (emission free electricity production, energy storages and user flexibility) are the core for our long-term

sustainable security of supply. We have, in a rather short period of time, managed to develop an integrated energy system in which fossil fuel free hydrogen is included, and where different energy sources, energy carriers, types of infrastructure and different kind of users interact – i.e. integrated value chains rather than multiple ones with Chinese walls.

Anyways, I'm still on my way home. As I walk through the city, I pass the new campus. It's a beautiful building in wood and natural stone. There are flower beds on the roof to help pollinators. All the windows are solar panels. It's what we call a plus energy house, i.e. a house that produces more energy than it consumes. It has several energy efficiency components and is constantly self-sufficient on energy, hot water, heating, and cooling. Don't you just love that this is more or less standard for new public buildings nowadays? The fact that this one even got built, is due to this referred earlier 2019 energy pilot and the fast hydrogen development. There was simply a lack of knowledge and competence on how to plan, build, maintain, integrate, develop appropriate frameworks and regulations, get public acceptance, maintaining biodiversity etc. I love the fact that students come from all over to study here. We sort of import thoughts and ideas from outside our own box and export thematic competence – win-win.

As I reach the bus station, the sun is high and it's rather warm. I drink from one of the public water fountains. Sweden's still on the top list of best tap water quality in Europe, together with our Nordic neighbours and countries around the Alps. I get on the bus while it's still charging. Not that full charge is necessary. The long-haul buses going South more or less follow one of the two main roads. These are since at least ten years e-roads, meaning the buses (and trucks and agricultural machinery)

can charge while driving. Superefficient! Saves time and the vehicles don't need to carry loads of heavy batteries.

There's no bus stop right by our house, but the driver is usually nice and lets me off there anyway. I've been here all my life. I know this place better than my own pocket: this house, this garden with its fruit trees, roses and the lavender alley that leads to the front door of the main house, the birch wood, the sheep on pasture and not to mention the sea. But nevertheless, every time I've been away for some time, it strikes me how lucky I am and much I love it. And yes, hydrogen is a vector and part of economy now, even in Gotland's paradise, used particularly for storing intermittent energy. See picture below for an impression of the house:

The 'little paradise' house. Source: author's photo collection

United Kingdom, 2035

Authors: Tom Baldwin, with inputs from John Baldwin

From the hydrogen landscape to NetZero to Liverpool victory

April 2035

Liverpool Football Club are on course for their 5th straight league title under the stewardship of Steven Gerard who has done a remarkable job since replacing Jurgen Klopp in 2029. Jurgen, who is entering his second term in government of Germany, has just announced a substantial investment (via government grants) into a green hydrogen pipeline from Algeria, the second from Northern Africa, parallel to the Moroccan pipeline commissioned in the early 2030s. The second pipeline is deemed necessary to diversify the EU Energy supply away from issues with natural gas supplies. The economics of wind and solar in the Sahara, with the vast scale and high combined electrolyser load factors, are expected to deliver <€1/kg hydrogen to the no regret industrial clusters and beyond[68] across Central Europe.[69] The hydrogen backbone is loading.

Klopp celebrating the new deal with a pint of his favourite beer (so say the ads). Source: author

I sip my orange can of Brewdog as I approach Liverpool Lime Street on High-Speed Rail 3 (HS3).[70] The new canned beer, creatively named "*Dutch IPA*" is not made with fizz, because the price of carbon is so high that the beer is left *flat* in the production process. In fact, the carbon price in 2035 has exceeded £400/t CO_2.[71] The idea is marketed as a means of reducing the carbon emissions of the final beer product[72], however, it is rumoured that the economics no longer stack up and fizzy beer no longer makes economic sense with alternative, nearby carbon export opportunities. These high carbon prices have resulted in highly complex and innovative coupling of industries intertwined by the delivery and offtake of CO_2 in regional grids in the North West and North East of England. An example use of the CO_2 produced in the fermentation process is at a large biomass facility, x, in the North of England.

Gasification of biomass produces hydrogen, which is then blended with brewery CO_2 to make renewable methanol, which is then burnt to generate electricity to operate a direct air capture plant[73]. Possibly not the most efficient of processes – but certainly an innovative one. Not to be confused with its close cousin known as "liquid wind", where the source hydrogen is supplied via an electrolyser connected to offshore wind generation[74], or what you get from drinking too much *flat* beer.

On a related and unexpected note, 2035 is tipped to see the full decarbonisation of the electricity grid in the UK, meeting the 2021 target which rose from the fog of the 2021 retail crisis[75]. Back up generation is provided by gas generation with Carbon Capture Storage (CCS), and at smaller sites with green certificate (both hydrogen and biogas) supplied gas generation, which helps explain both the rise in carbon prices and the cost of green gas certificates. The caveat, of course applied to a decarbonised power grid, is an average wind year. Unfortunately, the same positive result of full decarbonisation cannot be said of the gas grid and domestic heating. Yet, huge investment in offshore wind and distributed generation assets in the past 15 years have led to significant periods of low prices in the UK. Thus "incentivising" over 1 GW of grid connected electrolyser capacity and raising the percentage of the grid supplied by low carbon gases to 5% (thanks to a great contribution from biogas with over 1,000 biomethane to grid plants now in operation in GB.) Alas, dedicated domestic hydrogen feels dead in the water. The HSE (Health and Safety Executive) is down to the last 7 evidence gaps before they can decide if it is safe to burn hydrogen in the home, but it doesn't matter anyway as the handful of welders left in the country

are focused on industrial clusters and finishing Hinckley Point C. It's not all doom and gloom, heat pumps are truly starting to take off. The heat pump I ordered in 2025 has finally been installed, I can almost hear Ronald Reagan patting himself on the back that his anti-Soviet joke about new cars and plumbing is still applicable 50 years later in 2035 in Europe.[76]

I don't know why Russia is at the forefront of my mind at the time of writing this diary entry, but I can't help it, and it reminds me of the beautiful cruise I have just booked to celebrate my retirement. I will set sail from Plymouth tomorrow and will arrive in four weeks in St Petersburg. The ship will be a FOAK (First of a kind), entirely fuelled by hydrogen, with refuelling at the Port of Amsterdam, Hamburg, Copenhagen, Riga and Tallinn. From there I will return to the UK in an electric plane via Rome, where I will watch Liverpool win the champions league final.[77] The inclusion of shipping and aviation in the reformed Emissions Trading System (ETS) has been revolutionary in its results and will allow me to retire and travel at ease with myself, without the use of suspiciously cheap offset schemes on the Ryanair checkout page.[78] Not all offsets are bad though, well audited schemes run by NGOs are widespread. Ethiopia and other Nations have ramped up their rates of tree planting (if possible),[79] raking in a heaps of carbon cash as they do.

What the hydrogen cruise ship may look like arriving at St Petersburg. Source: Author

Final thoughts. A glorious day

Back to the present, I leave Lime Street Station and jump in an autonomous electric vehicle to arrive at the stadium. Unfortunately, the charging infrastructure is not quite there, and we queue for 45 minutes as the car auto-charges itself and pumps up its own tires at a self-service garage. It's not usually this bad, only a pre-match quirk, electric vehicles are dominant on the roads of the UK and have been for a while. At the ground, I try the cricket stew, part of the 'Go Grasshopper'[80] campaign launched by an environmentalist group of conservative backbenchers – not delicious I must say, but land-use change and eating habits are firmly on the political agenda in 2035, finally. Every premier league club has now followed in the footsteps of "Game Zero" between

Spurs and Chelsea in November 2021,[81] with Net Zero carbon emissions (yes, offsets play their part.)

It's been a glorious day, the hottest April day ever in Liverpool, exceeding 30 °C. Liverpool neatly dispatch newly promoted Manchester United 3-0. It has been a great day to be a Liverpool Fan. It is here that I reflect on my career working in Energy. I have turned 40 and will therefore be retiring as is typical these days, with universal basic income kicking in, and the 'done thing' being that you free up your position in the ever-shrinking workplace for the younger generation. I will be hanging up my PowerPoints, solid in the knowledge that the momentum behind Net Zero will be difficult, if not impossible, to slow as we reach the halfway point of the journey from COP26 to 2050.

Liverpool 3-0 Manchester United, Anfield, April 2035. Source: author

France, 2040

Author: Thomas Querrioux

14 May 2040. A self-driving car trip across countryside

The beach

The smell of freshly grounded coffee beans hit my nostrils as soon as I approach the cafe. I sit outside; I order my favourite - medium-roast Ethiopian Yirgacheffe green coffee beans. Soon, the waiter leaves a comfortingly fuming cup on the table. I stretch my legs, ready for the sunrise. I take a sip - as always, pleasantly surprised by the outburst of floral aromas.

6:42 am, the sky turns red, and his majesty appears on the horizon, igniting the ocean- the sun, always on time.

Nearby, I hear a burst of laughter. Some people clap. The city is already busy. A few decades back, it would have been quieter; people have adapted to the global increase in temperature. Our days start early, and we avoid afternoons. The spring morning is already warm and beautiful. Down the cliff, in front of me, I can see surfers playing with waves. In Biarritz, that is a religion - where the sport first appeared in Europe. I recall this old

documentary - Biarritz surf gang. The coastline looked very different back then, and the "Grande Plage", once a surfer's favourite, is now below sea level.

A ringtone pulls me out of my daydream. It is time to catch my car. From the app, I see it is parked a few streets away, at the nearest dropping point. I am excited.

The car could not reach me as I was in a pedestrian zone. At first, it looks very normal. So much for the 1980s pop-culture dream of flying cars… Although there are a few twists. As I approach, the car greets me. *"Good morning, sir, welcome on board."* The voice is Arthur, my dedicated virtual assistant, addressing me with the same tone (that I preselected, the perfect blend between obedience and sarcasm), be it to fix an appointment at the dentist or to play the last hit. The door opens. I step in. Now, 1980s fan, here is the second twist: no steering wheel, just a comfortable working space, as I ordered. The door shuts. The car starts moving swiftly. "*Welcome, sir*", Arthur repeats, "*Our trip will last two hours. The outside temperature is currently 23 degrees Celsius, no cloud, and light wind conditions*." I dock my phone into the terminal at the centre of the working table. *"Arthur?"*, I replied. *"Yes, sir."* Then, I continued: *"Can you give me this car's specs?"*. *"Yes, sir, you mean, the car that you specifically ordered?"* I do not reply. After a pause, the sarcastic robot proceeds *"You are on-board the Peugeot 300000009, hybrid edition. This car is the most recent iteration of the series. It was released six month ago. The propulsion is ensured thanks to a fuel-cell motorization, allowing the car to develop a power of …"* I interrupt, smiling. *"Tell me more about fuel-cell electric vehicles*." *"Please"*, Arthur replied. *"What?"*, I said. *"…Tell me more, please*". Damn, I have to remember to tone done the disrespect a notch. *"Please*, Arthur". The program catches the impatience

in my voice, and proceeds swiftly. *"Proof-of-concept Fuel-cell electric vehicles where developed in the early 60s, however by 2020, very few manufacturers were interested in producing FCEVs on a large scale.*[82] *In the context of the Energy Transition, one of the main challenges was transport. This was, in particular, true in France, where the energy mix, largely reliant on nuclear power, saw one-third of the national CO_2 emissions generated by trucks. Electric cars were a partial solution, as some issues remained to be solved in the context of the production of batteries, and the relatively limited range over which electric cars could travel before needing a recharge."* I take a stroll down memory lane. France is at the crossroad of Europe, and the pollution triggered by road transport has been a heated public debate in the late 2010s, leading to civil protests when the government suggested raising taxes on fuel. The current energy mix is more environment-friendly, but it has taken a few technological breakthroughs to make it economically acceptable to all, especially in those rural areas where commuting distances to work are significantly longer. The concept is rather simple: use the surplus of electricity when demand is low, to produce and store hydrogen. The concretization has taken great industrial efforts and creativity. This adventure is the focus of my investigation today.

The salt cavern

I like wine. What a surprise. The southwest of France is famous for Bordeaux, but I am now heading to the no-less delicious Jurançon region. Salt is on my mind rather than wine - not the local salt-cured ham, but the salt caverns. The car stops in the parking lot of an underground hydrogen storage facility. Amused, I notice that Arthur followed the reverse parking rule

that remains the security norm on industrial sites, even though cars are nowadays driven by A.I. (Artificial Intelligence).

Paul is waiting for me. He is going to give me a tour. As I step out of the car, the heat is striking. I shake Paul's hand and we swiftly proceed to the main building, a discrete structure in the middle of cornfields. *"How was the drive?"* Paul enquires, politely. I reply enthusiastically "*Very smooth, I must say. The car is definitely worth trying*." *"I was thinking about a trip to the coast this weekend, I will try to book one of these."* Paul continues, seriously *"now, let me first talk you through our security rules..."* I listen carefully, while I am told about the main risks and rules to prevent an accident. These concerns have always been at the core of the culture of industrials dealing with natural gas first, then hydrogen. It starts on the parking lot and becomes second nature. Employees always use handrails when using stairs, always wear a helmet when moving around, know where to walk and what to do on-site. I am told about emergency rules, before being given a green helmet. *"Now let's go"*, Paul says, with a smile. We get out in the sun. We walk in defined corridors through what looks like a scree field. From time to time, Paul points to installations and gives me some elements of information. *"What you see is all the 'plumbing' needed to inject and withdraw hydrogen in our caverns."* He points at a few green tubes going in and out of the ground. After a few steps, I see, in the distance, what looks like a few oversized containers. *"This*, Paul explains, *is a key element of the station: our compressors, that allow injecting at very high pressure and extracting at a lower pressure the hydrogen we have stored*." He smiles, reading the mild expression on my face *"all of this is pretty underwhelming, isn't it? Well, we do not mind keeping it that way... You see, everything happens underground*." While we walk back to the main building, Paul

continues, *"We used to store natural gas in the region since the late 1950s, in aquifers and salt caverns. In 2020, researchers started to investigate the possibility to use salt caverns to store hydrogen.*[83] *You see, aquifers have a certain inertia, and were good to meet seasonal variations of demand, but salt caverns are reactive and flexible enough to provide the flexibility needed in the hydrogen production to consumption chain. When electricity production exceeds demand, the surplus is stored in the form of hydrogen and not wasted. Hydrogen can then be used as a primary fuel for transport, as in your car, or to meet peak electricity demand, once extracted." "How does the hydrogen come and go?"* I ask, surely a bit naïvely. Paul shows me a dashboard, behind him. It is a map of France, representing what looks like highways associated with parameters. There is no *"you are here"* icon, but I am sure that the circle at the lower left-end corner is where I am standing right now. *"Have you heard about the hydrogen backbone?"* I reply in the negative. *"Over the past twenty years, European system operators strived to develop a dedicated infrastructure to connect supply and demand. Two-thirds of this infrastructure comes from a repurposing of infrastructure previously dedicated to natural gas."*[84] After a short pause, he continues. *"You see, in France, the structure is close to our highway system, which allows a delivery close to hydrogen stations for long-distance transport."* He points to the dashboard *"Also here, and here, you see that the network reaches so-called industrial clusters. This particular one is one of our nuclear power plants... for an efficient synergy."*

I process the information in silence before asking: *"So, it all seems so simple... What is the catch? Why wasn't hydrogen used before?"* Paul smiles: *"I will limit my answer to my area of expertise. When it comes to infrastructure, the strong push came first from the "Fit for 55"*[85] *package by the EU, setting a program for the so-called*

Energy transition. Regarding hydrogen, the package took account of the EU hydrogen strategy set in 2020.[86] *Previously, hydrogen was caught in a chicken and egg conundrum - what should come first, infrastructure or users? The strategy set, hand in hand, goals for the heavy-duty industry road transport, in terms of vehicles, but also the infrastructure. As a result, by 2030, more than 60,000 FCH trucks (FCH stands for fuel cell hydrogen) were benefiting from refueling stations every 150 km along the main axes I showed on the dashboard. This was key to bringing economies of scale into the production of hydrogen, driving prices below 6€ per kg of* H_2*, and reaching prices below 2€ per kg today."*

* * *

As Arthur is driving me out of the parking lot of the storage site, somewhat sarcastically - but can an A.I., or for what matters, anyone drive *sarcastically*? - I observe that having gathered elements on the use and transportation of hydrogen, I am still missing some on its production. I feel, however, that these are just a quick nap away…

The nuclear power plant

A gentle vibration of my seat awakes me. "*Next destination of your extremely active day"*, Arthur says. I raise my eyebrows. I was expecting a massive structure of concrete, like in the old movies, but while the industrial structures, hidden behind greenery, are imposing, they are nothing like my preconceived idea of a nuclear power plant. Another surprise - we pass what appears to be the main facility to reach an even more modest-looking alignment of hangars and pipelines.

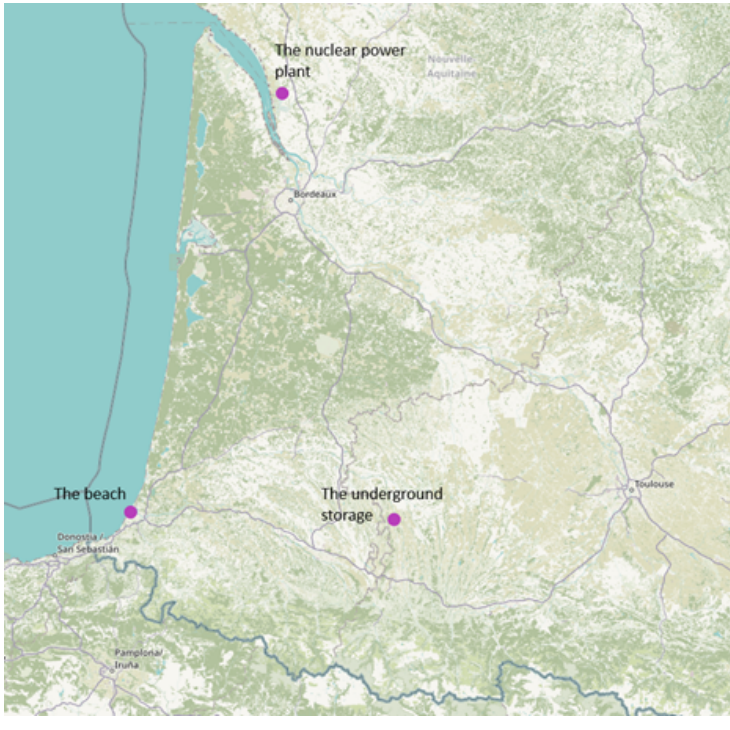
Aurélie is the new Paul. She welcomes me with a smile - *"underwhelmed, aren't you?"* History repeating, to quote Miss Shirley Bassey. *"Well, we do not mind keeping it that way..."* I think, *"You don't say…"*, but let her continue. *"What you passed is a Generation IV nuclear reactor. It solved some of the issues of its predecessors, more resistant to aggressions and more environmentally friendly... It blends better into its surroundings..."*

A pause, an awkward silence - nuclear is a tricky topic. Aurélie, trained in public relations, knows how to defuse criticisms swiftly. *"Let's be clear, nuclear is not green, and that's not what I am saying here. I do recall the old debates triggered over the role of nuclear power in the decarbonisation of Europe.*[87] *Anyway, the topic of the day is hydrogen, right? Then, let's proceed with the visit!"* She gives me a white helmet and smiles enthusiastically, while we enter the site. *"OK, you've heard about the hydrogen backbone?"* The good thing about history repeating is that it gives you a chance to look smarter, the second time. I nod. *"Well, then, nearly 23 thousand kilometers of pipelines filled with hydrogen, you have to wonder, where the hydrogen comes from..."* I observe, *"It probably did not happen in a day?"* She laughs politely enough for me not to be hurt by the fact that I did not intend my question as a joke… *"Indeed, over the course of nearly twenty years, the amount of hydrogen carried in the pipelines increased progressively. Initially, up to 10% of hydrogen was blended with natural gas; within a decade, it went up to 20%.*[88] *Already a lot of hydrogen to produce! When this endeavour started, in the early 20s, most hydrogen was made by steam reforming of natural gas or coal gasification,*[89] *both processes emitting carbon dioxide. Experts back then categorized processes according to their carbon impact, using all the colours of the rainbow and more. The conclusion was clear: only green hydrogen, produced from renewables, and yellow, from nuclear, are reliably zero-carbon."*

We now enter one of the hangars. *"France has the second-largest nuclear fleet in the world, after the United States. It now generates 50% of its electricity based on nuclear power, but it used to be up to 70%. It's always been part of the picture. It seemed wise to use off-peak capacity, and perform electrolysis using the heat and electricity from the nuclear reactors."* I object *"But why not use electricity directly? You must be consuming quite some energy in the process..."* Aurélie nods *"It is a fair comment. Let me make a few observations. First, some of the uses for hydrogen precede the energy transition, and today the chemical and steel production represent 40% of the hydrogen consumption. Then, converting the unused electricity from wind and solar sources into hydrogen simplifies the management of intermittency within the electrical grid. The conversion of the natural gas grid allowed avoiding some investment in the electricity grid. Finally, the overall process efficiency improved greatly, from 25% with low-temperature electrolysis to 50%*[90]*, as we mastered the high-temperature thermochemical production of hydrogen, using nuclear heat to perform a sulphur-iodine cycle."*

A pause, an awkward silence. *"You see, I majored in political science"*, I say. Without hesitation and I think, without judgment, she rephrases *"We feed water into the process. We split it in two steps, using both electrolysis and a thermochemical reaction. We get hydrogen and, as a by-product, oxygen...Which also has a market value, by the way."* She shows the pipelines behind me. *"We produce it and feed it into the network directly. Zero-carbon."* I must admit that I am impressed. *"And this is sufficient to produce all the hydrogen we need?" "Unfortunately not. Currently, we produce about 60% of the hydrogen consumed this way. The rest is produced combining fossil fuels with carbon capture and storage."* I look disappointed. She continues, *"I understand. You have been piling up numbers all day, and you were expecting hydrogen to be a miracle*

solution. Take a side step: hydrogen is one element of a complex system. The use of hydrogen in the electricity chain allows avoiding certain networks investments, and provides flexibility, for example when demand and the availability of solar and wind generators do not match…"



Source: openstreetmap.org

* * *

"Arthur, let's go home." The car leaves the parking lot in silence, leaving me lost in my thoughts. The story of hydrogen sure is interesting. In the early 20s, challenges were as great as opportunities. I think about these times of uncertainty. Hydrogen certainly did not come as the answer to life, the universe and everything. Nevertheless, it was an important piece of the puzzle. To this day, it contributes to the energy transition, as a clean energy source as well as a tool to manage an electricity grid backed with variable renewable generation. Assessing the benefit of hydrogen requires assessing the value of the service rendered to the system, and not only pure technical performances of this energy source.

"Arthur, let's make a stop in Landiras". "To the Chateau de Leyre, I presume?" I am too tired to be offended by the cheeky tone. *"You presume well, Stanley."* Well, as I said, I like wine. The *Chateau* produces a *Graves,* an excellent red wine of the Bordeaux region. This will be the perfect conclusion to a lovely day. *Santé!*

Spain, 2035

Author: Rosa Puentes Fernández

July 2035. From Jaén to Madrid

It is time to leave. During the two minutes left for the bus to refuel[91] I have time to say a last 'goodbye' and find a seat next to the window. The bus door closes, and the trip begins.

The sun is shining bright, as it usually does at this time of the year in Andalusia, yet the heat is not unbearable anymore. I remember those days during summer 2021 at 46°C when one could barely breathe, the pavement was almost on fire, and we were all lying on the sofa covered in sweat because electricity prices were too high to turn on the air conditioning.

I keep looking through the window. Surprisingly, even after all these years, I am glad to see that the views from the bus still resemble Machado's [92] poems: green hills "*combed*" by the sun, centenary olive trees "*dusty and thirsty*" under the clear light of the day.[93]

Jaén. Source: Shutterstock, ABB Photo

In less than thirty minutes, the bus stops at Linares-Baeza train station. While I am getting off the bus, I realise that birds are signing while resting under the shadow provided by the solar panels located at the roof of the station. With my eyes staring at the horizon, I get a glimpse of the lithium-ion batteries[94] and the electrolyser of the HRS (Hydrogen Refuelling Station). The integration within the natural landscape of the site is such, that unless you are specifically looking for them, you would not notice their existence. This was not achieved by accident, but it was one of the pre-requisites from the regional government to grant the permitting to construct here. Without a doubt, the centenary olive trees of the site are grateful for that choice.

On my way to catch the train, I meet Juan, the station manager, who accompanies me to the platform where the brand-new Talgo Vittal-One[95] is expected to arrive. Even in 2035, Jaén has no airport, and the medium-distance train is still the single

fastest and most sustainable public transport mean connecting Jaén to Madrid, and to some other parts of Spain. Interestingly, the trip usually takes longer than going by car, and the train ticket keeps getting more expensive every year. But that is another story.

Juan has spent the last thirty years working at this station but when I met him, he did not know anything about hydrogen or solar energy. I remember that day, already more than a decade ago, when he joined the first promotion of *"H_2 Safety Risk Training Academy."*[96] He was aware that major changes were coming since all sectors were transitioning to a 'climate-friendly' version of themselves. He knew that, sooner than later, he would need to learn new skills to stay in the job market. *"Making the decision to learn something totally different was a real game-changer. Some people told me I was too old for all that new and fancy stuff, but the truth is that the only time that it is too late to make a change is when you're dead"* he told me once. And I could not agree more with him.

During the time I am waiting for the train to arrive, Juan briefly informs me about his plans to move to Córdoba. The e-methanol[97] plant was looking for a new plant manager and he was contacted for the position.[98] *"How exciting!"* – is my first reaction. *"Well, changes are as exciting as challenging. It is not going to be easy, but if I do not take the chance now, there might not be another 'big' one for me... I am getting old, you know. The world keeps changing fast and I feel this is my last opportunity to ... "* – Juan's sentence is interrupted by the 'beep' sound from the station speakers followed by the announcement requesting all passengers with a ticket to board the train. The voice behind the speakers reminds us that we must use the underground access to switch between platforms, since it is forbidden to

cross the railways. Before closing the microphone, the voice gives a last warning: *"We would like to remind you that people without a boarding ticket cannot get in the train. You can say goodbye from the platform."*

When the train stops, there are literally forty seconds left to get on, so I can barely say a few words to Juan before the door closes. I realise that the next time I will visit, Juan will most likely not be here. Yet, my nostalgic thoughts are interrupted by a nervous voice shouting *"Hey, don't leave!"* - a man is hitting the glass door. *"I need to get out! I am not travelling!" "Here we go again"*, I tell to myself and I wonder, whether it is part of human nature to ignore instructions. So much progress and we are still incapable of following simple rules. *"Well, life has a funny way of teaching us some lessons"*, I said in an inaudible voice while looking for my seat along the narrow corridor of the train.

Already in Castilla-La Mancha, I start thinking about how the lives of millions of people have changed along the past years in order to accommodate the transition towards a net zero economy. Although a lot has been achieved, still more is needed to *'avoid a climate disaster'*, to paraphrase Bill Gates.[99] Yet, making the shift to a sustainable economy is not simply about switching energy sources but about changing people's behaviour and lifestyle towards more sustainable one. Great efforts were needed to make people understand the importance of this transition and their role in making the world a better place to live in. As always, there were, and there still are, people around the world that could not accept that the rising sea levels, the unbearable high temperatures and skyrocketing CO_2 emissions in the atmosphere were not acceptable for the planet and for all of us. Yet, much has been accomplished in the past decade and our lives have been directly impacted by this

decarbonisation process.

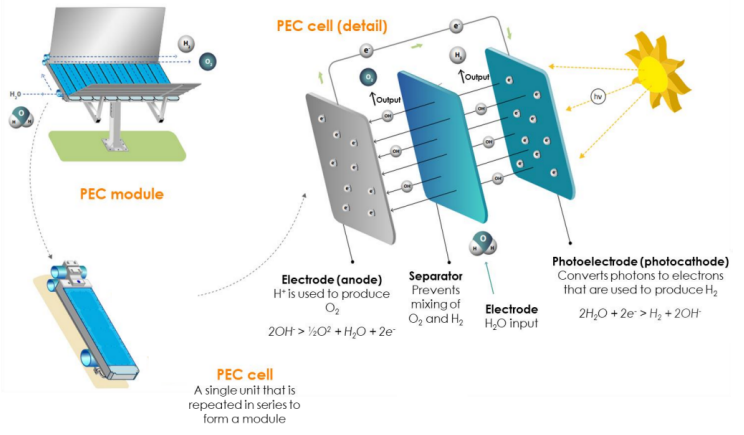
Particularly, the introduction of hydrogen in different economic sectors has been one of the greatest changes so far. As it always happens with new technology, it all started with the promises that hydrogen was the single technology needed to achieve climate neutrality. Hence, the hype around hydrogen in the early 2020's surpassed all expectations. On the other hand, it soon became clear that hydrogen was not the 'silver bullet' and renewables and efficiency alone were not going to meet the ambitious climate goals and sustainability objectives. Although they were both a good and necessary starting point.

After more than a decade from the publication of the European Hydrogen Strategy,[100] and the 'domino effect' it triggered, including the publication of national hydrogen strategies in more than fifteen Member States[101] and announcements of hundreds of projects around the continent - we can already see the results from the 'implementation era'. In Spain, local industrial clusters started to emerge in different parts of the country. Now more than 25% of the hydrogen consumed at industrial level - mainly in refineries, chemical and steel plants - is green (representing approximately 10% of total EU one.) Besides, more than 4 GW of electrolysis capacity is already installed. Considering that in 2020 natural gas was the primary source for the production of approximately 500,000 tonnes of hydrogen consumed yearly in Spain.[102] This shift was key to achieve the emissions reduction of 4.6 Mton CO_2eq[103] between 2020 and 2030.

Already in 2026, Spain was also one of the first countries in the world to produce green hydrogen cheaper than blue hydrogen.[104] And the best is yet to come, since Spain will soon start producing the world's cheapest green hydrogen.[105]

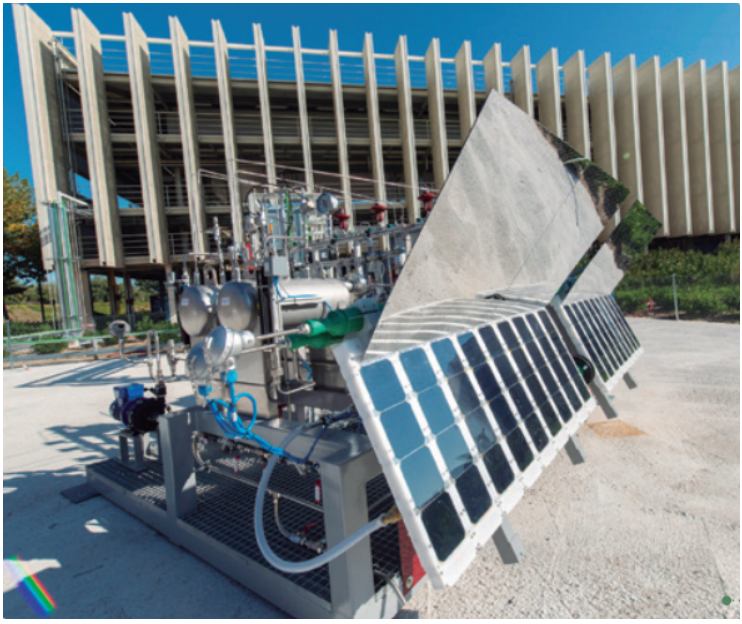
During the past decade, the rapid development of the hydrogen economy in Spain was favoured, by numerous private and public investments. In 2021, Spanish government identified hydrogen as a key priority and allocated 1,555 million euros of public investments for its development, with additional 2,800 million euros of private ones.[106] Those investments enabled the development of technology, knowledge, industrial capacities, the integration of hydrogen in all major economic sectors, and the development of new business models to reinforce Spain's leadership position in the energy transition process.

Furthermore, the introduction of Spanish hydrogen technology in the market proved to be a game changer for the sector. One of the key additions 'designed & made in Spain' was the photoelectrocatalytic (PEC) technology to produce green hydrogen from the sun's energy via a direct transformation process (without electricity input).[107]



SUN2HY project: Technology Overview. Source: Enagás

There have been many and different approaches to this technology at global level, mainly in Europe, the US and Japan. However, in 2020 these developments had very low levels of technological maturity. The SUN2HY project managed to scale up the technology by developing PEC modules at real scale, which was later validated experimentally in a pilot plant (see figure below) located at the Repsol Technology Lab facilities in Móstoles municipality in Madrid, Spain. The results have shown that this technology can simultaneously meet three key requirements: high efficiency (over 14%), photoelectrode stability, and low cost due to usage of cheap and abundant materials.[108] Technological maturity was reached in 2028, and from 2030 the technology was exported all around the world for utility-scale projects.



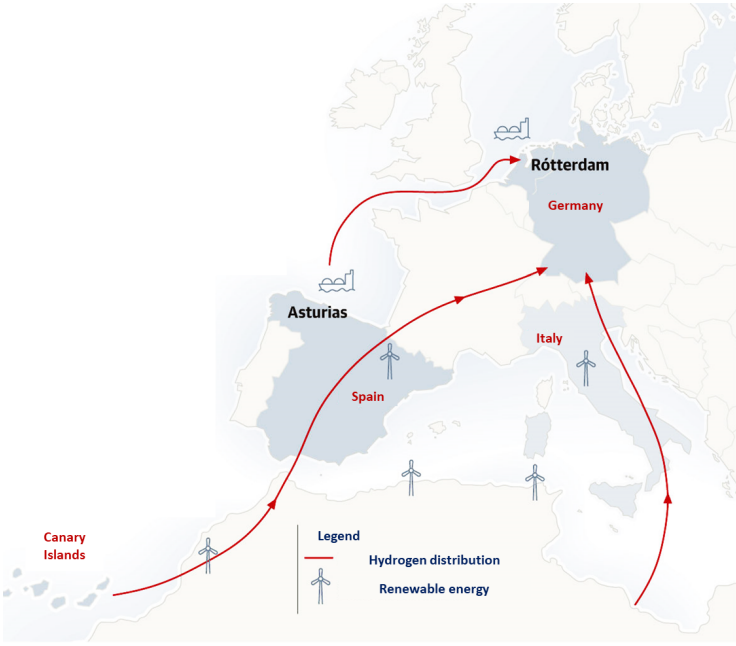
SUN2HY pilot. Source: FuturEnergy Dec.21 - Jan. 22 issue

At the beginning of the decade the use of hydrogen was no longer restricted to industrial processes, due to the decreased costs, targeted investments and introduced policies to incentivise the market uptake of different technologies. Hydrogen was used also in sectors such as mobility - heavy-road vehicles, maritime and rail transport, as well as power generation and domestic heating in some areas.

The train starts to slow down as we arrive to Atocha Train Station, in Madrid. One can clearly enjoy the view of the city from the window. Since traffic was restricted in Madrid's city centre, the pollution levels have decreased tremendously. One may remember that in 2021 the Spanish capital was leading the

list of the cities in Europe with the highest number of premature deaths linked to nitrogen-dioxide pollution.[109] Yet, the traffic restrictions combined with other measures taken in the past years - like the replacement of 1,000 diesel[110] taxis by fuel cell ones[111] - helped to bring back the 'fresh' air to the capital's historic neighbourhoods and streets.

My thoughts are interrupted by the image of a large, long-legged, and long-necked bird in the distance. I must say that I am not good at distinguishing between type of birds but something 'clicks' in my mind: The 'Green Crane.'[112] This project started in 2019 with the aim of paving the way for South to North green hydrogen flows in Europe and later turned out to be one of the most utilised corridors for the export of green hydrogen to the rest of Europe.[113]



'Green Crane' illustration. Source: El Comercio (translated by the author)

Along the same line the 'HyDeal Ambition' project, which in 2021 was the biggest announced green hydrogen project in the world,[114] is delivering since 2030 more than 3.6 million tonnes of green hydrogen per year to users in the energy, industry and mobility sectors via the gas transmission network from Spain to France and Germany.

With such low costs for green hydrogen production, Spain soon became a hydrogen net exporter to other European countries. Hydrogen was either exported in gaseous state via pipelines, liquified or as part of ammonia.[115] Consequently, ports became important pieces of the hydrogen value chain as

they facilitated the trade of hydrogen. The Port of Valencia, for example, started using hydrogen to power heavy-duty port equipment[116] and has become one of the most important hydrogen hubs in Spain.

Port of Valencia. Source: Valencia Port website

* * *

"Hey! Where are you going? Didn't you see me?" - a soft hand touches my shoulder while I am about to get into a brand new autonomous Tesla Taxi. *"Do not tell me you forgot I was going to pick you up!"* - Marta stares at me smiling. *"Oh, yes. I am sorry!"* – I close the door of the taxi, click twice my right earphone and say *"Alexa, cancel the taxi."*

We both head towards the parking. *"So, how was the trip?"*- Marta asks me. *"Well, I was thinking about all the changes that*

happened in the last decade. Especially about hydrogen and..." – I get interrupted by Marta's sigh and she starts talking: *"Oh, no. Here we go! Look, I tell you as a friend: if you keep talking about this hydrogen whatsoever to every person you meet, they are going to think you went mad! I know it is your job and you really like it... but for non-expert people like me, this is just another political movement that only makes consumers pay more. So please, let's not start again..."* I take a deep breath. Definitely I could answer her with good arguments explaining why the increase of electricity prices are not a consequence of the introduction of hydrogen, and that her taxes have not been used to sustain the so-called hydrogen economy but since this is not the first time we are having this conversation I decide not to answer. Yet, it always makes me wonder whether we may have failed in making "ordinary" people understand the importance of changing the system towards a more sustainable one, and the impact it could have in their lives. Now we have to face the consequences which, obviously, come with criticism.

My thoughts are suddenly interrupted: *"So, let's focus on the important things: where do we go for lunch? I let you decide this time since you will definitely miss the Mediterranean flavors when you are back in Belgium."*

Morocco, 2029

Author: Nesma Aboshanab

Violent dreams of climate crisis, and hydrogen role

The dream – a night in 2029

It was massive and indescribable as if the earth is roaring violently with anger. In the beginning, the sea was receding rapidly, it was unbelievable, the people on the Mehdia beach rushed on the naked seabed recording this significant scenery with their cameras, then suddenly, a fast-rising wall of water started to chase them.

I was standing there, I wanted to run but I couldn't, the tsunami was way faster than my legs, in seconds it hit the shore taking everything in its way including myself.

I felt as if I am sucked in a whirlpool or a washing machine, it was battering all over my body, I was driven down again and again as if it was the end. I remembered my family, I know nothing about them at this exact moment, I remembered our summer memories in Kenitra, and few of the images rushed past my eyes (see figures below).

Mehdia Beach in Kenitra, Morocco. Source: SanaaFariat

I started to see the faces of my family and friends, I wanted to call out for help but I couldn't, I wanted to fight the waves, the rushing water, and the destructed wood and bricks. I couldn't call out. Would I survive? What about my family?[117]

Alarm rings

5 November 2029. Onternship in the Green Hydrogen cluster in Benguerir

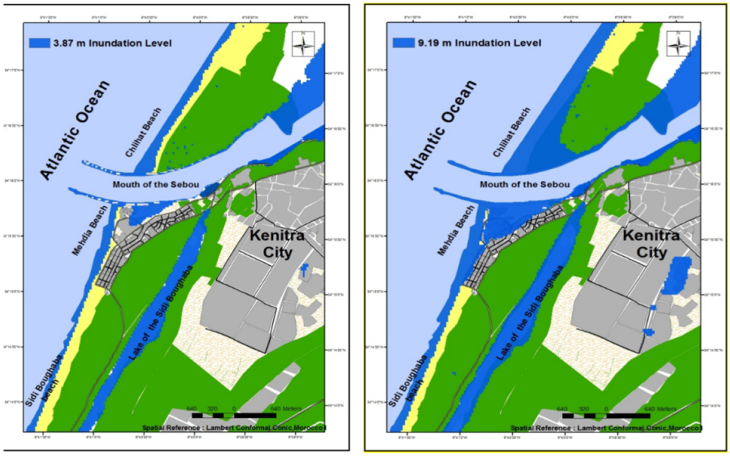
I woke up suddenly, I was sweating, my body was shaking, and my heart was pounding. It's the same nightmare again and again. I checked my room everything was in place. I stopped the alarm. It was 7:30 in the morning. I sighed and laid back again on my bed. Then I remembered that it's Monday, 5th of November 2029.

I excitedly jumped out of my bed: It's my first day in the internship. Two weeks ago I got accepted as an intern in the green hydrogen cluster in Benguerir, and I am very excited about it. The GreenH2, as we call it, was launched in May 2021 by IRESEN the "Research Institute for Solar Energy and New Energies" to connect different stakeholders in the hydrogen industry including researchers, public authorities, and industry in order to boost the hydrogen economy in Morocco.[118]

I was ready in 20 minutes. Although my hostel is only 3 kilometers away from the Green city of Benguerir (see figure below), I decided to leave early to have some time to explore it before my introductory meeting in the GreenH2 cluster.

Ben Guerir. Source: googlemaps

On my way to Ben Guerir, I first checked the news - there is nothing about any tsunamis hitting the kingdom of Morocco or Northern African shores. I took a deep breath thankfully. My mind wandered: *"It has been nearly 10 years since I started having this nightmare. It all started one day in 2021 with 3 successive events; first the COP26, second a google search, and third a movie night. My mother is an engineer and an environmental enthusiast, and she was very keen on following the COP26. Although I had no interest, I managed to catch some keywords from the talks including hydrogen economy, global warming, decarbonisation, exporting energy, and the color 'green', and out of curiosity I started to do a random search about Morocco using these keywords, it was interesting yet complicated to me as a 13-years-old kid. Then, I accidentally learned about the effect of global warming on the sea level rise; I can still remember the figure showing land areas vulnerable to flooding including Mehdia beach and Chlihat beach (see figure below);*



Coastal land area vulnerable to flooding in Kenitra city in 2025[119]

The article mentioned strong tidal waves and mini tsunamis, I have had heard about tsunamis before in schoolbooks but didn't have a visualization of it.[120] *Later that day, my friend invited me for a movie night; it was a movie based on the 2004 Tsunami called "The impossible." That's how my imagination as a 13-year-old teenager visualized the consequences of global warming, with a big Tsunami ending the world. And since then, I decided to do my best to take part in changing this, to take part in facing global warming. And, sadly, having the dream as that morning."*

My mind wandered back to today, 2029. On my early arrival, I took a bike tour around the city. I was astonished by the urban planning of the city, the various means of mobility; renewables are everywhere with everything digitalized and electrified. Benguerir has been known as a mining town, so seeing such a transition was magnificent (see figure below for an impression.)

Green and Smart Building Park in Benguerir, Morocco. ***Source***

I arrived at the GreenH2 cluster in time, where I was welcomed by Mr. Saber as well as the other interns. He is a very decent man. He works as a researcher in the green hydrogen cluster, and he has been there since the beginning, he started by saying: *"We are days away from the year 2030, 10 years ago the news headlines were highlighting the effective role of Morocco in the area, also Morocco was described as a European leading strategic partner thanks to the green hydrogen. Today the installed capacity of renewable energy in Morocco is exceeding 52% as announced at the 2015 United Nations climate change conference COP21 and due to such a ramp-up in renewable enery, we are able to capture nearly 4% of the green hydrogen global demand of 600 TWh"*[121]

He proceeded to mention the current developments of the green hydrogen industry in Morocco including the local use of green hydrogen as a raw material in the production of green ammonia, and also how Morocco is achieving the decarbonisation objectives by using green hydrogen to produce various products and export them. Then he asked, *"Anyone can briefly mention one of our developed pilot projects?"*

I raised my hand. I knew them by heart as I have been following all the details either because of my mother or because of my developed responsibility, passion, and curiosity since 2021. Mr. Sabri picked me, so I proceeded *"Actually I know the two pilot projects. In June 2020, Morocco and Germany agreed to form a 100-megawatt (MW) renewable energy plant to produce green hydrogen in Morocco through electrolysis with Masen, currently, it produces green ammonia and it's been financed by the German government. It's part of the execution of the spirit of the MoU (memorandum of understanding) between the Kingdom and Germany."*

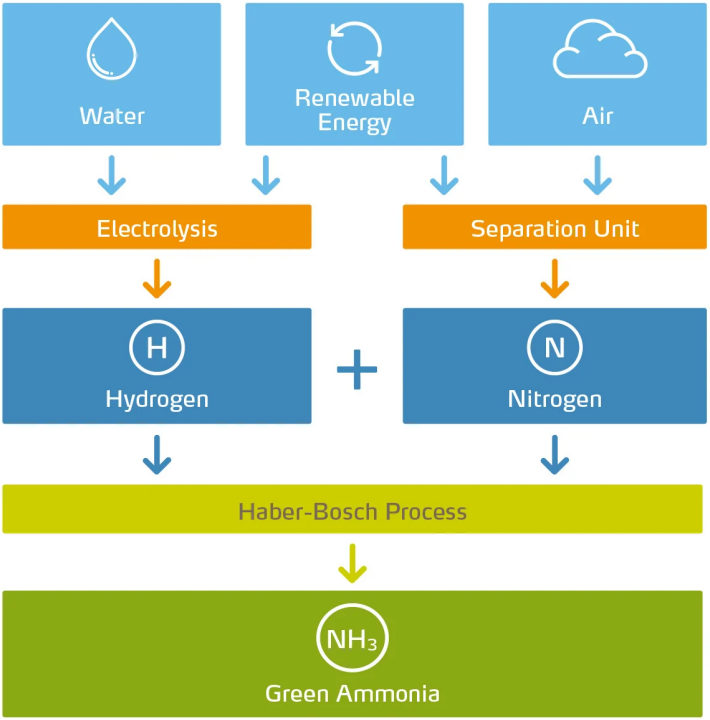
I continued, *"This was the large-scale project, there is another*

small-scale project to produce green ammonia with OCP group, IRESEN, Fraunhofer institute, and Université Mohammed VI Polytechnique, this small project aims to mainstream the green hydrogen and green ammonia for the fertilizer industry.[122] *"*

"Perfect! So, anyone can explain how green hydrogen is used in producing green Ammonia" said Mr. Sabri

I excitedly answered, *"Through the Haber-Bosch process!"*

A girl from behind commented, *"But this is not what makes the ammonia green, the Haber-Bosch process is also used in producing grey and blue ammonia".* She proceeded, *"Green hydrogen produced through the electrolysis of water using renewable energies like solar or wind energy. Then the green hydrogen and nitrogen separated from the air react together at high temperatures and pressures to produce ammonia."* Then she added, *"Also, the production of hydrogen in the ammonia industry can account for nearly 90% of the carbon dioxide produced through the whole process."* (See figure below for an illustration of the process.)



Green ammonia production. ***Source***

"Well said, Rania!" Mr. Sabri commented.

Rania's answer was confident and knowledgeable. I didn't know about the impact of the hydrogen production method on the carbon footprint of the ammonia industry. And reflecting on the fact that Morocco is one of the biggest importers of ammonia in the world, producing green ammonia for local use and for exporting is such a great move in the decarbonisation process.

After discussing the week's schedule, Mr. Sabri ended the

session with a question *"So what do you think are the major current challenges for green hydrogen from the perspective of the Moroccan hydrogen economy as part of global hydrogen one? And what are we longing for in the next 10 years?"*

Although I had an answer, I felt interested to hear Rania's perspective on answering this question. Rania said *"In this period the cost of green hydrogen products is (still) higher than conventional ones, and I think this is the main challenge, as well as the 2040 goal to reduce the costs of these products and establish environmental regulations to incentivize the use of green alternatives. Also, I think Morocco is longing to expand the use of green hydrogen as a carrier for energy storage in the power sector and as a fuel in transportation."*[123]

"The question was well answered", I thought to myself. I also believe that the main challenge is the cost. I wanted to mention challenges like the scaling, as well as working on use cases such as transportation including opportunities offered by the likes of Alstom hydrogen-powered trains, including its dual-mode that includes onboard electricity production and connection to electrified railway lines. Then I thought that it was only the first day and there is still so much to learn and to share, so I decided to research more and not to volunteer my thoughts.

At the end of the day, I felt enriched by all the knowledge I gained and being given the space to share what I knew already. I convinced myself that today I did something good to the world through sharing and learning, and I hoped that tonight I can sleep tight without any global warming nightmares.

Namibia, 2030

Author: Oghosa Erhahon

Namibia. The Energy Port of Africa

'Welcome to the Energy Port of Africa' a bold billboard read as we drove into the city from Hosea Kutako International Airport. Aina originally from Namibia but a trained and experienced communication strategist in Europe remarked how impeccable it was that in 10 years Namibia was at the center stage for the whole world. Unlike the last time she was in the country, when the diamond markets took the nation's attention.

Aina and I had met in Europe a few months ago, at an energy congress. I shared that I had been living in Windhoek since the completion of the first ever green hydrogen production plant in Southern Africa in 2025.

The weather is cold in July across Namibia, Aina coming from the subtle European summer had to remind herself of the coat she had in her backpack. We boarded the newly built fuel cell train[124] to Luderitz right by the coast of the country - the once sleepy seaside town which was now a buzzing city.

Aina: *"I almost forgot Namibia experienced winter and summer at opposite times as Europe and North America. How do experts and*

foreigners cope when they first arrive?"

Me: "*I think most of them actually do not mind it. On average for the next few 'winter' months, the average minimum temperature is around 7°C/45°F but can fall to below freezing at night in the deserts and higher areas. This lasts between the months of July and August. Although it's hard to predict the climate after all these years."*

Aina: "*Some things never stay the same do they - Well, after the last elections, I was very concerned about the turnout of investors in Namibia. How does an African country important to the energy transition not drift with a change in government?"*

Me: "*Namibia has one of the strongest governments in Africa, regardless of changes in government. The powerhouse (that Namibia is) remains committed to the economic and development interest of the nation. The Harambee Prosperity Plan II which was introduced by H.E. Dr Hage G. Geingob reached fruition, and the politics never lost focus of where Namibia could potentially get to."*

Aina: "*I have heard a lot about the Harambee Prosperity Plan, but could you in a nutshell explain what it was about?"*

Me: "*The Harambee Prosperity Plan II was introduced in 2021 to maximize the national benefits.*[125] *It was a published document that included pathways towards building the now, Namibia's hydrogen Sector*." (I quickly pulled my phone to show Aina few photos of the pilot project in Lüderitz - see some images below.)

Southern Corridor development initiative (Karas Region). Source: Green Hydrogen Namibia

Wind turbine outside Lüderitz. Source: Alexandra Wexler. The Wall Street Journal

Me (continued): *"These activities meant financing - The vision saw that hydrogen development would include green, blue, transition*

bonds and carbon credits as innovative financing tools. Since then, 3 other banks including Bank Windhoek[126] *have become commercial banks part of the Nasdaq Sustainable Bond Network.*

Through Namibia's government support, the HPP II has been impeccable through developing key activities, to engaging advisory for the strategy plan as well as putting in the right regulatory framework and enabling environment."

Aina: *"How did Namibia possibly secure the largest projects for hydrogen in Africa, with the sand dunes and the nation known for the least amount of rainfall in Sub-Saharan Africa - Green hydrogen requires a significant amount of water?"*

Me: *"Well, this one is quite interesting. This is a nation where the ocean meets the dunes shares borders with Zambia and Angola to the North, Botswana to the East and South Africa to the South and East, and the Atlantic Ocean on its West border. Namibians boost about 300 days of sunshine per year - reliable solar energy and increased capacity for wind farms.*

This 'Land of the Brave' as the nation is often referred to - developed a deep-water port through PPP models[127]*. This was used as a benchmark for so many water port development and financing across the region. There have also been new water authorities set up across communities - Green hydrogen process involving electrolysis has improved the water situation in rural areas through introduced seawater desalination techniques.*

The initial green hydrogen production pilot projects received €40 million in funding, worth $45.3 million, from Germany used on feasibility studies."[128]

The evening train got busy with chats about the elections and distant speakers playing music by the national icon, King Elegant.

Aina had picked up reading material at the airport and

between the transit. The following day – she had made a few other observations on the economic and energy situation in the country. One of articles read: *"Namibia, the 'Energy Port of Africa' is no longer dependent on imports for electricity but on a pathway to be the first African nation to electrify 100% of its communities and cities, with 100% renewable energy."*

Aina: *"It makes a lot more sense now, the traffic jams, busy trains and booked out hotels in the city...the population increased. Did you know according to the UN, Namibia was 2.5 million people in 2020, now there are over 500,000 people working across the hydrogen supply chain alone – how incredible is that!"*

Me: *"That's very true. The influx of financing for green hydrogen projects meant increased supply of renewable energy to neighboring countries. Oh, and with electrification came some new industries too. Textile manufacturers, African and international businesses have found Namibia to be a good location to build industries – so more people in the job market!"*

Aina: *"And we no longer import electricity either?"*

Me: *"Nope. Built on electricity access – Namibia for decades depended on the electricity imports from the South Africa Development Community (SADC) region. Pathways for export to African countries like South Africa are being set up to encourage decarbonisation in those regions."*

Aina: *"That's fantastic! The GDP (Gross domestic product) has also increased, and according to my family here the standard of living is almost unimaginable to what it was."*

Me: *"Yes, completely. The government introduced the energy transition into a lot of the school curriculum as well as sustainability and conservation areas too. So now, post-graduate students are specializing in joining the e-mobility manufacturing plants, financing institutions, circular economy and low carbon emission*

research, and taking part in a host of other programmes. So many international students from across African regions now study here, gaining professional courses every year."

Aina: *"I'm so proud and happy to be back home, Namibia over the years strategic positioning as an attractive investment destination in Africa really paid off. Those highlights from Bloomberg, as an emerging market economy*[129] *in Africa had no doubts either."*

Me: *"It sure did, positioning itself as a leader in the emerging market for another hot resource: green hydrogen*[130]*. A joint communique signed in August 2021*[131] *gave birth to a series of continental and international and bilateral partnerships on the production of green hydrogen. In 2021, a report by hydrogen Council, in collaboration with McKinsey & Company, identified 228 large scale hydrogen projects across the value chain that have been announced*[132] *– this figure has significantly increased over the years now."*

Aina: *"This was such an eye-opener for me. In 2021, there was no need to downplay the challenges of hydrogen emerging as a global fuel. The cost was daunting, I recall a time when a supply chain could barely be established."*

Me: *"The Namibia government saw and understood hydrogen to be an enabler for a renewable energy revolution, positioning itself in a space that is now inevitable.*

The Africa energy corridor has been rightly renamed as the 'Energy port of Africa'. "

* * *

It was about time for Aina's first communication meeting, she had the role to work with the government of Namibia towards dealing with the Public Relations activities and international

publications from the Energy Port of Africa.

We waved our goodbyes and looked forward to attending the Africa hydrogen Summit in Durban, South Africa, in the coming weeks.

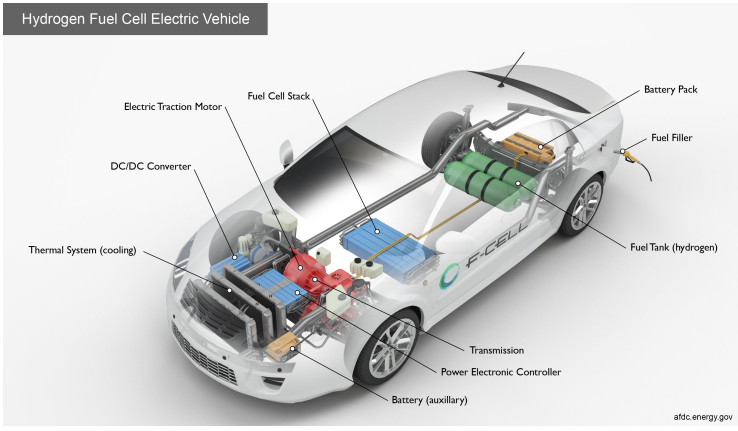
South Africa, 2044

Author: Gerhard Human

Phalaborwa to Mokopane

It is the year 2044. I am on holiday in the Kruger National Park[133] with my wife and my son's family. We spent the last three weeks staying in lodges, going on game drives, and staring at the stars next to campfires. My son lives in Johannesburg while my wife and I will be travelling back down to Cape Town. We'll be driving through the Northern parts of the country to Johannesburg and then fly down to Cape Town.

It is the morning of our departure and after packing my son's SUV we get in the car and set off. The cars of today all have a very impressive display of how the energy is distributed between batteries, fuel cell and other parts including electric engine[134], and this is something I find fascinating. See figure below for an impression of how fuel cell electric car functions:



H_2 fuel cell car functions. Source: US DOE

I often find myself staring at the screen and watching how the energy is consumed. Whenever I get into a car, I have the habit of staring and analyzing the information on the screen. I am very much aware of our low fuel level. We've done almost 700 km since our last fill, and of course I make my son attentive to this. He annoyingly replies that he knows, and his car has already identified a station and booked a re-fill. The computer shows that we can only fill up to 50% fuel level. Although hydrogen is abundantly available in the country, remote places still have some infrastructure limitations. 50% is however sufficient to get us to a major filling station on the N1 highway, also pre-booked.

We fill up with hydrogen in Phalaborwa[135] before our journey back. Phalaborwa used to be a mining community which ended early 2020s when, once South Africa's most productive copper mine, it eventually reached the end of its production life. During the mine's years of open pit operation, it was already

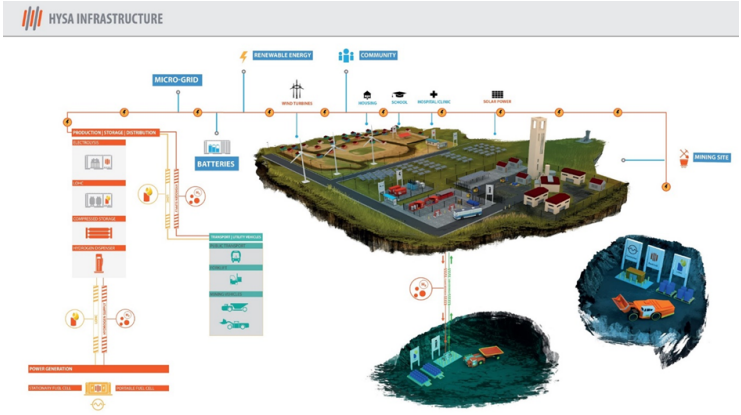
a leader in decarbonising before this term even existed, by employing a trolley-assist system for haul trucks coming out of the pit to save diesel.[136]

Mokopane – the hydrogen hub

From Phalaborwa we drive to Johannesburg on the N1 highway past Mokopane,[137] location of the very famous Anglo American Mogalakwena Mine site, where once the world's largest hydrogen fuel cell vehicle was first demonstrated more than 20 years ago (in 2022). An example of mining truck is shown below:

Open licence. Source

Example of hydrogen as part of the mining ecosystem is also shown below:



Mining H_2 overview concept. Source: HySA Infrastructure

At the time, I was travelling regularly to the site where the electrolyser and fueling station were being installed. It was a challenging site and time, with wind, dust and COVID fears and restrictions causing project to delay more and more. The project eventually turned out to be a big success and today the site hosts around 120 MW electrolysers powered by solar energy supplying green hydrogen for around 40 haul trucks and fueling stations along the N1 and N3 highways all the way down to the South Coast.[138] Because of this site, hydrogen is now abundantly available in the area and resulted in pioneering deployment of fuel cell busses, trucks and eventually cars in the country.[139] Took me a while to convince my son to get himself a hydrogen fueled vehicle. Now we can drive the more than 700 kilometers from the lodge without having to stop for too long, which is a major advantage since we don't have much time to stop if we want to catch our plane.

I haven't been in this area since moving down to Cape

Town. I must say, this (once rural and struggling) area is now flourishing since becoming a hydrogen hub. If we had the time, I would have loved to take my grandson to the nearby science center where all sorts of hydrogen related technologies are showcased. Although today they are probably not that impressive. All this was a direct result of the mining truck project focusing the world's attention on that one truck. For my grandson, his father's hydrogen car is just a car. He doesn't even understand the term 'harmful emissions' as most of the energy he uses is powered by the sun. He is only 12 and grew up in a world completely different than ours, where we had to choose between diesel and petrol. Today the choice is between refuelling hydrogen or charging batteries.

Lessons on hydrogen fueled mobility

As we drive, almost every 3rd truck passing by is hydrogen fueled. Twenty years back not a single hydrogen vehicle was driving on any South African or even African road. Being very excited about this, and seeing my grandson staring at mindless videos on a screen since we left, I thought I'll give him a little Q&A.

Me: *"What is powering your father's car and those trucks? Pointing to the ones with the H_2 decal on them?"*

Grandson: *"The sun."*

He thinks everything is powered by the sun, and off course that is 100% correct. All life and energy, even the "bad" kind, is in some way a result of the sun. In his defense, his father is not technical and when asked by his son -to avoid having to explain the complex process of harnessing solar power and using water to produce fuel- he just says, *"the sun"*. Not at all wrong, but the

kid is not learning anything. So, I take it on me to educate him a bit. I start telling him about fossil fuels and how countries like South Africa used to have almost all their electricity and fuel produced from fossil sources, being coal, oil, and gas. I then start explaining how cleaner energy and fuels emerged, but he quickly interrupts me.

Grandson: *"That's the stuff you guys used to burn that caused pollution and damaged what's left of our environment."*

He used the term *'you guys'*, referring to my generation, and '*ours*' referring to his. As if I was responsible for what was decided and started +200 years ago, and as if he had anything to do with solving the problem. In fact, my generation was part of the start of the change towards the solution. I explain this to him, and his reaction is: *"OK"*, still staring at the screen. I lose motivation, probably hope for an immediate dialogue, and turn to his little sister who just woke up. She's only three and easy to impress.

Sasolburg - Prieska

My wife wakes me up. I dosed off in the car. We arrived at Johannesburg's Oliver Tambo International Airport. From Johannesburg my wife and I get on a plane back to Cape Town. A couple of minutes after take-off I see in the distance what is likely to be the town of Sasolburg.[140] Tall chimney like towers, characteristic of a chemical plant, can be seen in the distance. It is the site where South Africa first started producing fuels and chemicals 94 years ago.[141] At the start of the 2000s, the fuel and chemical industry in South Africa contributed more to CO_2 emissions than 100 small countries.[142] Today the situation is much better. In fact, 200 kms away in Secunda,[143] which used

to be the highest CO_2 emitting single plant on the planet,[144] the first sustainable aviation fuel was produced from green hydrogen and biomass being the carbon source.[145] Impression of Secunda-based industry in 2020s below:

Secunda-based industry in 2020s. Source

Nowadays, approximately half of the site's 8,000 billion barrels per day is referred to as 'sustainable aviation fuel'. It fuels this very plane we are in. When I booked our tickets, I made sure the flight was carbon neutral – this is standard practice now.[146]

We fly South-West over two very distinctive large pipelines lying East-West emerging from that plant. At this altitude they are still clearly visible. These pipelines transport hydrogen from the solar abundant hydrogen hubs in the Northern Cape, to export ports at the coast and industrial users mainly in

the Gauteng and Mpumalanga provinces. These pipelines reminded me by the look to ones I saw transporting gas to Mozambique:

SASOL gas pipeline (Mozambique). Source: wikimedia

I fall asleep again and wake up again about halfway through our 2-hour flight. My eyes catch the flight tracking screen and realize we are almost directly over the town of Prieska in the Northern Cape. Prieska started producing green ammonia from renewable hydrogen 15 years ago. I look out through the small window and can make out the distinctive round crop circles along the notable twisting Orange River. Some square shaped blue, greyish objects. These are undoubtedly

large PV plants, or possibly CSP (Concentrated Solar Power).[147] Other than that, everything is too small from above to know what's what. Some of those solar power plants are surely supplying part of the power for the green ammonia plant's large electrolysers. Although it seems quite small in today's standards, more than 120,000 tons of green hydrogen is produced for the 70,000 tons of ammonia which is exported though Boegoebaai and Saldanha ports. We fly past some of the great Karoo. Karoo is these days abundant with PV and CSP plants. Once a dry semi-desert mostly unusable, today home to the country's biggest source of energy, made-up of CSP, PV and even GW scale wind farms. Ironically, years back it was hoped to be a source of natural gas, and today hosts large solar power plants and wind farms as well as green hydrogen, ammonia, sustainable fuels (sustainable aviation fuel), and e-methanol production plants destined to domestic use and exports.

Final thoughts

Although starting out slowly, South Africa has evolved today be one of green hydrogen production hubs of the world. At the height of the fossil era, South Africa's electricity was almost completely generated from coal. Today only 25% coal-based electricity generation remains of more than 90GW available. Approximately 44% (40GW) is wind and solar, with as high as 12% available from green imports.[148] These green imports, predominantly hydropower from East and West Africa, were a dream only 20 years ago. Today we are connected to the world's largest electricity network, connecting the entire Africa, enabling green electricity trading.[149] The rest of our electricity is from nuclear, hydro and biomass. Apart from this, an

additional 47GW solar and 16 GW wind power plants are dedicated to 28 GW of electrolysis. South Africa already surpassed it's 2050 green hydrogen production targets and today exports almost 4 million tons of green hydrogen, as hydrogen, ammonia, methanol, and sustainable fuels, through four major ports being Richards Bay, Coega, Saldanha and the newly completed dedicated hydrogen export port Boegoebaai. At one time we were home to the largest green ammonia plant in the world at Nelson Mandella Bay[150] and today we export at a hydrogen price of well below the US$1.2/kg. Our hydrogen economy has completely evolved and is still growing fast to meet the demand from Europe and Asia.[151]

* * *

My wife wakes me again. We've landed in Cape Town. After picking up our luggage we grab a cab home. At this point I am tired and just want to get home to a comfortable bed. Getting into our cab I notice it is a battery electric one, as almost all cabs are. As it is my habit, I check the information screen and notice sufficient charge for our trip. As we drive, I stare out the window and realize the number of hydrogen-fueled transit busses we pass on the way back home. Today, almost all vehicles driving in and around our cities are battery electric, with mostly bus and trucks being hydrogen fueled. I remember the day I took my first trip on a hydrogen bus in Cape Town 19 years ago. Time has certainly not stood still and luckily, nor have technological advancements. South Africa, once struggling to take advantage of our immense renewable resources, today exports those renewable resources all over the world.

Uruguay, 2021 - 2031

Author: Pablo Ignacio Ferragut Varela

Coffee insights full of hydrogen in 2021 and 2031

2021. Present times

A man (for his anonymity, I will call him: *Juan*) is on the stage at a famous international conference, presenting the results of the successful energy transition in Uruguay to an enthusiastic audience.

"In the last 3 years, 98% of power in Uruguay was generated by renewable energy sources, being 55% hydro, 34% wind energy, 6% thermal-biomass, 3% solar PV, and only 2% thermal-fossil, used just for occasional backups[152] *(...) Uruguay is ranked as the second country in the world regarding wind energy, only behind Denmark*[153]*, and is recognized in the world for having made great progress in the energy transition. Not in vain, it is the best ranked Latin American country in the WEC's Energy Trilemma Index,"*[154] Juan stated in a proud tone.

Example of wind resources Uruguay. Source: earthisland.org

He made a brief pause, and loud and long applause invaded the room. Immediately after he left the stage, many people came to congratulate him, eager to exchange some words as if he was a celebrity. He took some minutes to talk and thank each of them, one by one. After that, he was a little bit overwhelmed, so that as soon as he could, he looked for a space to breathe quietly and go for a coffee.

Juan is now at the coffee machine station of the conference. He takes a cup, a plate, a sugar sachet and waits for his turn at the queue. Some people there looked at him, making gestures of approval because of his excellent presentation.

It was his turn now; Juan gets his coffee and stands quietly, close to the coffee machine, trying to have some peace at last. However, a shiver ran through his body when he saw a man

with long and thin fingers serving a coffee to himself. Before he was able to look at the face of the man that terrified him, he heard that voice that he had not heard for a long time.

Mysterious man: *"You are wrong again!"*

Juan reacted with a spasm, and spilled some coffee but without burning himself or getting dirty this time. He was in shock, recognizing long forgotten voice.

Mysterious man: *"Do you remember me? It has been a long time, I must congratulate you as many people are doing here, or maybe you should congratulate me. I see that I was right in more things than I could tell you last time. I told you that we will have a coffee in 15 years, and a promise is a promise."*

Before answering, Juan got more surprised when he realized that the mysterious man did not get even one minute older since their last encounter. He was still that lean man with an imposing presence, delicate features, and a peaceful but extremely sharp way of looking that gave the impression that he had already seen everything.

Juan: *"Of course, I remember, although I tried to forget. However, I am still wondering if that encounter was a real one."*

Mysterious man: *"So...How do you explain the two cups of coffee on your desk? By the way, I forgot to say thank you then. I apologize"*

Juan:*"But...who are you?"*

Mysterious man: *"It doesn't matter. I only can tell you that I have seen the future, and it is magnificent, my friend."*

Juan, losing interest in the chat, was still hesitating if the encounter was actually happening and threatened to move away; but the mysterious man reacted quickly to get Juan's attention again.

Mysterious man: *"You are wrong again. You, in Uruguay, have*

transformed the power generation matrix, reduced and stabilized the cost of supply; this is a great achievement, and for sure these are the foundations to continue building. H*owever, 40% of your energy matrix is still imported hydrocarbons, most of them for transportation*[155] *As I told you last time, you should take a look at domestic resources..."*

Juan took the challenge and came back to the discussion, answering with some apathy.

Juan: *"We were not successful with the oil and gas offshore exploration campaign. Albeit we were very hopeful about the potential results."*

Mysterious man:*"No, no, no. I am not talking about that, I am talking about green hydrogen potential."*

Getting excited, the mysterious man continued.

Mysterious man:*"Listen to me. Uruguay has 180 thousand square kilometers of land, low population density, and an incredible complementarity between wind and solar PV energy that can reach together load factors around 60%*[156]*. This would allow a high utilization level of the electrolysers."*[157]

Juan:*"I think that you are daydreaming... I have heard that the cost of production of green hydrogen is about 3 to 8 USD/kg* H_2*"*[158]

The mysterious man smiled.

Mysterious man:*"I think you reasoned similarly last time. I remember you saying that the levelized cost of solar PV energy was around 500 USD/MWh, and more than 100 USD/MWh for onshore wind energy.*[159] *You said the only possible solution was increasing thermal-fossil power capacity, or even opting for nuclear energy. Please, you make me laugh (again)! Look at what happened with your predictions, and your presentation today."*

The mysterious man was silent for a brief moment.

Mysterious man: *"Electricity is by far the main cost of green*

hydrogen, and as you see, things have changed dramatically fast in the last 15 years. But let me tell you something, they will change even faster in the next 15."

Juan: *"Oh, I am a little bit overwhelmed now...but you need lots of water, and the electrolysers, are pretty costly too, or am I wrong again?"*

Mysterious man:*"Well, you do not need so much water. This is a myth; you can travel almost 100 km in a hydrogen-fueled car with just one bucket of water,*[160] *and there are huge amounts of water everywhere in Uruguay.*[161] *There will be so many green hydrogen projects around the world in the next few years, so that the cost of the electrolysers will be reduced drastically."*[162]

Juan is now lost for words, so the mysterious man continued his reasoning.

Mysterious man: *"I will be very concrete. Under certain conditions such as parallel global scaling of electrolysis*[163]*, if you install 2 GW of electrolyzing capacity, powered by a combined 2 GW of onshore wind power and 2 GW of solar PV, you will be able to produce 200 ktons of hydrogen per year and reach the magical competitive benchmark of 1,5 USD/kgH_2 by 2030."*[164]

Juan, still out of words and feeling touched again in this intellectual fencing combat, came back with a challenging question.

Juan: *"Well, this is a lot of energy, but who would consume so much hydrogen in Uruguay anyway?"*

Mysterious man: *"You are right on that. The potential domestic demand for the transport sector by 2025 is about 150 ktons of H_2."*[165]

And before giving time to Juan to answer, he continued.

Mysterious man: *"It must be an export development, that will allow to develop the internal market of Uruguay and some niche use cases too, mainly in transport and industry, but also thinking*

in more traditional use such as using hydrogen for ammonia for fertilizers. Is the agricultural sector no the main exporter in your country?"

Juan: *"But...do you think that there will be so much demand in the world?"*

Mysterious man: *"Well, you are committing the same mistake you committed last time. The past is a great school to learn, but please do not project the past into the future; the future of energy will look very different. decarbonisation is one of the most relevant topics in the European political agenda; they will be hungry for hydrogen. You should look at the largest European ports, Rotterdam or Hamburg; for sure there will be lots of investors and off-takers looking for opportunities, looking towards countries like Uruguay."*

The mysterious man continued with enthusiasm but without losing his thoughtful tone.

Mysterious man: *"Do you know? Uruguay has many advantages; it is a reliable and stable country with a strong institutional landscape. Besides, thanks to the transition experience in the power sector, it has created incredible capabilities in their people. In summary, a great place to invest...I cannot find a better example than offshore oil exploration in Uruguay. Some of the largest companies in the world came to an unknown province; the same companies that are now committed to net-zero, investing in renewable generation, carbon capture and storage. It may sound a little bit ironic, but the same areas that were tendered for offshore exploration could be now offered for offshore wind farms and hydrogen islands."*

Juan: *"Well, but then one needs to develop offshore wind infrastructure, and..."*

The mysterious man, guessing the further reasoning of Juan, interrupted him.

Mysterious man: *"Please, do not stress the cost of developing*

offshore wind energy. It is true that the average can be around 80 USD/MWh today,[166] *but these costs will fall rapidly, and you can have load factors over 55% in your offshore wind platforms."*[167]

Both stayed in silence for some seconds.

Juan: *"So...If I correctly understood, you are saying that Uruguay has the right conditions to attract massive investments to produce green hydrogen at a competitive cost. Hydrogen that could replace most of the imported hydrocarbons in the heavy transport sector, which represents only 4% of all the motorized vehicles but 36% of GHG emissions*[168]*, while creating quality jobs for our people?"*

Mysterious man: *"Local investments of at least between 3.2 and 6.2 billion USD in the next 20 years are easily feasible.*[169] *I am happy to see that you are finally understanding* (Juan was nodding.) *Can you imagine how the future could be? Please add the potential to produce fertilizers, methanol for bunkering ships, or even synfuels for aviation."*

Juan: *"Well, but you told me that you have seen the future. May I ask you how it looks like exactly?"*

The mysterious man looked like he felt uncomfortable with the question, although he seemed at the same time accustomed to it.

Mysterious man:*"I cannot tell you that; I would lose my (mental) power to jump through time if I do so. I only can tell you that as it already happened in all the past energy transitions; the sources and technologies that solve the problems of its time are the ones that finally dominate. The big problem of our time is decarbonisation of our society. Don't you think that hydrogen has enough attributes to help us solve this problem? Don't you think that Uruguay has a great opportunity to position itself in this new technological global wave?"*

Both men stayed in silence.

Mysterious man:*"But you know? You will need to move fast; there are too many horses running this race. I am sorry, I cannot tell you more, but we are going to have a coffee in 10 years again"*

Juan put the coffee cup on the table, and when he came back again to say something else, the mysterious man had already vanished. He was in shock again. While Juan was recovering, he saw a high government official looking at him absolutely astonished.

When Juan realized why the official was surprised, he instinctively pointed to the dirty cup that the mysterious man laid over the table, but the official still looked confused. Juan, without letting place to be interrogated about the episode, rapidly said to the official: *"You know? We need to continue working on an ambitious green hydrogen strategy*[170]*"* and gave him a long explanation that the official could barely follow.

A hydrogen conference. December 2031

Ten years later, we are in December 2031. Juan is now doing a presentation to a European delegation visiting a conference by Reuters "Global hydrogen – Latin American edition", explaining how Uruguay had implemented the H_2 national strategy back in 2020s.

It commenced with the H2U project,[171] which was supported by the government and the State-owned energy companies. This helped to test the technology and create knowledge and capabilities to scale-up future developments. The pilot project – was in itself quite small – it produced green hydrogen for some 10 heavy buses and road trucks with an electrolyzing capacity of 1.5 MW. The project was awarded to a private company in a competitive auction, with more than 60 companies having

shown interest. That is how the future of hydrogen in Uruguay started.

He also explained on the National Oil Company's initiative early in 2020s to attract investments for the development of offshore wind farms dedicated to hydrogen production. The development built on know-how of same areas awarded decades before for oil and gas exploration, taking advantage of the knowledge acquired about the climate, sea, and seabed conditions during the exploration campaigns.[172]

He also mentions other initiatives, which were developed, including the green hydrogen exports to European mainland via the Port of Rotterdam.[173]

After showing some more facts of developments in 2020s, he closed his presentation exultantly: *"Uruguay is now a large green hydrogen exporter while advancing in the definitive decarbonisation of transport and industry and solving a 100-year problem of costly oil imports. Green hydrogen is no longer a dream, but a reality that is helping drive jobs and opportunity our country."*

Immediately after finishing his presentation, he realized that a tall and lean man who had taken his place at the meeting table initiated the applause. He felt a little bit strange because he did not notice him before. He appreciated the applause and rapidly took his cell phone and notebook, eager to come back to his place, and talk again with the mysterious man who looked exactly as the one 10 years ago. However, when he looked at his chair again, the mysterious man had already vanished.

A dirty cup of coffee on the table was the only trace of him.

Chile, 2030 - 2040

Author: Eric Ehrhardt

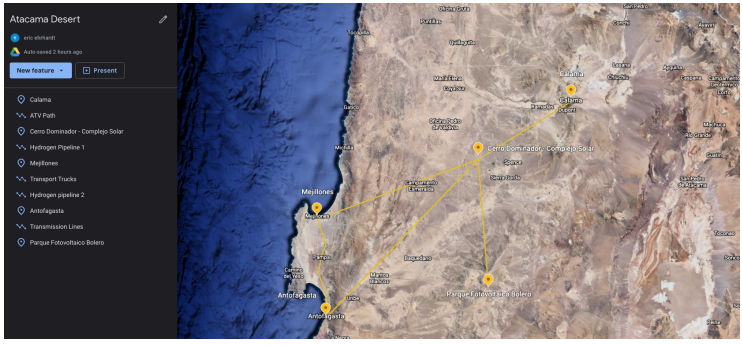
Over the next few pages, I'm going to take you across the extremely diverse and beautiful 4430 km of Chile. All the way from the northern red-rock deserts to the lush southern valleys full of lakes and glaciers. We'll make sure to stop by the bustling capital of Santiago with the Andes on one side and the Pacific on the other.

Chile is at a time of transition; it's reaching towards energy independence through clean energy. The new policies and strategies are shaping up to be some of the most forward-thinking in the world concerning the environment and the role energy plays. We'll be looking at how hydrogen could develop in Chile over the coming years.

Different locations of the story. Source: Google Earth

Have you ever wondered what a country completely run-on clean energy might look like? Chile in 10 years just might be one of the first. Let's travel to that time in the Atacama desert; afterwards, we'll jump through time twice more, and to 2 new locations: Santiago and Patagonia, to give you a feel of the possibilities of hydrogen in Chile. Through the stories, we'll look at hydrogen through the lens of locals across the country. Let's go.

2030. Atacama Desert



Atacama Desert. Source: Google Earth

The distinct red sands of Chile's largest desert battered my helmet's visor as I sped up and down the dunes. My hydrogen-powered ATV (all-terrain vehicle) roared as I pushed it to its limits. It had already taken me most of the way on my 70 km rocky trip from the closest town of Calama. With the

sun beating down you could tell that the most powerful solar radiation on the planet is found in Chile's north (>30-35% solar load).[174]

I was on my way to the recently expanded 'Cerro Dominador Solar Power Plant', having been bought by the Chilean government from a Spanish energy provider a few years ago. It was the first big step to an energy independent Chile. It's been my job to oversee all the green hydrogen plants that have been added to the growing solar fields. I'm typically working from the office, but every now and then I like to get out and see the plants for myself.

Ever since the National Hydrogen Strategy[175] was announced back in 2020 the goal of 25 GW of electrolysis capacity was set, and it keeps me busy. My mind started to drift thinking about how far we've come. But before I could indulge in memories too much my partner Martin came in over the radio "*Alejandra, I see it, it's just over the ridge.*"

As I reached the top of the hill, there it was -the concentrating solar power (CSP) plant. It's beautiful in a way, it looks like a mosaic made up of thousands of solar panels all facing the central tower. Despite having visited the plant the previous year it looks like it has doubled in size, the scene is mesmerizing to the eye. I wanted to stay there for some time to take it all in, but Martin was already speeding down the dune.

Martin is my right-hand man, he's the technical specialist when it comes to anything hydrogen and has more energy than anyone I know. Good thing he does, because we have received a solar-to-hydrogen plant proposal every 6 months from the developers. Don't get me wrong the progress is incredible, but I wish I had Martin's energy to keep up.

On our way to the hydrogen plant, we made sure to keep

our distance from the panels, as to not cover them in sand. We passed the massive 1 GW electrolyser installations each capable of producing 0.15 million tonnes of hydrogen a year. That's the equivalent of 2 coal-fired power plants or 750,000 homes.[176]

We went inside, and mercifully the air conditioning was blasting, a perk of affordable energy. We were greeted by the plant manager, a former supervisor at the Ventanas coal plant down in the Valparaíso Region, which was phased out 6 years ago. Martin wasted no time, before the man could say anything more than hello Martin asked *"So how's the production start looking? Have we finalised installing the 5 GW? Have we started shipping hydrogen out to Antofagasta?"* The manager, obviously a little overwhelmed, took a second to gather his thoughts and answered Martin: *"Yes sir, everything has been running better than expected, the last installations were made last week and our electrolyser capacity is now just over 5 GW. The current batch of hydrogen supply is already flowing through the pipeline, we're also filling up some tankers headed to Mejillones with liquid hydrogen for exports."*[177]

My hometown Antofagasta is next to Mejillones, right on the coast of Chile some 130 km from the plant. In the past few years, they've seen millions in investment, having become one of the main export shipping hubs for the hydrogen being produced.

Martin responds, *"That's great to hear, could you give us a ride around the production plant, as our ATVs are going to need a refill as well."* The plant manager nodded, and we got on our way. We couldn't stay long we were still planning on visiting the Bolero solar plant some 75 km south. On the tour of the plant, Martin was like a kid in a candy shop. Running from electrolyser to tanker loading area (which included liquefaction

and compression installations for filling tankers, depending on the needs of clients), and then back to the control rooms asking questions no stop.

I had prepared a surprise and I was certain that it would have Martin at a loss for words. After a walk through the solar field, we came out on the other side and there it was a state of the art hydrogen helicopter.[178] Martin was overcome with excitement spouting facts to anyone who'd listen "D*id you know that the hydrogen fuel system in this has four times the energy density of existing Li-ion batteries!*" [179] We made our way to the helicopter and got ourselves ready for the short trip, with the next stop being Bolero.

Up in the air looking down at the mosaic of solar panels and the fields full of installed electrolyser installations, nicely blended into the surrounding nature, I thought back to where it all comes from. It still blows me away how an element so simple can be harnessed to revolutionize a country's energy supply and uses.Now we race forward in time and make out way south to the heart of Chile, Santiago.

2040. Santiago City Centre

As soon as I open the door to the apartment building, the sounds of the city flood in. I put my headphones on and step out into the bustling street making my way towards the metro. Ever since Chile has become one of the major green hydrogen exporters, Santiago has exploded with investment and people. I still can't believe the city is on track to reach 10 million inhabitants by the end of the year. I walk down the steps of the metro and can already hear the high-pitched whining of the trains as they rush past. I get down to the platform and glance at the updated

metro map, 2 new lines have been added in the last year. The steady hydrogen and renewable energy supply have fuelled the expansion of the metro in the past few years from 100 km of rail to 175 km.[180] Better yet, the government keeps dropping the prices of the tickets because it's so affordable to run the trains, it's also helping get cars off the street.

I step into the train and find a seat, they're much more comfortable than the older models. They had to switch out the older carriages to work with the new high-speed electric tracks. Now the metro accounts for 5% of the domestic energy usage.[181]

The light in the carriage flickers, just a faulty bulb but it makes me think back to daily power cuts that used to occur. Those days are behind Chile thanks to the backup hydrogen cells. Whenever there is an excess of renewable power that isn't sold directly on a centralised power market or used, it gets stored in hydrogen tanks[182]. With every building in Santiago being topped with solar panels that problem is more common than you'd think. I remember 3 years ago when we got hit by one of the biggest storms of the last decade, a significant portion of the renewable's infrastructure was damaged, solar panels and wind turbines alike. The hydrogen reserves are what kept the country running during the rebuilding period.

I've been an energy trader for the past 10 years. The industry grew exponentially once Chile made strides on its hydrogen plans and became a net exporter of energy. I can barely keep up nowadays, with green hydrogen dropping close to 1 USD/kg, as Chile has become one of the leading exporters of energy in the world. Chile and Santiago in particular are flourishing, but everyone in South America wants to repeat the success.

Today I have been invited, as a senior expert, to speak with

the energy Minister of Peru. They've been looking to us, their neighbors in the south and have taken an interest in investing in a green hydrogen project on the border of our two nations. Being immersed in the world of energy, specifically hydrogen, it was my job to clear up any doubts they have about the project and green hydrogen as a whole.

The phone rings, it's the energy minister calling "*Como estai minister, I've been looking forward to speaking with you.*"

Energy Minister: "*I'm doing well Vicente, let's get right into it, I have some questions for you.*"

Me: "*Sounds good, I'm here to discuss with you why green hydrogen is the right direction for both our countries.*"

Energy Minister: "*Alright then, first things first why should we pursue green hydrogen rather than any other energy vector, given the high energy and water requirements?*"

Me: "*Valid question, our two countries are in a unique position; we have an expansive renewable energy capacity and untapped potential. Look at Chile, we've utilized the coasts and mountains for wind power with attractive load factors > 70%, vast deserts for solar with attractive load factors > 30% as well, and the spanning rivers for hydropower. Few countries on earth rival our ecological diversity, our load factors and thus renewable energies we have access to. So, for Chile, the problem hasn't been generating renewable energy, it has been utilizing it and storing that energy efficiently and effectively. It is all well and good to have 25 GW of solar energy capacity, but that clean energy doesn't transfer by itself into lowering the emissions of our mining operations or dropping the carbon footprint caused by heating our homes. It doesn't even really help Chile become a net energy exporter. That is where hydrogen molecules came in and helped build the Chile we live in today*."

Energy Minister: "*Well that covers some of my "why" concerns*

but what about the water costs, as I understand, electrolysers require 'freshwater' for green hydrogen and lots of it."

Me: *"This is true,*[183] *and it was one of the main concerns Chile had when committing to green hydrogen. However, after doing the research we found that desalinization was the answer. With less than 1% of the world water being 'freshwater' we decided to keep the burden off the people's water supply. We found that the power required to run desalinization plants was at most 0.13% of the energy required to run the electrolysers, so the choice was simple. Even from an economic perspective desalination added no more than 0.01 USD/kg*[184] *to the cost of hydrogen production which enables us to stay below our 1.5 USD/kg goal."*

Energy Minister: *"That's all very compelling Vincente, I have to think it over. If Peru did decide to partner with Chile on a project, what could we expect?"*

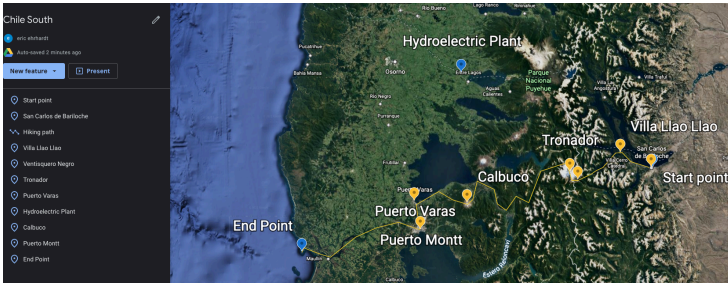
Me: *"I'm not sure if you know this Minister, but green hydrogen can be used to create green ammonia. So the hydrogen we'd produce on our border doesn't have to necessarily go towards the energy grids. I know Peru has been trying to reduce their carbon footprint, and the green ammonia, which is used in the fertiliser industry, would go a long way in dropping the environmental impact of your large agriculture industry. Like my father used to say, 'Technology is mouldable' - green hydrogen is no exception."*

Energy Minister: *"Thank you Vincente, I hadn't thought of that connection and am sure that'll factor into our decision. Thank you for the information, we'll talk again soon."*

Moving on to our next location we make our way further south to the beautiful Chilean Patagonia.

2030. Chilean Patagonia

I'm so glad I'm finally getting the chance to climb Volcán Calbuco, it's giving me time to clear my head and admire the countryside. The air is thinner up here at 2,000 metres, regardless the breeze feels like it goes right through my coat.



Chilean Patagonia. Source: Google Earth

Doting the countryside below me, I see the wind turbines, most of them supplying the power to the neighboring green hydrogen plant. They're becoming more common, as I get closer to the coast where the bulk of them are, most of them feed the 4 GW green hydrogen production facility there. The towering 120 m turbines cast a shadow across the valleys, where you can see the herds of Guanaco grazing on the picturesque landscape.

I've made it 6 days into my 10-day hike, I'm on the back end of my 240 km from the Argentinean border to the Chilean coast. So far Cerro Tronador gave me some trouble being 3,500m but Calbuco is a walk in the park in comparison. I reach the peak and look out over the valley; I just barely spot the hydroelectric dam in Pilmaiquén with my binoculars. It

provides over 310 GWh a year[185] so it was one of the first to get a hydrogen production facility next to it.

I start making my way down the other side of the mountain, meanwhile looking ahead, and plotting my way through the boulders. There's a clearing coming up, turns out it's a decommissioned copper mine. Surprisingly the air feels crisp and clean in the quarry. With the rise of the energy export era in Chile, we could afford to scale back the mining operations. The drills, still active, have been switched over to electric or hydrogen cells limiting their environmental impact. The positive impact is easy to see in the recovery of the local wildlife.

4-days later

Lining the coast I can see not only the 120 m offshore wind turbines, but also pipes sending saltwater to the nearest desalination plant. 15 years ago, Chile wasn't even in the top 50 when it came to the percentage of energy consumption that came from renewable energies[186] now, they've reached the top 15, in no small part, thanks to hydrogen. Through export profits being used to expand renewable energies infrastructure, Chile has preserved its environment and most importantly invested in the people, as the hydrogen economy brings jobs and opportunities.

Peru, 2032

Author: Rocío Salas

It's Friday, a normal summer day in Lima. January is known for being the best month in Peru to enjoy vacations with family. Marina, the most renowned researcher at the Glacier and Mountain Ecosystem Research Institute - INAIGEN,[187] is preparing to attend her last day of work before starting her vacations of this year.

This day is special, because she will give a speech to the Ministry of the Environment during the Commemoration Ceremony for the 10 years of approval of Supreme Decree No. 003-2022 MINAM. The Decree declared the climate emergency of national interest in Peru in order to implement urgently the climate action measures in accordance with the provisions of the Nationally Determined Contributions[188] for the year 2030. This was a milestone that contributed to the global goal of limiting the increase in temperature and aligned Peru with the fulfillment of the Sustainable Development Goals, the economic reactivation, reduction of socioeconomic gaps, risks and vulnerability to the adverse effects of climate change. Among the measures adopted to meet the objectives established in the national energy policy, the Ministry of Energy and Mines

of Peru prioritized green hydrogen, quote: *"Design promotion programs for the development of technologies, use and production of green hydrogen",* as well as other measures promoting the use of renewable energies including *"the entry of electric vehicles, hybrids and powered by green hydrogen."*

The years after the approval of Supreme Decree No. 003-2022 MINAM were characterized by the implementation of emblematic projects in Peru in the fight against climate change, and by the accelerated development of the green hydrogen economy. To achieve the continued commitment of all sectors in this crusade, researchers and scientists, such as Marina, presented the effects of climate change on Peruvian ecosystems. The today's status quo (2032) was achieved thanks to the collaboration of all actors: Government, academia, private sector and civil society, who committed themselves to develop the first pilot projects for the change of the energy mix towards the integration of more renewable sources and the reduction of CO_2 emissions. This was particularly relevant for areas of protected nature reserves, with the goal of preserving the beautiful geography of Peru such as:

- The Amazon in the jungle,
- the Cordillera Blanca with its system of mountains in and lagoons,
- the highlands, and
- the hydro biological wealth of the Peruvian sea in the Coast.

Such pilot projects will be replicated in the current decade of 2030-2040 in the main protected natural reserves of Peru, and will set the example for to the main economic sectors and cities of Peru.

* * *

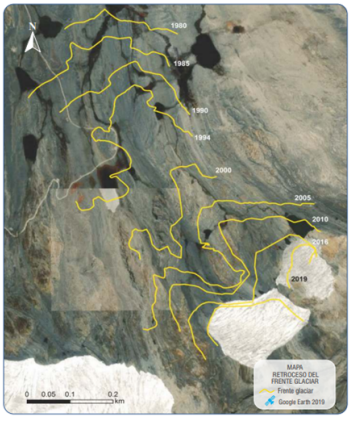
Marina's presentation begins with photos of the jungle, mountains and coast of Peru, and continues showing the conclusions of the publication "Pastoruri, 40 years of glaciological studies"[189] published in 2021. That year was the beginning of the entire transformation process of the Peruvian energy mix that allowed Peru to achieve its Nationally Determined Contributions under the Paris agreement by 2030: The 30% reduction in greenhouse gases.

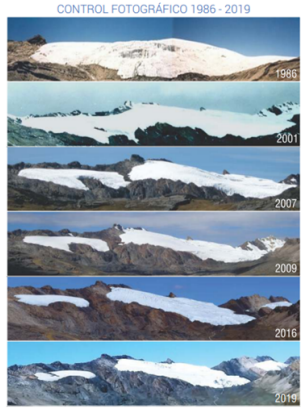
Landscape of MANU National Park located in Peruvian Jungle. *Source*

Landscape of Paracas National Reserve located in the coast of Peru. Source

"*Pastoruri*"- Marina points out during her presentation, with a clear expression of nostalgia on her face and voice, "*used to be one of the most important tourist destinations in the Huascarán National Park and later became one of the symbols for addressing the effects of climate change on our planet. International media such as National Geographic back in 2018 analyzed this problem.*"[190]

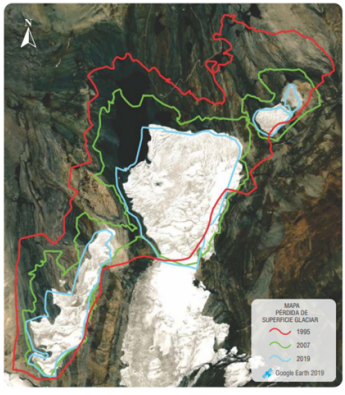
Front Retreat of the Pastoruri Glacier Peru. Period 1986 to 2019

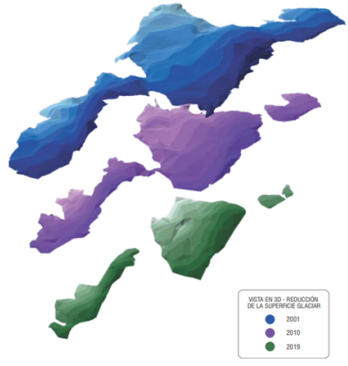




Source: PASTORURI 40 years of glaciological studies/ National Water Authority. 1a. Ed. Huaraz: ANA, 2021

Reduction Area of the Pastoruri Glacier Peru. Period 1995 to 2019





Source: PASTORURI 40 years of glaciological studies/ National Water Authority. 1a. Ed. Huaraz: ANA, 2021

Marina continues the presentation: *"As can you see in the images, and the aforementioned study points out, during the period 1980-2019 the glacier front receded 651 meters. The average glacier retreat per year was 15 meters between 1980 and 1994; and it increased to 23 meters per year between 2000 and 2019. In 25 years, the Pastoruri mountain had lost 70% of its glacial surface. Since Peru is a country with great biodiversity, it was a priority to take urgent actions to preserve this natural competitive advantage that has led Peru to become a leading producer of super foods and highly valued products in the world. In this context and the global energy transition towards Net Zero, the Supreme Decree that was approved in 2022 catalyzed the changes we commemorate today."*

Distinguished members of the Peruvian Academy, who played a key role in advancing the economy of green hydrogen in Peru, were present in the audience including leading universities such as the National University of Engineering. The latter led scientific research projects for the production and storage of green hydrogen and lithium batteries for electromobility contributed significantly to the progress made by Peru in the past decade. Dr. Arturo Talledo Coronado, Vice Chancellor for Research at the National University of Engineering, when interviewed by the Andean News Agency a decade ago, presented the University's plans in this field and its strategy of articulation with companies and Peruvian researchers.[191] Since then, Peruvian companies approached the academy to form alliances that allowed them to achieve their carbon footprint reduction goals, to contribute to the Sustainable Development Goals of their respective strategic plans and, at the same time, to achieve the National Determined Contributions.

Thus, in 2020s, Marina remembered, with the contribution of all stakeholders, the first pilot project was carried out in

the regional hub of the Pastoruri mountain in the Ancash Region,[192] which promoted the use of green hydrogen in industrial processes, transportation, energy storage and mining for most of activities in the area. In fact, one of the 10 largest mines in the world (in the ranking of production capacity) is located in the Ancash Region, and was the most enthusiastic stakeholder to participate in the pilot project. Also the major steel producer in Peru and other representative industries in the region took part. In parallel, the public transport service and tourism buses incorporated electric vehicles and vehicles powered by green hydrogen into their fleets. Likewise, the minerals transport fleets, which previously used mainly diesel as a fuel source, were replaced by green hydrogen vehicles. The generation of energy for mining operations was greened as well given the aim to be carbon neutral by 2040. Providing thermal heating comfort for the populations located in highlands of Peruvian Andean areas, where the temperature usually drops to below zero degrees Celsius in winter, was also a priority of the pilot projects. This consideration for local citizens was greatly supported by the regional authority.

In parallel other just transition initiatives were promoted related to the region's livestock activity, such as raising Vicuñas[193] and Alpacas,[194] to reduce their rates of mortality due to climate change. Vicuña fiber products are highly appreciated in the local market and abroad. It was ensured that any green hydrogen economy development would not affect water or land use of the traditional livestock activity by consulting and planning the use of water and space for producing green hydrogen. The successful implementation of the pilot projects in the Ancash Region evidenced that it was possible to replicate green hydrogen economy development in other protected

natural areas highly sensitive to climate change.

The sense of urgency that the approval of Supreme Decree No. 003-2022 MINAM provided, allowed the accelerated changes that are commemorated today (2032), and that would be gradually implemented in all regions of Peru, not only those located in protected natural areas in the coming years.

* * *

Finally, Marina closed her presentation with a reflection: "*Peru was a pioneer in South America in the production of green hydrogen: The Cachimayo industries ammonia is a plant located in Cusco that produced hydrogen by using the electrolysis process since 1965, being fed by a hydraulic power plant. 65 years had passed since then!*" This final reflection led to a standing applause from the attendees.

Colombia, 2040

Author: Miguel Ballesteros

The following story will take you to a trip in Colombia, mostly the Caribbean region in the north, which became the epicenter of the energy transition in the country. Let us go a couple of decades into the future and discover this place with abundance of natural resources, with hydrogen being a nascent energy vector, but aiming to stay for the decades to come…

Let's begin.

* * *

On Friday, January 13th, 2040, we left the apartment at 04:30 AM to catch our flight scheduled at 06:00 AM from El Dorado airport in Bogotá, situated 2,500m above sea level. All my family was excited to visit Cartagena, a magical city with a historical heritage and beautiful sunsets by the ocean. I like to teach my children about the places we visit, and we had planned a very special tour for them this time in the Caribbean region.

Julieta, our daughter, had recently turned 6 and she was always asking questions about the surroundings; but not yet, she fell asleep in the taxi, and she was very warm, completely

unaware of the 10°C outside. Arnold, however, looked by the window with surprise: *"Dad!"* he exclaimed with horror. *"We need to go back home, now!" "Calm down champ, if we go back, we risk missing our flight, did you forget something?"*, I answered. *"Yes, my iPad, I need it for my energy project and I have important information there that I need while we visit the fields you promised me for this trip"*, Arnold continued. *"I brought mine, don't worry, you can access your account and all the information will be there, that is why I always tell you to work in the SharePoint, trust me it will be alright"*, I said. *"Stop being so nerdy,"* grumbled Julieta, evidently annoyed by her brother who had woken her up.

We made it on time, and we were sitting in the plane at 05:30 AM, awaiting to take-off. I was next to Arnold while Kathe, my wife, was in the row in front of us with Julieta. As time went by, I decided to help Arnold start his energy project: *"Did you know that aviation, globally, is gradually becoming the mode of transport that emits the most CO_2 to the atmosphere? It is one of the greatest challenges remaining to meet the carbon neutral ambition by 2050 that was announced back in 2021 during the presidency of Ivan Duque and many other countries that attended the United Nations Climate Change Conference COP26 in Glasgow. Aviation is soon to become the most polluting transport method in the global energy mix of this sector, not because it is getting worse, but rather because light passenger vehicles, trains and heavy trucks have extensively been decarbonized in the last couple of decades thanks to alternative solutions such as fuel cell hydrogen electric vehicles! Traditional manufacturers like BMW and Toyota, as well as new entrants have taken advantage of hydrogen costs around 2 USD/lb, which coupled with other characteristics such as long range and being emission-free, have significantly reduced purchase price as a result of economies of scale.*[195] *That is why you can now see plenty of*

hydrogen refuelling stations in the main cities as well as electric vehicle charging stations as a normal thing, but this was not really the case before you were born." I took a break to inhale deeply and I continued: *"Nevertheless, emissions from shipping and aviation have been more difficult to abate due to less accessible clean fuel alternatives. Hydrogen, however, is a very versatile molecule and a few years ago, in Colombia, the first domestic commercial flight landed successfully using a sustainable fuel that combined hydrogen produced from renewable energy and sustainable carbon dioxide, captured sometimes from the air or also from biomass.*[196] *This is mixed with conventional kerosene to produce the synthetic kerosene that significantly reduces the carbon footprint. While sustainable aviation fuels are very important, in other regions like Europe, hydrogen powered flights were deployed in the last decade, combining hydrogen combustion and fuel cells resulting in a highly-efficient hybrid-electric propulsion system for planes.*[197] *In the global mix, the aviation industry has tackled mostly medium-range aircrafts, which is the segment that emits the most, to avoid hundreds of millions of tons of carbon dioxide, using different solutions of hydrogen propulsion technologies, including a significant reduction in the mass of liquid hydrogen tanks."*[198] As we took off, the sunrise enlightened our journey and Arnold had already drafted the first part of his project.

"Dear passengers, welcome to Cartagena, local temperature is 27°C and local time 07:30 AM", announced the pilot. We immediately went for a traditional breakfast with arepas and coffee to energize the day. After unpacking and putting some sunscreen, we went to San Felipe castle before it began to be too crowded; the fortress was erected during the Spanish colonial period in the 1500s. Before the arrival of the European, indigenous tribes in different parts of the country had a rich civilization and

culture evidenced by some gold and clay relics found nowadays in museums. In that time, they already used coal to provide the heat required to mould the materials and produce ceramics such as cooking utensils.[199] Around 5 years ago, the way we use coal has evolved and now, after several centuries, it is also a source of hydrogen production. *"Are we going there in our trip?"*, asked Arnold. *"Yes, we will!"*, I answered. In the meantime, we contemplated a magnificent view of the city from the top of the castle. Towards the end of the day, after having fresh fish for lunch, we walked through the beautiful streets of the city, which was declared World Cultural Heritage Site[200] in 1984, almost 60 years ago!

San Felipe de Barajas Castle. Source: Wikipedia

Cartagena. Source: unsplash.com

The next day we visited Barú and Rosario islands with a spectacular show of dolphins and other marine animals. In Barú, we spent all day in the beach and Julieta covered her brother with sand up to the point where his face was barely visible. The colors of the sky turned reddish as the sunset approached and we hopped on the boat that took us back

to Cartagena. Julieta was amazed with the immensity of the Atlantic Ocean. *"That is why our geography teacher told us that Colombia is located in a blessed place with two oceans (Atlantic and Pacific) and also many rivers that go through the Andes mountains!"*, she said. *"And that is very true"*, I answered and continued *"In fact, this is important for Arnold's energy project. Colombia has relied on its water resources for a very long time, 70% of its electricity was hydro-powered*[201] *in 2020, but the share of the electricity has been significantly replaced by wind and solar energy. That explains why we saw some windmills today and there are many buildings with solar panels; we will also see enormous solar farms when we go to La Guajira."*

* * *

The next day we prepared to go to *Barranquilla*. *"Did you know that we are going to the city where Sofia Vergara was born?"*, asked Kathe to the siblings, but they had no clue of who she was. Shakira, who is now 62 years old, was born there too! They knew her for sure since we still listened to her songs at home. The bus that took us to Barranquilla was among the fleet of around 4,000 hydrogen-fueled heavy vehicles in the country. From 2021, when the hydrogen roadmap of Colombia[202] was launched, an increase of foreign investment and government support schemes allowed the country to meet its 2030 targets with 2.5 GW of hydrogen capacity with electrolysers and a Levelized Cost of hydrogen (LCOE) of 1.7 USD/Kg, at least for the Caribbean region with the greatest renewable potential. The hydrogen used in this bus may have come from those plants (green hydrogen) but also from blue hydrogen, also known as low-carbon hydrogen, produced very close from here in the

refinery of Cartagena, via Steam Methane Reforming (SMR), a hydrogen production process using natural gas, with the addition of Carbon Capture, Utilization & Storage (CCUS) technologies to avoid the carbon dioxide being emitted to the atmosphere, but rather used for a different application or stored underground. Two hours and a half later, we reached our destination.

We did some tourism in Barranquilla and visited Kathe's relatives there, people were very welcoming and we noticed there were already some preparations ongoing for the carnival in one month, one of the major folkloric festivals in South America. We visited the Bolivar Port[203] and had an interesting talk for Arnold's energy project. From this port, hundreds of millions of tons of coal have been exported overseas over the years as these resources are essential for our economy and we have reserves for a hundred years more. However, carbon dioxide emissions from coal are a big cause of global warming and the situation has changed significantly. This port has recently begun for the first time ever to export hydrogen to China and Japan! In the future, revenues from hydrogen are expected to reach the same level of several billions of dollars previously coming from coal exports. Most of the new hydrogen demand is coming from Asia, but Europe will also be a significant importer, and this port will be critical for our economy. Julieta relished watching the ships, especially an enormous Newcastlemax vessel that would start its journey to Flushing in the Netherlands[204]

We spent one night in Barranquilla but early in the morning we left towards the coal mine *El Cerrejón*. To get there, we surrounded the National Park *Sierra Nevada de Santa Marta*, characterized by the surprising proximity between the sea

and snowy mountains. It was a long six-hours ride but the landscape was totally worth it. Kathe explained the children that we were now very close to the border with Venezuela; they found funny the accent of the people we spoke to, as it was very fast. *"Why is Colombia still producing coal?"*, asked Arnold. Then he continued: *"You said it is not good for the environment."* Production levels have decreased significantly in the last decade, but it remains to be a necessary energy source for the energy security of some countries, especially those with a rapid population growth like Pakistan or India; besides, it still contributes to our GDP. Nevertheless, to attain carbon neutrality in 10 years, it is being significantly offset by CCUS technologies, in order to prevent CO_2 emissions to the atmosphere. *"You must remember I told you coal is now being used to produce hydrogen here with a gasification/conversion process where coal is heated to produce a syngas, rich in hydrogen but also CO and CO_2, that is why CCUS technologies*[205], [206] *are being employed, along tax breaks,*[207] *for carbon dioxide sequestration to certify the exports as brown hydrogen"*, I answered. *"Only the storage potential of five suitable clusters of oil fields for EOR in the country oscillates around 150 million tons of CO_2"*[208] We explored for about one hour the open pit mine, despite of not stopping sweating due to the 38°C of temperature. The children were surprised by the dump tracks, dozers, excavators and other machinery; we also saw the unit trains which serve to transport the coal to Bolivar port, where we were before, via a 200 km railway.

We then went to Maicao, where we just rested after such a long day. The Caribbean region has been the epicenter of the energy transition in Colombia[209] and you will see soon some of the reasons why! Once recovered, we left again early morning and after two hours and a half, watching many windmills on our

way, we arrived to Cabo de la Vela, a remote desert village with a world-class solar radiation and wind potential; also cultural hub for the indigenous Wayúu people. In this region, most of the electricity supplying homes is coming from renewable energy. The first wind farm in the country was procured here in 2004, called *Jepírachi*, meaning *"winds from the Northeast"* in Wayúu dialect, but no new projects continued for almost two decades later. Nowadays there are many more wind farms across the Caribbean region that account for a capacity of almost two thousand Megawatts. We also saw some solar farms when we were coming here. When the installed capacity of solar and wind are combined, only in the Caribbean region, several Gigawatts of renewable power are available for thousands of families, including those in rural areas that some years ago did not have access to electricity.

"How about the green hydrogen? Is it produced here to take advantage of all the renewable energy available in this region?", asked Arnold. *"That is correct, the cheapest green hydrogen of the country is produced here! It provides international competitiveness for green hydrogen production, but it still needs to scale-up in order to meet the ambition of exporting it to many other countries. For instance, irradiation in the northern region of La Guajira*[210] *is around 2,000 kWh/m*^{2} *and the wind energy potential in the Atlantic coast alone is around 21 GW.*[211] *New technologies have emerged and now the electrolysis process, which separates oxygen and hydrogen with electricity coming from renewable energy in this case, is much more cost-efficient". "I like hydrogen"*, said Julieta. *"It sounds like a very colorful molecule, like the rainbow over there!"*, she continued while pointing towards the beautiful rainbow that had appeared in front of us. It had started drizzling while we were talking, which was unusual since we were in the dry season and the

Guajira department is in general very dry, with less than 5 days of rain per month during this time.

* * *

The competitiveness of hydrogen is allowing hydrogen to progressively dominate other applications such as shipping and other industries in general, you will witness much more progress Arnold and Julieta as time goes by, it is very satisfying to know that future generations will continue living sustainably and global warming halting, partially thanks to hydrogen. This should be good for your energy project! In the meantime, let's continue enjoying our last few days in the Caribbean region. Our next adventure starts in the city of Santa Marta, we are going to "*Ciudad Perdida,*" meaning "*lost city*" in Spanish, an old city some say existed before Machu Pichu and a magical place to discover walking during four days through mountains and rivers, to get an idea of its remoteness. There is no phone signal or access to internet there, so this is the end for now!

United States, 2035

Author: Anne-Sophie Corbeau

Hydrogen in the United States, 2035

Flying in

I wake up with a start as the flight's steward announces our arrival in thirty minutes in New York city. It is almost 5 PM local time. Unfortunately, that means it's 11 PM for the French frog, and I am starting to feel a little bit tired due to the jetlag. I should get used to that now, it has been 14 years that I am regularly travelling between Paris where I live and the University of Columbia in New York.

Thirty minutes before landing. With some luck, I will be able to see the offshore wind mills.[212] Here they are…There is quite a lot of capacity now on the whole US East Coast, about 40 GW: it has been a great area for the development of offshore wind.[213] These windmills have become real giants now with a height of 150 m.[214] Some contribute to power the State of New York and the city with renewable power, and to produce green hydrogen.

It's year 2035, and as I hear the noise of the engines preparing

for landing, I just think that for all the things achieved over the past decade or so, we don't have long-range hydrogen planes able to cross the Atlantic ocean, despite some attempts from airplanes manufacturers since the early 2020s[215] to develop the technology and have the first zero emissions aircraft by 2035. Too bad – I was a big fan of some of the concepts proposed. We have seen a handful of prototypes using hydrogen for short range travel[216] within Europe and within North America but the technology has not massively taken off so far for the general public.

I am not surprised by this development, aviation was always going to be one of hardest of the so-called 'hard-to-abate' sectors to convince and to convert. For the moment, it seems that biofuels are still in the lead followed by synthetic fuels for aviation. As these synthetic fuels are based on hydrogen, it is a semi victory: we are using power-to-liquid technology to produce green hydrogen and then combine it with carbon dioxide, which has been captured. It is a bit expensive although considering that today the price of carbon in Europe and North America is $260/tonne (about $200/tonne ($2022)), what is expensive is all relative. It was only $100/tonne CO_2 back at the end of 2021.

Loving trains, taxis and trucks

Checking my watch, I am calculating how much time I would need to arrive to my hotel downtown depending on the different options. Ordering a hydrogen taxi is usually a good option, but the traffic looks pretty congested, so I will opt for my second favourite option – the hydrogen train[217] running from Jamaica station to Penn station. I have loved this train

since the very first day I took it – it was a few years ago but it seems ages ago. Replacing the old trains running on diesel on one of busiest commuter railroads in North America with these brand new ones running on hydrogen was ambitious, but it did work out pretty well and the public love the trains. The design has not massively changed from the first ones and they still have the hydrogen tanks on the rooftop. Not only are they quiet (a big difference from the previous ones), but also fast and clean as they only emit water vapour. They can also be refilled fast – in about fifteen minutes. Other train lines switched to hydrogen as well, not only in New York but across the country. California was one of the first to move. To be fair, California was, as always, one of the prime movers to develop hydrogen, including for trains: after all, they had been looking at that option for quite some time.[218] Using hydrogen for trains was a great initiative because they had provided a predictable but also substantial demand for hydrogen. That predictability and the fact that the first generation of trains had a range of over 1,000 km had also simplified the logistics of supplying hydrogen in the early days. (See figure for an impression of a hydrogen train.)

H_2 train. Source: Maxpixel

Tomorrow I will certainly hop into a hydrogen taxi to go to my different meetings in the town. Even though the take-off of hydrogen into private cars has been modest due to the prevalence of electric vehicles and the absence of a widespread deployment of refuelling stations, hydrogen taxis have thrived. As companies could set up refuelling stations at a few strategic points within the city, notably the airports, the implementation of hydrogen powered taxis had been easier. I remember taking a hydrogen powered taxi for the first time in 2021 - quite by coincidence. The rapid train was down again in Paris, and I had to switch to a taxi. To my greatest delight, it was a Hype taxi based on a Toyota Mirai.[219] The driver was very surprised that I could identify his car as a fuel cell car. I was apparently the first person to ever tell him that. I had been pleasantly surprised by how quiet they were and still are. At that time, the cost of hydrogen in Paris was €12/kg. With the tank of that first generation of Mirai able to hold 4.6 kg, you would pay about 55€ to refill your tank.[220] Now, thanks to the progress made to reduce the cost of hydrogen and develop the

refuelling infrastructure, this cost has significantly come down across the world. In New York, the number of hydrogen buses has also been increasing lately. Despite the competition from electric buses, hydrogen buses beat them on one critical item: the charging time. Electric bus fleet operators need to operate larger fleet in order to compensate for the charging times and charging depots occupy valuable space in a city as crowded as New York.

The other part of the transport sector, which started using a lot of hydrogen in the United States was long-haul transport. As soon as a few trucks models started to appear,[221] there had been buy in from a few key transport companies, eager to improve their green credentials. There was even a competition between drivers on who would have the funniest *"I drive a hydrogen truck"* logo. This adoption of trucks had contributed to bring their total cost of ownership (TCO) down to the level of diesel trucks before 2030, making the economic switch easier. Of course, these trucks needed to refill, despite their 800-miles operating range. Such a range is made possible by the use of liquid hydrogen, with the four tanks stored right behind the truck's cab. Meanwhile the refilling had been facilitated by the simultaneous development of hydrogen highways along specific corridors.[222] (See figure for an impression of the hydrogen truck.)

H_2 truck. Source: Wikimedia

Back to the future. Why the second hydrogen revolution succeeded

But I digress, as usual. I always tend to think about the transport sector first. Well, I did start my hydrogen career in 1999 by working for OEMs (Original Equipment Manufacturers), and I also married a car engineer. This brings me back ever down the memory lane. That was what people called "*the previous wave*" of hydrogen, the one which did not lead to a massive take-off of this energy vector. There was very little talk about electrolysis and its potential at that time. To be frank, I ran into hydrogen because I ran into fuel cells. People were talking more about fuel cells and how they could be used than they

talked about hydrogen. At that time, my job as a young engineer working for OEMs in Germany and then in France consisted in understanding the reforming process to produce hydrogen and trying to see whether we could have an on-board reforming system within a car. Looking back at my young self,[223] it seems almost crazy all the things we were looking back at then, and which did not materialise.

Fortunately for the world, the situation totally reversed in the late 2010s and on the way to COP26 in Glasgow. When I look back at the past 13 years of our hydrogen journey, I cannot prevent myself from marvelling at the progress we have made collectively. In 2020, the United States was consuming just above 10 million tons of hydrogen and was one of the largest consumers of hydrogen in the world, only second behind China. At that time, hydrogen was consumed mostly in refining and to produce ammonia or methanol. Besides, it was mostly grey hydrogen as we called it back then and therefore the source of CO_2 emissions. Around 80 percent of US hydrogen production was based on natural gas reforming. A lot was needed to convert that to renewable and low carbon hydrogen.

The early 2020s were a period of euphoria quickly followed by constructive realism about what was needed to build a hydrogen economy and increase clean hydrogen production, not only in the United States but elsewhere in the world. Back in 2021, significant funding started to be allocated to hydrogen, both in countries which wanted to use the fuel as well as in potential producers and exporters.

In 2021, the US government launched the first Energy Earthshot focusing on hydrogen. The target was to achieve a cost of clean hydrogen of $1 per 1 kg in 1 decade[224] and this has been almost achieved. And then the Bipartisan Infrastructure

Law dedicated $9.5 bn funding for clean hydrogen, including $8 bn with the target to develop at least four hydrogen hubs. But one of the most essential actions was taken when an agreement was finally reached regarding the hydrogen production tax credits that would support the uptake of clean hydrogen. It was really seen as critical to spur investments. What I always liked about the US approach was that it was colour-blind. In Europe, the priority was clearly put on green hydrogen, and by green I mean supported by solar or wind. At least, the US decided to focus on the carbon intensity, which gave a chance to blue hydrogen, while it also boosted the development of green hydrogen by reducing the cost of electrolysers and renewable electricity.

I remember visiting Plug Power's green hydrogen project in Western New York[225] back in the time it started. It was then one of the largest green hydrogen plants in the United States, with a 120 MW electrolyser powered by hydropower from Niagara Falls and producing 45 ton per day, or around 16,500 ton per year, a fraction of the hydrogen demand back then. It seems so ridiculously small now as we have reached a several GW electrolyser scale, but at that time, it was tremendous progress.

There has been so much work done to incentivize hydrogen demand as well. During the previous decade, we have seen a lot of testing for different applications, various segments of the transport sector, high grade industrial heat, power generation to complement renewables and some trials to blend hydrogen into the natural gas system. That has enabled a much faster development of hydrogen since 2030, which was not so different from what had been anticipated by some.[226]

Some American cities had been leading on both hydrogen and renewables since the very beginning. As New York state

developed renewables to reach 70 percent of its electricity by 2030 (they got there by 2031, but nobody is really going to complain), some hydrogen had been needed to provide flexibility to the grid. Using electrolysis, the green electricity was used to produce green hydrogen in order to manage the intermittency and store the high volumes of energy for later when demand would be higher.

* * *

As I was preparing to turn on my laptop to do some writing, my mind wandered on where hydrogen revolution took us by 2030s.

Demand for hydrogen has now really started to pick up strongly in the United States since 2030, like in the rest the world. The country is using a majority of clean hydrogen powered by a mix of solar, wind and even biomass and the demand for hydrogen has almost doubled since 2020. A large part of hydrogen demand is still in the "traditional" sectors, such as ammonia production. But demand has expanded beyond these sectors to entirely new applications. What surprised me most was the expansion to new use cases – as that path, detrimental to fossil industry – was not an easy one.

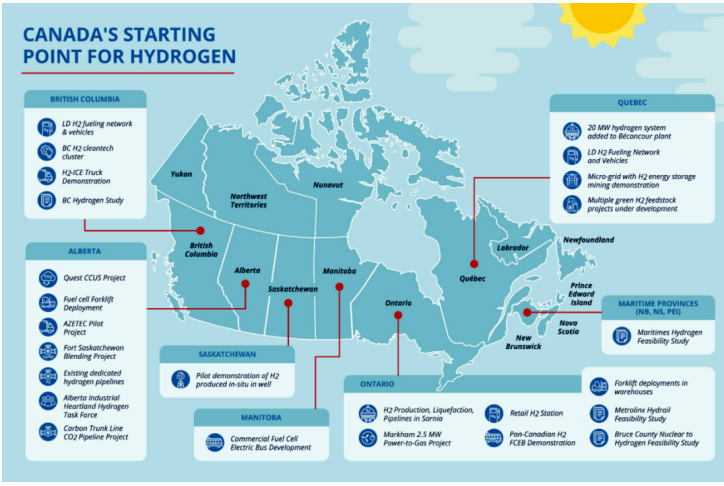
I am confident that we are now on the right path to decarbonisation.

Canada, 2040

Author: Robin Macpherson

Breaking the vestiges of carbon economy in air

I generally don't do very well in lotteries, or at least that is the reason I normally give to myself for not entering them. But something about the prize – the opportunity to be a passenger on the maiden voyage of a hydrogen powered flight[227] from East to West coast – piqued my interest, both because I love seeing the vast expanses of Canada from the air but also because it seemed exciting to venture out on what could be a real hope to break one of the last vestiges of the old carbon economy. But the flight wasn't just the usual Toronto to Vancouver shuttle that crisscrosses this enormous country multiple times each day, no, this was the Hydrogen Special Charter that would zigzag its way East to West, taking in all that has enabled Canada to become the hydrogen powerhouse that it is by 2040. See figure below for 2020s Hydrogen strategy graphic overview, as the inspired travel guide, offering a glimpse of my experience to come.



Canada hydrogen strategy bird eye view. Source: Hydrogen Strategy for Canada[228]

After an unusually short taxi to the runway (presumably we were given preferential treatment by the control tower given our maiden status!) the low hum of the engines powered by a mix of synthetic fuels[229] (one of them being a derivative of hydrogen) propels us forward and we are soon airborne and leaving the big city lights of Toronto behind us, as we set course North-East for Quebec and the wilds of Atlantic Canada.

Quebec. Green hydrogen, sourced in hydropower, helping in hard to decarbonise sectors

An hour or so into the flight, we come across the first of several huge hydroelectric facilities in Quebec and Atlantic Canada which forms one of the backbones to the Canadian hydrogen story. Built originally as pure power generators that could serve the province but also send renewable energy to the power-hungry US East coast, the advent of green hydrogen has seen the power diverted instead to industrial scale electrolysers. Using water and clean electricity the electrolysers produce green hydrogen for energy intensive long-haul trucking and mining operations – both sectors feature in the hard-to-decarbonise category which has enabled notable reductions in Canada's carbon emissions. Before heading in land, our flight heads South crossing over the St. Lawrence gateway to the Atlantic where plans are afoot to develop new port capacity to further use green hydrogen for export to the European, and Asian demand centers.

Ontario. Nuclear powered hydrogen powerhouse

Heading westbound we are soon back over Ontario. While the province may not quite be able to match neighboring Quebec for hydroelectric output, it more than makes up for it with emissions free nuclear generating capacity. Ontario has seized on green hydrogen production as a means to effectively combine ample freshwater from the Great Lakes with the surplus baseload output from the nuclear fleet to develop a regional 'Hydrogen Hub.' With close proximity to a number of demand centers both in Canada and the US, Ontario has

developed infrastructure to move green hydrogen to meet the needs for a range of end uses. Perhaps most significant has been the expansion of green hydrogen as a heat source and feedstock to the heavy industry in South West Ontario.[230]

Trucks winning the hydrogen prize in Prairies

Having taken all this in, we leave behind then urban centres of Ontario and begin our journey across the vast open spaces of the Prairies. Even here though there is evidence of the hydrogen revolution that has taken place as we look down and spot the occasional 'fast-fill' facilities that have popped up to support the long-haul trucks which run on hydrogen fuel-cells. While electric batteries have mostly won the day for the light-vehicle market, hydrogen has proved highly attractive for the high-energy consuming heavy-duty trucks where the alternative battery units proved too cumbersome. This, combined with faster fueling times for hydrogen has seen an ever increasing number of long-haul trucks make the hydrogen conversion, supported by a rollout of fast-fill infrastructure to meet the demand.

Alberta. Home of blue hydrogen

As the aircraft slowly turns North-West, the resource rich lands of Alberta come into sight and we begin to see the other side of the hydrogen revolution in Canada: blue hydrogen. Extensive natural gas reserves in the region meant that as soon as the carbon capture and storage technology was proven,[231] Alberta was an obvious place for blue hydrogen production. Favourable geology in the region provides good access to

salt caverns for the carbon storage and hydrogen (in separate caverns), which drives down costs and further improves the competitiveness of locally produced blue hydrogen. Once produced, the legacy of the oil and gas in the region means there is existing pipeline infrastructure which can be leveraged for shipping blue hydrogen to the West coast export terminals and other end users.

Vancouver. Final thoughts on creating green economy from vestiges of carbon world

After taking in the splendor of the Rockies - which never fail to amaze, no matter how many times I see them – the captain announces that we will shortly begin our descent into Vancouver, and the end of our maiden longhaul hydrogen powered flight. The sightseeing isn't entirely over though as we fly over several more hydroelectric facilities, now paired with electrolysers, which supply emissions free public transport throughout the region.

As we touch down I am in a reflective mood on what has been achieved with low-carbon hydrogen. Perhaps the most striking thought is how it has leveraged existing and legacy infrastructure with new technology to make such a significant contribution to the transition to a low-carbon economy, creating green jobs out of vestiges of the carbon world.

Australia, 2040

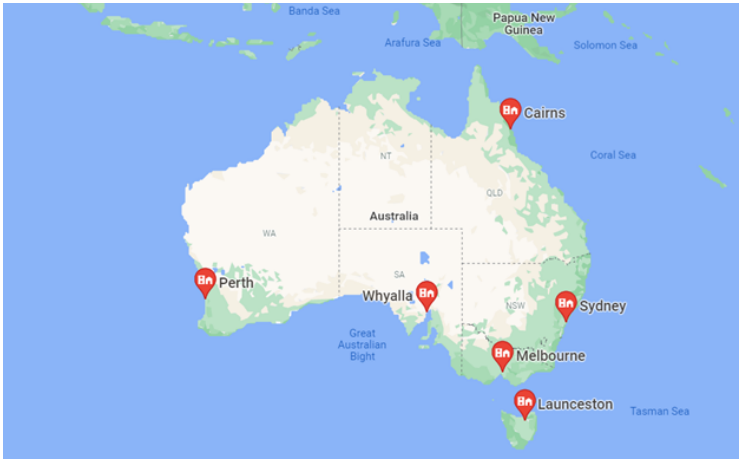
Author: David Sheipouri

Just a bit on Australia. Smallest of continents, 6th largest country

Our journey takes us all the way to Australia – the land down under. A continent of harsh, arid plains and gentle, embracing coasts. A mysterious land of deep, ancient connections with Aboriginal ancestors dating back over 40,000 years. An ecosystem of unique wildlife, from hopping Kangaroos to semiaquatic, egg-laying, duck-billed, Platypus – not to mention, all the spiders and snakes!

At 7,692,024 km^2, Australia accounts for five percent of the world's land area, is the smallest of all continents, the largest of all islands and the 6^{th} largest country. Things are a little different when it comes to population though. Ranked the 55^{th} country by population size, there are only 3 people per square kilometre of land in Australia – that's Iceland level of crowding. With this being said, much of the land is barren and 85% of all Australians live within 50 kms of the coastline, which may explain those golden tans. The figure below shows the journey we shall travel to the future, where hydrogen economy is a

reality:



Overview of the 2040 journey. Source: google maps

The Australia shaped souvenir clock of my grandfather. The guide to journey

It's 2040, we're only 10 years away from our net-zero targets,[232] and what a ride it has been. For some it was the best of times, and for others it was the worst of times. Much like 'A Tale of Two Cities', radical change and transformation was the only way anything could survive.

The COVID-19 era has become but a fleeting memory, taking with it policies and attitudes we would rather forget we held at all. No more hiding behind others when it came to 'Global Climate Change' forums. The time had passed when time used

to pass like that.

Australia was a place I always heard stories about as a child, so much so I felt like I had lived there a million lifetimes. My grandfather was one of the early engineers heralded as the founders of Australia's gas exploration and export boom in the late 1980's. He would never shy away from a good story. As he sunk into his equally tired couch, his hands, equally scorched as the ground he once tread, would reach over and grasp the Australia shaped souvenir clock sitting on the television cabinet. "*I have a story for every hour on this clock*" he would exclaim, life beaming from behind his magnificent green eyes. By the time I knew myself, I had all but felt the radiant beams of sun burning away at the back of my neck, all but surfed the most pristine of golden beaches, all but driven through the vast, red plains and all but bitten into the saltiest of Vegemite[233] sandwiches.

"*We made that place what it is today*" his voice only prouder when talking about the sacrifices Grandma had made for the family while he was working. A quiet confidence would roll into his grin, "*Worlds largest exporter of LNG! All they knew was coal and iron ore, coal and iron ore, occasionally gold, but always coal and iron ore. Sometimes copper, but always, always, always, coal and iron ore*!" He wasn't wrong, even in 2020 Iron Ore accounted for over 21% of Australia's total exports at $100 billion, Coal over 11% at $54 billion and LNG closely behind at 10% for $47 billion Australian dollars.[234]

The years passed, and the second-hand memories grew fonder, as I watched the hours on the clock turn to my 21st birthday. Mum had warned me that this year everyone pooled in some funds, and I only have one present to open. This had to be the first example of our family being able to agree on something, so I was equal parts excited and worried. "*Open*

it, open it" the crowd chanted as Mum handed over the oddly shaped present. Is this what it feels like to be on a game show? As the first bead of nervous sweet formed on my forehead I locked eyes with what I could only describe as a child at Christmas inside the body of a pensioner. He's behind it, I know it. The familiar grin rolling up his creased face, now nodding with persuasion.

Carefully, I pried the tape from the paper, making sure not to ruin the only present I will see this year. It's the clock. It's the clock? It's Grandpa's Australian shaped novelty souvenir clock, gifted to him by his Australian colleagues. Okay, that's an honour, but I must be missing something, the clock means much more to him as it does me. Maybe the card will tell me more? Seems thick…money? Okay, money makes sense. Just as all the ideas on what I could spend the money on flicked through my mind like a slideshow, out slipped the ticket. A ticket, on its own such a limp, lifeless product. No taste, no smell, no sound, and hardly a desirable texture. Australia! I'm going to Australia! I am going to, AUSTRALIA! Cheers broke out and the bead of sweat transformed into a welling up of my eyes, as if it had resorbed itself and found its rightful home.

A heavy hand rested itself on my shoulder, the grip – firm and familiar. *"I've made you a plan"*, in all the commotion I hadn't noticed Grandpa sneak up behind me. *"The clock, it will be your guide and with time, it will become the filling cabinet of your memories"* We spent what felt like a few minutes, discussing all the amazing destinations scattered around the clocks face, it seemed to disagree with us, striking midnight as if to mark a turn of the page into a new chapter.

-"I've let everyone know my grandson is finally coming and to take good care of you."- my Grandpa said.

-"Everyone? Who's everyone?"

-"My old Oil and Gas buddies, they're not all still in the same roles or in the same states but Australia has done well to use their knowledge – you might even learn something" Cue rolling grin.

Okay, Grandpa was well loved and well connected. This should be interesting.

-"Just follow the clock and tell them Uncle Paul sent you, they'll take care of the rest - Lord knows I've saved a few nephews in my time", he continued.

With that the adventure starts, just follow the clock – let's go! Airbus? Boeing? I hadn't even noticed; all I knew was that I was finally on my way!

Far North Queensland, Cairns. From diesel to a weekly hydrogen truck

My first stop is Far North Queensland, known more colloquially as The FNQ by the locals. Cairns airport is bustling with tourists, seems that UNESCO's recommendations in protecting the Great Barrier Reef is paying it's dividends.[235] Between all the tour bus drivers I see my name in big bold letters, BENJAMIN! Exhale. Sigh of relief, they didn't forget! A warm, friendly smile lights up his face. *"G'day mate! I'm Timmy, you must be Uncle Paulo's favourite grandson, Benny. Welcome to Cairns mate and watch out for the banana benders"*. If all I had to go by was his bellowing laugh that followed, I knew I was in good hands.

Timmy was overflowing with stories about the good old days, it seemed he had a special place for Grandad and their time on major LNG projects in his heart. *"That's all changed now, mate. We're all about green up here now – even the off-gridders have*

turned" He went on into colourful detail on how the coal fired power stations wrapped up their operations in Queensland with all the wind and solar farms being installed. *"They never had a chance mate; it was only a matter of time – they held on for a while, I'd give'm that"* as he stared out into the horizon. *"Once they got electrolysers and hydrogen storage to the right price it was practically game over from there."*[236]

It turned out Jimmy never shook the old days from his heart, perhaps why he held Grandad to such high regard. With coal-fired power generation becoming too expensive to continue, the Australian Government kept the industry alive with subsidies over the years.[237] This was only until energy storage was at a scale ready enough to take over. From there any time the wind stopped blowing or the sun stopped shining, it was covered by hydrogen. Even remote communities switched the diesel delivery truck with a weekly hydrogen truck, turning up to top up their hydrogen reserves until they had enough renewables and storage to be truly independent.

"We're not getting outages no more and my clothes don't stink of diesel, so that's a win" His laugh this time forgetting to bellow. Although Timmy was a huge asset to the transition away from fossil fuels and they consulted with him for decades, it seemed the familiarity of a bygone day was hard to shake.

I was taken by Timmy's experience, it seemed time and tide waited for no man and even something so astonishing as the transition in Queensland, took with it a silent casualty. It was time to follow the clock that also did not wait, this time New South Wales!

New South Wales, Sydney. Blending natural gas wealth with green hydrogen

Landing in Sydney I was welcomed by Michael, not as colourful this time. Michael was a Financial Manager on projects Grandad worked on and it turned out they didn't always see eye-to-eye. *"He was a larger-than-life character, occasionally even too large for his own boots"* his tone of voice unchanged throughout the entire monologue.

"Times change, Benjamin – everything has an expiry date, even you and me. It would only be an obscure act of wilful ignorance to think otherwise". If I called him calculated it would have been an understatement. His stories meticulously broke down every step he took in navigating the energy transition his industry had faced with surgeon precision. *"Yesterday I was presenting exploration figures to investors, promising them all the wealth the Earth concealed, today I'm presenting investors models to dilute that same wealth with green hydrogen."*

For Michael it seemed ever increasingly obvious that his business of blending hydrogen was a matter of pure economics. When the renewables were producing more power than the consumers were using, his solar and wind farms would divert the energy into electrolysers. The electrolysers produced the hydrogen and instead of needing to store it at a central location, he would blend it into the natural gas pipelines. Helping save the environment was, for him, a side effect.

"275 petajoules, peta – that's a trillion times kilo, 275 trillion kilojoules. That's how much natural gas storage is available on this great country. More than all the gas every house and business in Australia uses in an entire year."[238] He went on to describe how he influenced an entire nation into accepting blended hydrogen

into their household and into their appliances, made fortunes by balancing the electricity market whilst securing gas supply to Australia.

"My next target is the aviation fuel industry. I'm going to blend them too. My hydrogen is worth far more per kilogram that way, and I will get paid to take the CO_2 from prehistoric businesses still handling fossil fuels. Once we create the aviation fuel from mixing my hydrogen and their CO_2, we can sell the responsible flying dream."[239] It was calculated, the details were colder than the first plunge into a swimming pool on a summer's day, but once your hair was wet it started to make some sense. Michael was an industrious man, where there was money to be made, he was there. For the sake of the environment, we were lucky that making money was a side effect. Time was ticking and we had to move – next stop, Victoria!

Victoria, Melbourne. Place of hot fashion, fine coffee and converted oil & gas rigs

Now 2,950 kms, as the hydrogen fuelled plane flies, away from my first stop in Australia – there were 3 differences I noticed immediately in Melbourne – weather was cooler, fashion was hotter, and an intoxicating aroma of the finest coffees, seemed to swirl around me like the southern lights – Aurora Australis!

Abraham was at the gate, as promised. He'd arrived 2 hours before I was scheduled to land in case something happened… His build was slight and his stature strong, forged from the beating of a laborious life. *"Benjamin, finally mate, I was a minute away from calling your Grandad!"* Abraham, or Abe as I was instructed to call him, was an astute man, alert as a fox at mealtime. All his years as a Safety Officer on major projects

around the world had raised his resting vigilant level to Meerkat status.

"He always knew what he was doing and had a funny way of getting anything done, regardless of the years he took off my life in the process" as a fondness relaxed the muscles in his neck. *"You wouldn't get away with half of what your Grandad used to get away with, these days – that's all I'll say."* 10 minutes later he proved it wasn't all he would say, and the next 3 hours confirmed it. *"But that's all in the past, our systems are so protected now that you couldn't flush a toilet twice without an executive order from the UN General Assembly."*

Abe found himself in an interesting position over the energy transition, his extensive experience on oil rigs and on renewable energy projects meant he was a shoo-in for his role. *"We took all the Oil and Gas assets that I worked long and hard making sure were built to the highest standards and converted them to be clean. Offshore oil production platforms turned into wind turbine platforms,*[240] *crude oil storage tanks now hold liquid organic hydrogen carriers*[241] *and gas compressor stations now refuel hydrogen cars, buses, trucks and boats."*

Interestingly, Abe failed to mention was he was awarded a Medal of the Order of Australia (OAM) for his service to the energy industry, both for building the original fossil fuel exports and transitioning it to where it stood now. Perhaps it had something to do with the $75 billion Australian dollars he saved the Government at the time in decommissioning liabilities[242] – one can wonder.

From the world's largest island to the 26th largest, we are off to Tasmania!

Tasmania. The world hub for producing e-methanol as a game changer

Landing in Launceston airport I was surprised and a little confused by the amount of advertising space that energy companies had invested in. Every possible square centimetre was another company touting their latest project, in a rather polite and silent yelling match.[243]

This time I was greeted by Franz, strong handshake, strong moustache, and strong appetite. *"Hello, and welcome and good afternoon, Benjamin. It is remarkable to see you and fantastic you could make it all this way to visit. Please come with me in this way"*. His polite manner was oddly confident and disarming.

"You have arrived in the worlds most foremost green energy and chemical hub ever created on the face of this wonderful planet, we take very much pride in our works and are very hardly working for the future of our great, great, greatest grandchildren." The unwavering facial expression underlining how serious he took his assignment.

Franz was brilliant, if you missed it from his aura, the room dedicated to awards and medals in Chemistry would fill you in. *"Your Grandfather is very much in my thoughts every day, without his belief in my work I would not have achieved half of this, even in two lifetimes. The old industry helped us understand, moved us out of the dark. Once we understood and could see, it would only be foolish to continue in the same way – for sure I am not washing my clothes by hand, this is the same. We must continue to use the tools we have now found in the light! Can you for even one moment imagine where this can take all of us? You could be Batman, Spiderman, Superman, whatever-man, Übermensch*[244]*, who knows – no body, but it is our moral obligation and duty to light the candle for those*

who may follow, as those before us have lit for us."

Rare was it, that the man of many words was also the man of many actions. Franz pioneered the basis to commercial scale capture of Carbon from the atmosphere.[245] Pairing his technology with green hydrogen produced by Tasmania's abundant hydro power meant they could produce a synthetic version of Methanol without any fossil fuels, e-Methanol. This not only changed the game, but it also changed how the players played. Hydrogen was now transportable, in the form of e-Methanol. Ships now had an option to consume a green fuel, in the form of e-Methanol. Inks, solvents, resins, adhesives, and dyes had an option of using green raw materials, in the form of e-Methanol.[246]

As it was built, so they came. Consumers no longer wanted their products produced by fossil fuels, nor did they want their products shipped around the world on fossil fuel burning ships, thus pulling the e-Methanol and atmospheric Carbon capture industries through with their demands.

If I stayed any longer in Franz's intoxicating company, I wouldn't have left – his passion, conviction and intentions meant his results would never amount in failure, but only varying levels of success. Our handshake on departure was as much a farewell as an early congratulation, and with that we fly back to the main-land and into South Australia.

South Australia, Whyalla. Hydrogen brought jobs, and reduced risk of blackouts

Whyalla was the next stop, on this ticking tour. Andrew waited by the gate; I could tell it was him from the alternation between confident overcompensation and nervous stammer in his voice on the phone the previous day. Stand up, sit down, check phone, re-check phone, sit down, bite nail, stand up, check flight information screen, check phone, drink of water, sit down – this was my guy.

"Bennnnnjaminnnn, what took you so long, welcome, was the flight OK, the food is never good, I always eat before I fly, unless it's a short flight, then I would eat when I land in case I need to use the toilet and I don't have enough time because it's a short flight, even though I hate using the toilet on the plane, who knows who has sat on that seat, and that god-awful noise it makes feels like it's sucking the air out of the room. Anyways, are you hungry?" Okay, looks like I'll be doing the listening on this trip.

Through all the noise, it turned out Andrew was in Human Resources and had worked with Grandad in bringing the required talent to Australia in the early days while developing the local education curriculum to meet the industries requirements. "*I don't know how I always find myself in industries that are going through ridiculous amounts of change, it's like can't you just sit still for a second? Are you trying to make my life difficult? I just want an easy life. Anyways, it pays the bills*." Yep, more listening.

With all the changes in the energy industry, hydrogen had not only progressively become more available and more cost effective than burning fossil fuels, consumer demand, much the same as the situation with e-Methanol, had forced the industry to change its way. Hydrogen was now used to reduce the iron

ore back to pure iron metal.[247]

"Our first step was to make sure everyone knew this didn't mean they would lose their jobs; it actually meant the plant would be upgraded and increase its output and there would be more jobs. Then we took all the people we had and offered them up-skilling, this meant that we had people who already knew the rest of the plant and only needed to be trained a little, delta-training. Most people went with that. The next step was to fill in any gaps of staff with local, national, and international employees.

We're lucky the energy industry did a good job in influencing educational curriculums to meet their requirements. The effect was twofold, the more the hydrogen economy gained momentum the cheaper and more reliable our electricity also became. No more risks of blackouts! With the increase in our competitiveness, we then affected the manufacturing industries, and they love us to no-end now. It's a true win-win-wind-windsor-window-winter-wingardium levi ohhh saa. Anyways, everyone's happy."

Happy that everyone was happy, I took my happy self to the happy airport and on to the next happy destination. Final stop, Western Australia – The Wild West.

Western Australia. "Go green or go home" is now a bumper sticker here

With a land area accounting for 32.9% of Australia,[248] it would be ranked 11th in the world by size if it were its own country, and isn't so from lack of trying by the locals.

This time I was being picked up by a limousine, my guide was too busy guiding his business. Chauffeur, complete with white gloves and black hat, I could get used to this. *"Any guest of Swiggy Norris is certainly a guest of ours"* he calls out,

as he watches for my response in the rear-view mirror and recognises the contemplative look on my face. *"And don't mind the coasters, Swiggy loves to put his face on everything."* 20 minutes of enduring the piercing looks and we arrive at what looked like an enormous cucumber protruding into the sky. *"Welcome to the big pickle"*, okay I wasn't that far off.

I'm escorted into a high-speed elevator and whisked to what I imagine to be the stem of this magnificent vegetable, ears popping like corn kernels. The doors slide open into an open plan, no office cubicles, no partitions, one long, long table, chairs to suit and one man pacing back and forward, on the serving end of a very robust telephone conversation. The longer it went on for the more air was sucked out of the room, as if he was chastising Andrew's airplane toilet. No sooner was the call over than the grin I had come to memorise in the limousine was firmly back in its place.

"Benjamin, welcome and please excuse the ramblings of an old man. Sometimes even our closest confidants mistake a garden path with a green one. Simple error happens to the best of us – just have to nip it in the bud." Swiggy was a hospitable man, until he wasn't. I was lucky enough to be the grandson of the man who convinced him to enter the energy industry at precisely the right time, as it started to turn away from fossil fuels. *"I owe a lot to Paul, there's a man that can take a dressing down and understand it without taking it to heart. Everyone inside and outside this pickle is better off for it."* Turns out Grandad had his finger on a few pulses and knew the right people with enough courage and conviction. Also turns out that his final mark on this beautiful land was to instigate an evolution so great it revolutionised and eventually replaced the very industry he was heralded to have helped build.

"Go green or go home – I'm having bumper stickers printed

as we speak. I began by converting everything I own to run on hydrogen and its derivatives, and I have a lot of stuff – trust me, the diesel sales guys loved me. Mining trucks, converted. Power generation, converted. Bulk cargo trains, converted. Bulk carrier ships, converted. It wasn't enough though, we needed to get serious, we needed to scale it up, sell it overseas and reduce our costs per kilo."

Swiggy did exactly as he set his mind to, he gave me a rundown of the last 20 years and how he persistently lobbied and inspired the change Australia needed. *"We went from exporting natural gas, your Grandads fault by the way, to exporting synthetic natural gas. All we did was combine hydrogen, green of course, and carbon we already had laying around, no ridiculous holes in the ground. That was fun, seeing the oil and gas codgers squirm in their seats. Then we combined hydrogen with nitrogen, plenty of it floating around, and made ammonia – no one asked for whom the bell tolls after that*." Harsh, but someone had to do it.

As the clock ran out of hours, it was time to bid this most amazing of lands and most brilliant of people a farewell. I would leave, owing the magical lands of the Northern Territory a well-deserved exploration at another time. I wasn't expecting at all to learn what I did, but it showed me that with every change there was an opportunity and no matter who you were or what you did, growth was an uncomfortable process.

As the planes wheels lifted for the last time, so my mind wandered: *"For some, the opportunity of growth didn't start until it was more uncomfortable to stay still than to move. For others, growth was the only option and they knew to jump well before they were pushed. As for the politics of it all, let's just say that Australia went from being pushed to being the pusher."*

Japan, 2030 - 2040

Author: Dan Shulman

Christmas reflections on the hydrogen economy of Japan of 2030s

It was December 2040, and I was sitting by my small Christmas tree here in Tokyo and reflecting on the progress of the hydrogen economy in Japan. It was warm and cozy in my beautiful but modestly sized lodgings. (See figure below for an impression.)

Lodgings impression. Source: Author

My mind wandered:

Hydrogen in 2039 Japan

"From the beginning of the 2020s, soon after the Japanese government committed to carbon neutrality by 2050, it established hydrogen and ammonia as pillars of the new strategy to reach its environmental goals. The whole hydrogen supply chain was, however, close to nonexistent and, despite numerous announcements, progress on this front has been slow. It is now 2039 and Japan is still slowly rolling out its hydrogen plan. By now, hydrogen is beginning to be used in co-firing in thermal plants, as well as in industrial processes such as the production of steel and fertilizers.

Most of the hydrogen is imported from Australia and the Middle

East, with local production only in remote, sparsely populated areas. From the beginning, the Ministry of Economy, Trade and Industry (METI) had planned to import most of the required hydrogen. In order to develop the supply chain, the environmental value of the hydrogen and ammonia was not the priority at first and grey hydrogen found its way into Japan. Paris Agreement implementation and policy makers continued to influence the landscape, and you've seen for yourselves how things played out."

I still remember how Erik asked me to write something on the future of hydrogen, and I hesitated as I was slightly skeptical of how fast the hydrogen economy would really take root, and knowing how complex it is to design the correct incentives for industries to act, but I agreed nonetheless. My mind wandered again.

Back to 2021 and the original hydrogen strategy from METI

"METI had planned for hydrogen use to increase to 3 million tonnes per year by 2030, up 50% from 2 million tonnes at the time of the hydrogen strategy publication in 2021. This was followed by a 20 million tonne target for 2050.

The 2030 volume target was met, supported by generous subsidy programs such as the $20 billions 'Green Innovation Fund' (GIF),[249] *which financed pilot hydrogen production and utilization projects. By end-2021, the GIF had already allocated $3.4 billions to two major projects that will help create a large-scale hydrogen supply chain and develop hydrogen production through water electrolysis.*

While volume was achieved, METI's hydrogen price targets proved more difficult. From 100 yen per normal cubic meter in 2021, METI expected the hydrogen price to fall by more than two thirds, to

30¥/Nm³ in 2030 and further to 20¥/Nm³ or less in 2050 - below the natural gas cost forecast. It has been particularly difficult to achieve these numbers for CIF 100% "green" hydrogen.

METI's plan also placed targets on the demand side of the supply chain with the development of 1,000 hydrogen stations for mobility in 2030; 800,000 fuel cell vehicles in use by 2030 and 2-3 million by 2040; 1,200 fuel cell buses by 2030; 10,000 fuel cell forklifts by 2030 and 5.3 million residential fuel cell units by the same year."

I was reflecting that, yes, incentives (grants and subsidies) do work to make the world move forward with plans, but still, markets have minds of their own. My mind wandered again – guided helpfully by my experience in business consulting - following the various sectors where the hydrogen economy was now 'touchable'. My mind landed first on 'power generation.'

Hydrogen and ammonia in the power generation industry

"Japan had traditionally been heavily dependent on coal and gas for baseload power, and 40% of its power still came from these fuels in 2030. Rather than replacing this capacity with non-dispatchable renewable energy, Japan focused on reducing carbon emissions by mixing hydrogen and ammonia with gas and coal in its thermal plants. Companies like Mitsubishi Heavy Industries, Kawasaki Heavy Industries and IHI started developing co-firing turbines in the early 2020s.

For example, in January 2021, MHI jointly conducted an experiment with The National Institute of Advanced Industrial Science and Technology (AIST) and achieved stable combustion of 1005 hydrogen with a single-cylinder engine.

Momentum slowly built up, and in 2025 the first 30% hydrogen

co-firing turbine was commercialized, and in 2030 large-scale 100% hydrogen-fired turbines were available. This technology was partly the result of the experience of Japanese industrial firms' involvement in foreign projects. MHI had been involved in a project in the Netherlands to convert LNG-fired Nuon Magnum Power Plant (440 MW) to a 100% hydrogen firing plant. In 2025, MHI had provided a turbine for a 840 MW gas plant co-firing 30% hydrogen in the USA.

Nevertheless, the adoption of hydrogen and ammonia in the power generation industry was slow. By 2030, only 1% of the power mix came from these fuels. In the following years this number only slowly increased, with opposition to hydrogen from both politicians and the business world, which have questioned the environmental value of the technology. Green hydrogen is still not available in Japan at the price and scale that would be necessary to fully convert Japan's fossil fuel generation fleet and keep costs below 17¥/kWh (the original 2030 target from METI's plan). Many have argued that given the limited time and resources that Japan has to meet its environmental goals, other options might prove more efficient to decarbonize the energy mix whilst staying in the 3E+S framework[250] *defined by METI."*

The reflection of candles played in the windows; power generation was providing some light, and clean hydrogen was powering some of the turbines doing. Who could have imagined it? (See below for an impression of lighted city):

Lighted city impression . Source: author's photo

My mind moved on to 'mobility.'

Hydrogen and ammonia in the mobility industry

"Despite ambitious goals, individual fuel cell vehicles did not develop as expected. In 2021 there were 3,800 hydrogen cars in circulation in Japan and 162 fuel stations. The targets of 200,000 FCVs by FY 2025 and 800,000 FCVs by FY 2030 were not met. The price premium to electric cars did not erode, and more importantly the lack of a supporting infrastructure did not favor hydrogen cars. The incentives to push the adoption of electric vehicles, with their increasing role in the balancing of the grid and the emergence of new business models for vehicle-to-home and vehicle-to-grid after 2024, disrupted the adoption of hydrogen cars. The development of hydrogen stations

was slow from the beginning. By 2025 approximately 320 stations were developed and this number increased to 900 stations by 2030. The original plan was to stop government subsidies by the second half of the 2020s but the lack of demand made this option unrealistic. The lack of scale did not allow for the cost reductions expected and the construction and operating costs failed to reach the JPY 200 million and 15 million JPY/year expected by 2025.

However, while unsuccessful in the passenger vehicle market, hydrogen proved more successful in haulage and other long range, heavy vehicles, particularly in low density markets. In 2021 Tokyoites could already board one of the 104 hydrogen buses available in Japan. But today, it is places like Hokkaido that have really taken to the technology. The original 2030 target of 1,200 buses set by METI was met and the market has kept growing since. In these remote, low population density areas with few charging stations, the superior range of the hydrogen buses and trucks is a real advantage.

The cost of hydrogen buses decreased rapidly from about 105 million JPY each in 2021 to 52.5 million JPY by 2030, when government subsidies were stopped. Since then the market has grown steadily without subsidies."

A nice song in the background briefly caught my attention – Christmas radio was reaching its peak. I enjoy taking the bus sometimes (and it was a hydrogen powered bus now.) I didn't mind that my car was electric – heavy duty transport always looked to be a better option for hydrogen than personal vehicles. My mind wandered next to 'how we make things'.

Hydrogen and ammonia in the steel and chemical industries

"In December 2021 METI released a technology roadmap for the chemical industry to reach carbon neutrality by 2050. On the whole, this has proved accurate, with the necessary R&D and pilot projects being financed by the 'Green Investment Fund' in the 2020s as predicted, supported by study groups from major industry players such as Idemitsu, Iwatani, ENEOS, Nippon Steel, Mitsubishi Chemical, Air liquid and others.

In the early 2030s, steam methane reforming was partially replaced with imported greener hydrogen. A few years later ammonia was used as fuel to power naphtha cracking furnaces.

Green hydrogen is also the basis for green methanol and other new low carbon industrial applications. In steel making, hydrogen reduction is still in the early stage of application at Nippon Steel. Nippon steel has spent several billion dollars in the past two decades to develop and apply this new technology and is now building the first equipment. It expects to spend several more tens of billions of dollars on CAPEX. The technology is an important element of its decarbonisation vision for 2050, published in 2021. Green imported ammonia is also now readily used in the production of fertilizers in Japan."

Christmas started banging on the door in the form of noise from my next-door neighbors' my home - lots of materials used, or consumed (e.g. in my fridge), were now in fact made with clean hydrogen behind them. What a hidden but interesting change. It was time to remember how the supply of all this 'greatness' came about. My mind wandered once more.

Hydrogen and ammonia supply

"Looking back, it was clear from the initial green growth strategy and revised hydrogen strategy published by METI in 2021, that the Japanese government was relying on imports to cover the vast majority of its hydrogen needs.

Already in the 2020s several consortiums were developing pieces of the supply chain to bring hydrogen to Japan. Sumitomo, Chiyoda, Toyota and other members established a hydrogen import hub and distribution network in the Chubu area. ENEOS and Kawasaki city did the same for the Kawasaki waterfront area. Kawasaki Heavy Industry developed a liquid hydrogen carrier ship and joined forces with Iwatani Corporation, Shell Japan, and J-Power to pursue a liquid hydrogen supply chain.

Major Japanese players such as Iwatani and Mitsubishi Heavy Industries have been investing in hydrogen (brown and green) production projects in Australia since the 2020s and are now importing the fuel to Japan. The Kobe hydrogen terminal is one of the major hubs.

The Middle East is the other major partner in the Japanese hydrogen supply chain. By 2021, METI had signed a memorandum of cooperation with Adnoc to encourage cooperation in the field of fuel ammonia (blue and green). The same year Eneos signed an MoU with Saudi Aramco to consider development of a CO_2-free hydrogen and ammonia supply chain. These partnerships have been key to building today's imports of hydrogen from these countries.

Japan has also managed to develop some domestic hydrogen/ammonia production capacity. Companies like Asahi Kasei started to commercialize hydrogen production equipment back in 2025. The company scaled up operations and managed to drive production costs down to 330 yen/kg by 2030.

There has also been progress in producing hydrogen in remote locations where local renewable power is available and transport costs make bringing in hydrogen expensive. In the 2020s the 'Green Innovation Fund' financed R&D projects that supported local distributed generation capacity. It all started with pilot projects such as the one conducted by ENEOS and IHI who, in 2021, began development of hydrogen production in Fukuoka Prefecture. The project made use of IHI's energy management system to control multiple renewable energy power sources simultaneously. It was conducted under a public-private partnership with the Ministry of Environment's supervision, and the involvement of the Fukuoka prefectural government and of several cities. Around the same time, Hokkaido EPCo and Nippon Steel Engineering began a similar project in Ishikari City, Hokkaido, with the aim of producing hydrogen from offshore wind (under NEDO subsidy). The task was daunting as initially green hydrogen production costs were more than 3x higher than imported grey hydrogen. Today, after a cost reduction of 50%+ of both CAPEX and OPEX and the optimization of energy management systems to maximize the use of intermittent renewable power, the production of domestic hydrogen is competitive with imported alternatives."

As I emerged from my reverie, I tried to pull the thoughts together before departing for my neighbors' Christmas party. Today hydrogen is well integrated in the heavy industries and in remote areas with low population density. To reach this point in Japan the CIF price fell by almost 80% and strong political ties and joint investment with exporting countries was required, beginning in the early 2020s. Hydrogen has found its most victorious niche with buses and trucks in remote, low population density areas, not with personal cars. EVs have proven more attractive in most areas, due to cost advantages

and a lack of hydrogen fueling stations, as well as the integration and monetization of electric cars in the power system.

I had to admit to myself that the CO_2 value ($CO_2e/kg\ H_2$) of the imported hydrogen is still an issue, and each source has a unique level - which affects the degree of decarbonisation at end-use. For example, co-firing of hydrogen at thermal power plants has made limited progress because of cost disadvantages and a lack of an effective carbon price until the mid-2030s.

Japanese green hydrogen production is cleaner and costs continue to fall, but until recently, it had remained at a relatively small scale due to the limited availability of renewable energy. The latter did worry me as a citizen of the world and keen Paris Agreement fan. But since 2035, as the offshore wind sector has begun to grow in earnest, increasing volumes of surplus green wind power have provided a boost to Japan's green hydrogen sector, driving down power and hydrogen production costs at scale.

As the Christmas celebrations raucously continued, I felt hopeful for the hydrogen economy in its next decade – admittedly, racing much more slowly to its grand finale than many had anticipated in the 2020s.

China, 2030

Author: Joachim von Scheele

From Biggest in Grey to Biggest in Green

It's January 2030, I am about to land in Beijing. Skies are clear. I remember my Christmas prediction of 2021 that for China by 2030, the green hydrogen would have reached about 5 million tonnes with a corresponding electrolysers capacity of about 80 GW. It's particularly supporting industry and heavy duty transport. And, it (hydrogen economy playing a role in China) looks to be happening according to my hydrogen community friends who invited me over for a professional seminar. My thoughts wander back to winter of 2021/2022. I vividly see my computer screen of my laptop 9 years ago of my 'hydrogen going to be big in China', as my mind dozes off as airplane reduces speed. The mind races through its pages, here we go:

My 2021 speech. What role will hydrogen play in transition?

China is the world's largest emitter of CO_2 accounting for approximately 30% of the global CO_2 emissions. Since year 2000 more than 60% of the increase in global CO_2 emissions have taken place in China despite a 40% decrease in CO_2 intensity in the Chinese economy during that period. More than 80% of the CO_2 emissions in China are attributed to two key sectors, power generation and industry; the corresponding figure for the EU is 55%. In September 2020 President Xi announced the 30-60 climate goal, which means a commitment to peak China's CO_2 emissions no later than in 2030 and to become carbon neutral by 2060. This is of course an enormous challenge to fulfill, which also has been pointed out by President Xi. Will this even be possible to achieve? And what role will hydrogen play in this gigantic transition?"

My mind is briefly back in 2030 – yes, policy matters. And off to 9 years ago laptop screen again:

The policy framework

The 14th Five-Year-Plan (14FYP), for the period 2021-2025, was launched in March 2021 clarifying the fundamental changes required in the Chinese energy system, which will rely on four key pillars:

1. *Improve energy-efficiency both related to production and use*
2. *Electrify industry and transportation sectors, in conjunction with decarbonisation of electricity supply*
3. *A green energy supply by increased use of renewable sources and natural gas, and a significantly reduced use of coal*

4. *Strengthen research and innovation related to energy production and use.*

In April 2021 President Xi said that China will strictly limit the increase in coal consumption over the 14FYP and decrease it during the 15FYP. This implies a strive to have the peak in coal consumption already in 2025.

To increase sustainability and reduce carbon footprint the following general hierarchical approach based on efficiency, is principally applicable everywhere:

1. *Increase the life cycle of the products – a year longer in use saves a year of emissions from production*
2. *Increase the recycling rate – usually less impact compared to using virgin inputs*
3. *Electrify wherever it is viable to electrify*
4. *Increase the energy-efficiency in processes that are not electrified*
5. *Replace a high-carbon containing fuel with a low-carbon containing fuel, and ultimately with hydrogen where that makes sense.*

Accordingly, it is important to note that use of hydrogen is not the first action to take. We can clearly see much of China's laid out framework follows along this general approach.

There are several factors supporting a successful Chinese transition to carbon-neutrality, for example:

- *The Chinese population is not growing much, but will be contracting during the coming decades, probably already before 2030.*

- *Large investments in infrastructure made over recent years will not have to continue at the same pace, which will reduce the need for cement, steel, etc.*
- *The focus on the domestic market rather than on export, which began already 15 years ago.*
- *The enormous increase of production of steel and other metals over the past 40 years, which to 80-90% has been based on virgin raw materials, can now to a continuously increasing extent be based on recycled materials – this will have a huge impact on reducing CO_2 emissions.*
- *Ongoing reduction of emissions from transportation: Expansion of public transportation; the subway systems in Beijing and Shanghai are already the two largest in the world, Leading in expansion of electric vehicle fleet, automotive assets utilization (China is already world #1 in taxi rides, with most of them ordered electronically and basically all electronically paid.)*
- *Being world-leading in Artificial Intelligence and Big Data, which supports creation of more efficient and optimized processes for production and uses.*
- *China is habituated to change; the Chinese people have huge experience in adapting to change, particularly over the past 3-4 decades."*

Again back in 2030, thoughts race to adaptability, ability to change – that always impressed me with China. That also happened in last decade with energy efficiency, dealing with volatile natural gas markets and electrification. Those 3 developments were the ecosystem success needed for hydrogen to be big in China. I jump in my mind back to my notes 9 years ago:

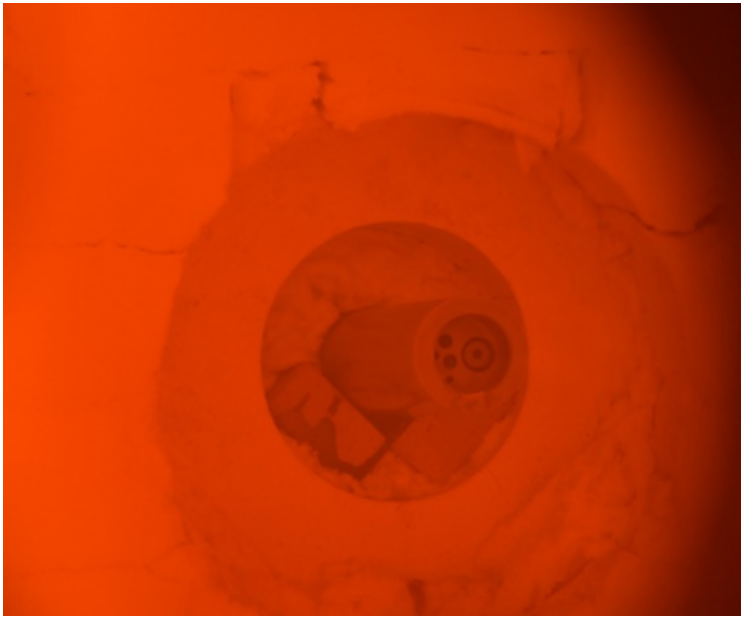
Making decarbonisation happen will need energy efficiency, dealing with volatile natural gas markets and electrification

"It is of interest to compare China to the US and to the EU. Two such parameters could be energy-use per capita, and energy-use compared to GDP ("energy intensity.") If we look at the per capita figures (2020) the US is at 266 GJ/head, and China at 104 and EU at 116. Accordingly, each US citizen is on average using about 2.5 times more energy than the average Chinese. But let us now also look at it from a GDP perspective (again 2020). The US figure is about 4,200 GJ/USD while the corresponding Chinese figure is 9,900 and EU's one at 3,000. To be on the safe side, let us apply 'Purchasing Power Parity' on the Chinese figure - we then get about 6,000 GJ/USD. Accordingly, in general terms we can then say that currently the US economy is at least about 50% more energy-efficient than Chinese, and the EU is at least twice as energy-efficient as China's. In other words: clearly there is room for improvements of the Chinese energy-efficiency, even more than in many other industrialized countries.

Let us just make a quick back-of-the-envelope check of what could be possible. Assuming the Chinese economy will grow with a conservative Compound Annual Growth Rate (CAGR[251]) of 2.5% until 2060, its GDP will then be 2.5 times higher than what it is today. Reasonably efficiency improvements in China until 2060 could make it reach an energy-use compared to GDP (energy intensity) same as EU has today (3,000 GJ/USD). That would mean that a richer China in 2060 would use 25% less energy than today. This is challenging, but doable!

In China there are more than 120,000 industrial furnaces in operation. The energy use in those furnaces accounts for more than 25% of the total energy use in China, and more than 60% of energy use in its industry. One of the proven ways to increase the energy-

efficiency here, is to modify the combustion system by using oxygen instead of air as the primary oxidizer, i.e., convert to so-called oxyfuel combustion. This would potentially result in a decrease of the fuel consumption and carbon footprint from those operations by 30% or more, and eventually with hydrogen as fuel eliminate it completely.



Flameless oxyfuel can reduce fuel consumption massively in many furnaces and other processes using combustion, and it is ready to use hydrogen as fuel. Source: Author

The Hebei province will screen out a total of 1,000 existing factories for replacement with less-polluting alternatives under 14FYP, and there are similar plans for each of China's 34 administrative areas.

Under 13FYP, concluded in 2020, Hebei reduced its installed cement production capacity by 12 Mt/y, which already has had a large positive impact as the cement industry is among of the top-3 industrial emitters of CO_2.For comparison, this reduction in Hebei equals shutting down all of Canada's cement production.

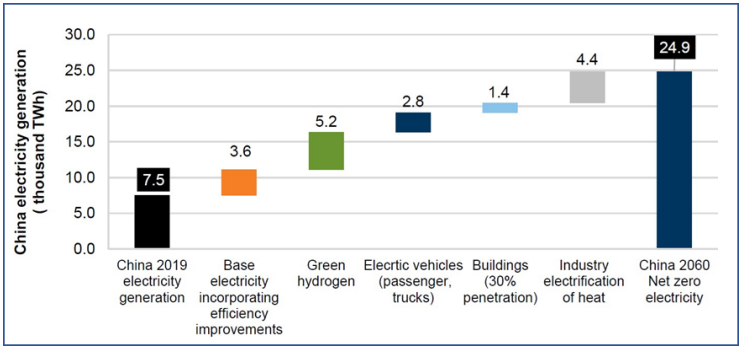
Another example is China's steel industry, today accounting for around 15% of the country's carbon emissions. There is now an ongoing expansion of China's electric arc furnace (EAF) steelmaking capacity, allowing for using 100% recycled scrap as raw material, which will have a large positive impact of the carbon footprint. China plans to boost EAF steel to account for 15%-20% of the total crude steel output by 2025, which is a doubling compared to last year. Eventually, more than 50% of China's total crude steel capacity could come from EAFs. In 2021, China approved the construction of 43 new EAFs, with a total crude steel capacity of 30 Mt/y. To put this in perspective, a 30 Mt/y output equals that of the 10th largest steel producing country in the world.

Today less than 20% of China's steel production is based on scrap. The 2020 figure of 260 Mt of steel scrap used is aimed to increase to 320 Mt by 2025. Assuming a similar addition of scrap use going forward and that the Chinese steel production will stay at around 1 billion tonnes annually, around 70% will be based on scrap by 2060. And assuming that all the balance would be supplied as Direct Reduced Iron (DRI) produced using hydrogen as reductant, those roughly 350 Mt of DRI would need 150 GW of electrolysers to produce the required 25 Mt of hydrogen. Adding 15 Mt to replace fossil fuel gases in combustion applications, we could then make China's steel industry "green" using 40 Mt/y of hydrogen. This would require a power supply at 240 GW.

It seems we can assume a considerable part of China's decarbonisation might take place without basically change fuels, but mainly

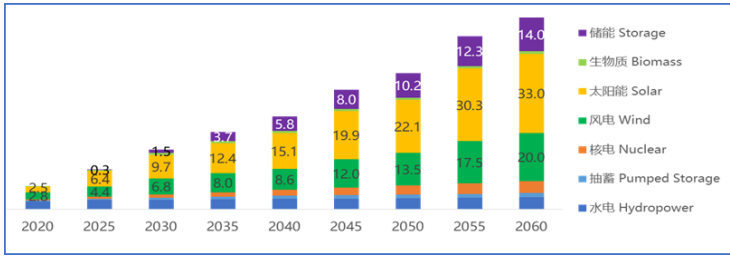
by increased energy-efficiency, less use of coal-based processes, electrification, etc. Then, still before going into hydrogen, there are two areas to touch upon: increased use of natural gas, and electrification. China has increased both its production and import of natural gas tremendously over the last years, and that trend seems to continue - now largely boosted by the decarbonisation agenda. The domestic natural gas production more than doubled from 2010 to 2020, reaching 192.5 billion cubic meters. The 2020 import reached 138.4 billion cubic meters, so altogether China used 331 billion cubic meters of natural gas in 2020. China's LNG import increased further to a new record level in 2021.

Electrification will play a central role in China's pathway towards carbon neutrality. Most forecasts indicate China's electricity consumption in 2050 could be doubled compared with the 2019 level, and even tripled by 2060, largely driven by transport, industrial sectors and applications of hydrogen produced from electricity.



A tripling of China's electricity generation estimated by 2060 (unit: 1000 TWh). Source: Author

An increased supply of non-fossil electricity is important for both electrification and for production for production of green hydrogen. The 14FYP and onwards, use of new and green energy will increase to become the main energy sources. By 2030 the non- fossil power installed capacity is expected to reach 2,300 GW, accounting for over 60% of the total installed capacity. It will further increase to 6,500 GW, accounting for at least 80% (sometimes even 95% is mentioned) of the total by 2060. To reach the goal of 1,200 GW of wind and solar capacity by 2030, as stated by President Xi at the Climate Ambition Summit in December 2020, it is estimated that as much as 5%-20% in storage capacity needs to be developed at the local level, depending on local renewable resources. The current prioritization can be seen from how China's finance ministry has set the 2022 renewable power subsidies: the allocated $607 million was distributed with 40% to wind turbines, 59% to solar power, and 1% to biomass power generators.



Forecast of non-fossil power installed capacity 2020-2060 (unit 100 GW). Source: Author

Since years, China is at the center of global supply and demand for renewable energy, accounting for about 40% of capacity growth from

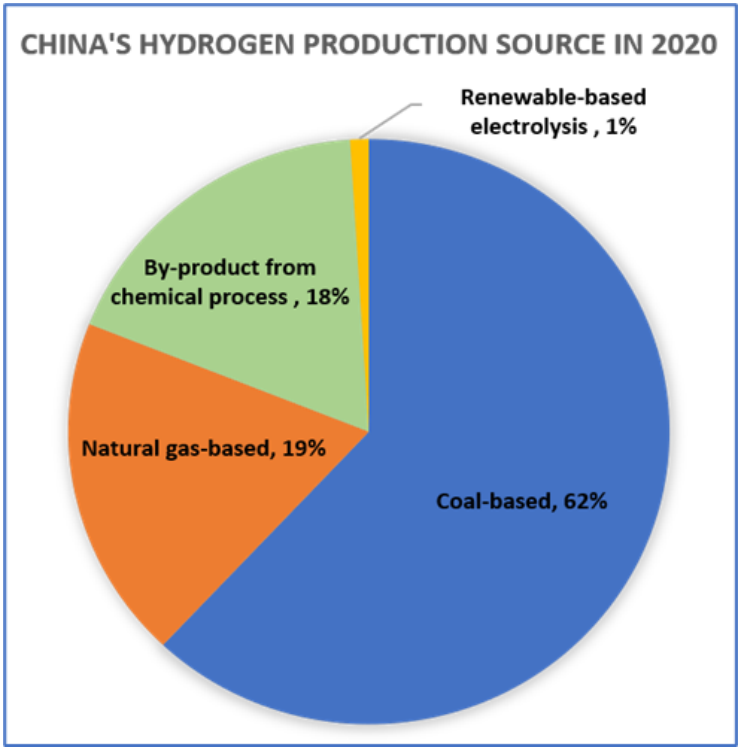
2015 to 2020. Naturally, electrification through renewable power will be the technology that dominates the 'low-cost decarbonisation' spectrum today, and it is believed it has the potential to support decarbonisation of more than 45% of China's CO_2 emissions and, additionally, support the production of green hydrogen. Similar forecasts for clean hydrogen estimate that to potentially drive 20% of the decarbonisation, playing a. a critical role in several industrial processes (iron & steel, petrochemicals, etc)., and long-haul heavy transportation."

Back in 2030, the pilot announces that she wants to take another tour through the airport approach, as we are a bit early landing – this allows me to see accidentally some of the hydrogen economy in action – we high over a highway, where I see some of the locally produced hydrogen-fuelled buses and trucks neatly travelling the road alongside electric personal cars. My mind wanders to my thoughts on hydrogen development in China back in those eventful early 2020s:

Hydrogen in China. By 2060, it may account for 130 million tonnes (about 20% of the energy consumption)

"China is the largest hydrogen producing country in the world, with an annual production of roughly 30 million tonnes. In China, cheap supply of grey hydrogen is abundant from coal gasification, catalytic steam reforming of natural gas and as by-products of chemical processes, such as partial oxidation of heavy oil. Production of blue hydrogen is still in an early developing stage, and production of green hydrogen has been limited. Green hydrogen production based on electrolysis contributed only 1% of the total hydrogen supply in 2020. However, this figure is expected to increase to 15% by 2030. Hydrogen production as an independent component (non-syngas or

in a mixture of gases) that meet industrial quality standards, what is normally referred to as merchant production, reached about 12.5 million tonnes.



Production of hydrogen in China by source in 2020. Source: Author

China is keen to develop its natural gas infrastructure. The current pipeline network for hydrogen is limited. It is unlikely we will see a large parallel expansion of a pipeline network for hydrogen, but rather a blending of hydrogen into the natural gas in the increasing

pipeline infrastructure.

The number of hydrogen FCEVs, mostly larger vehicles (busses and trucks) in China has grown rapidly since 2019, reaching over 7,000 by end of 2020. The number of FCEV is expected to reach 1 million by 2035. When it comes to hydrogen refuelling stations, China today has about 100, however, Sinopec alone aims to put up an additional 1000 during 14FYP. China's current vehicle fleet is about 300 million. Assuming it will increase to 500 million in year 2060 and 1% would be FCEV, that would mean 5 million FCEV. China today has 300 million electric scooters; it is unlikely fuel cell technology will compete much in that space.

China's 30-60 climate goal, together with China's ambition to accelerate its energy transition by increasing the total installed capacity of solar and wind to 1,200 GW by 2030 are the new policy drivers for China's green and high-quality hydrogen development. Specific targets for hydrogen development have been set up as an important component in China's short-term and long-term energy- and climate transformation.

To realise the high ambition of green hydrogen development, a large amount of renewable electricity of high quality at a competitive price will be a necessary condition, but also a key challenge. For instance, more than 70% of the cost of extracting hydrogen from water is electricity. It takes about 60 kWh of electricity to produce 1 kg of hydrogen. Assuming over 5 million tonnes of green hydrogen in 2030, means more than 260 TWh renewable electricity needs to be delivered. The critical factor is the electricity price, i.e., the scale-up of supply to meet all demands, not only for hydrogen,

Currently, average solar and wind on-grid prices are at $0.05-0.10/kWh in China. Estimates indicate renewable-to-hydrogen needs a renewable electricity price at $0.015/kWh to become competitive. The current production cost of green hydrogen in China is at

$3 per kg compared with just over $1 per kg for hydrogen from coal.

Up until 2020 the Chinese government had already invested more than $315 million in hydrogen energy and fuel cell R&D. In the 14FYP, increased financial funding will clearly target hydrogen production and research and innovation. China Ministry of Finance is planning to appropriate $125 million for hydrogen R&D in four technical areas: green hydrogen production, safety storage system, energy efficiency upgrades, and "hydrogen into ten thousand homes" demonstration projects. In those four areas, 19 research and innovation programs have already been launched in 2021.

According to China hydrogen Alliance, in 2030 China's annual demand for hydrogen will reach 37 million tonnes, accounting for about 5% of the final energy consumption. By 2030, the green hydrogen would have reached about 5 million tonnes with a corresponding electrolysers capacity of about 80 GW. Under the carbon neutral scenario in 2060, China's annual demand for hydrogen would then have to be about 130 million tonnes, accounting for about 20% of the energy consumption. At least 100 million tonnes of that will be green hydrogen, and most of the balance will be blue hydrogen. Industrial use of hydrogen will still be the largest accounting for 60%, while of hydrogen in transportation and building sectors account for 30%."

The pilot now firmly ask to fasten the seatbelts, and start being ready to get off the plane. I am thinking of what I will say at the seminar, if they ask me what I think on hydrogen role in China in last decade and going forward, as I will walk into the room full of students who are very critical and smart – I am practicing my response:

Hydrogen a vector in joint global village, not the sole or purely national solution

"Neither in China nor in most other countries of the world we have hydrogen as a sole solution today or in the coming decades.

Together with other ongoing sustainability trends – increased energy-efficiency and electrification which play large, and probably every year larger, roles. As elsewhere in the world, the key to a viable supply green hydrogen is a continuous viable supply of green power (or at least non-fossil power).

It appeared possible for China to make the enormous transition towards carbon neutrality, and hydrogen played and will play an essential role in that. And that is despite China which started in early 2020s from a position with comparatively low energy-efficiency, 30% of the world's CO_2 emissions, and – thought being the largest hydrogen producing country – a rather weak position in green hydrogen.

In first 20+ years of the century the world's wind power capacity has increased from 6 GW to 750 GW. A large part of this expansion had taken place in China, for example in 2021 having a capacity exceeding 300 GW. Looking towards 2040s ahead on green hydrogen, it is likely a similar development can be expected.

Remember students, how the journey with large-scale projects has started – Sinopec announced in early 2020s a 20 kt/y electrolyzer based on 300 MW solar power to be commissioned in Xinjiang in 2023. Remember the forecasts saying that more than half of the world's electrolyzer installations in 2020s onwards would be taking place in China. Well you know how this played out.

Reducing the carbon footprint continues to be a task for our joint global village, where China and all other countries contribute to our shared future. It seems China does, and will do its part, with

an important and huge of use of hydrogen across multiple sectors, and China will continue to transform from being the world's biggest producer of grey hydrogen to become the biggest producer of green hydrogen. Would you agree?"

Yes, I liked my speech to the students in the seminar – it was looking to be a promising day in Beijing.

* * *

Acknowledgement

The author is most thankful to Dr. Nannan Lundin and her colleagues at the Embassy of Sweden in Beijing and to Dr. Flora Kan and her colleagues at the EU-China Energy Cooperation Platform for their great support with input data.

Russia, 2040

Author: Irina Gaida

Russian 8 time zones of hydrogen & the Northern Sea Route

Life is good because one can travel

It is January 2040. I am reading a quote on one of posters in the train station "*Life is good because one can travel*" by a famous Russian traveller Przevalsky.[252] I just arrived by hydrogen powered high-speed train to St. Petersburg, which is a major hydrogen trading hub on the west border of Russia. Following oil, refined products and natural gas, spot and futures trade on hydrogen were introduced here as early as 2025 to facilitate both domestic and international hydrogen trading.[253]

I arrived to St. Petersburg from Kaliningrad, also a hydrogen hub, where first green hydrogen project was completed in 2024.[254] Later that day I will give a presentation reviewing how hydrogen economy has developed in Russia in last 2 decades.

I am reflecting both on Petersburg' and Russia's current role in global hydrogen economy, and the 8 time zones hydrogen economy trip across wide Russia that I have recently under-

taken with a group of friends. The cruise from Murmansk to Vladivostok took in total 23 days and allowed us to see some of the other (next to ones I already visited) major hydrogen hubs such as Yamal, Norilsk, Kamchatka and Sakhalin. My mind wanders first through the story of St. Petersburg as hydrogen hub, as I enjoy the fantastic views of Nevsky prospect.[255]

St. Petersburg hub

"St Petersburg became in last 2 decades home to a first turquoise hydrogen production plant, based on Russian proprietary hydrogen technology of pyrolysis of methane in molten metals and plasma pyrolysis. These technologies are now licensed to the producers across the world to provide low carbon hydrogen from natural gas or bio-methane.[256]

Building on nuclear, airspace and manufacturing engineering centers, which were always abundant in the city, St. Petersburg is now home to a major educational, R&D and engineering cluster. More then 500 students from all over the word graduate annually from H2University in technical and business disciplines of hydrogen economy."

I remember boarding the hydrogen powered cruiseship in St. Petersburg that took us to Murmansk[257] – the first port of the Northern Sea Route. What a great invention, the Northern route. My mind reflects what a great economic boost that provided, and how Murmansk hydrogen hub came about.

Northern route

"As a result of the climate change, the duration of navigation season on the Northern sea route has increased significantly and it became the shortest and fastest searoute for the shipment of goods between Asia and Europe.

The volume of goods (! not hydrogen) transported through that corridor has grown to 130 million tons (tn) goods in 2035 and now exceeds 200 million tn goods. From the beginning of the active development in 2020, this corridor was supported as a low carbon transport route with LNG powered vessels and nuclear ice-breakers. After the approval of hydrogen development roadmap significant share of shipping vessels was converted by ammonia, hythane (mixture between methane and hydrogen) and eventually to pure hydrogen. Now the Northern route is a driver of major economic impetus to the Russian economy taking part in global trade."

Murmansk hydrogen hub

"Murmansk is the first hydrogen hub of the Northern see route. It has two major production clusters – nuclear-power based Kolsk hydrogen plant, operated by Rosatom and a joint venture project between ENEL and Rosnano combining a wind generation and green hydrogen production. Kolsk project allows to export surplus power available from nuclear plant through the sea route. Domestic demand for power was declining and power lime construction was not a viable solution. Hydrogen export to EU market became a cost effective alternative after the implementation of EU "Fit for 55" and the "Gas decarbonisation package." While ENEL project was from the beginning targeted on export markets, the introduction of Carbon Border Adjustment Mechanism (CBAM) regulation significantly

increased domestic demand for the low carbon power and hydrogen and the project is now primarily targeting the needs of the local metals and mining industry."[258]

Murmansk . Open source

I continue to draft my notes for the presentation I am preparing, using my trip memories. Next stop, a harbour along Yamal peninsula[259] – so far away, so vast. And so interesting to see how it transitioned from its carbon past to a low-carbon future.

Yamal hydrogen hub

"Yamal is now home to Novatek hydrogen cluster. Novatek started experimenting with hydrogen as the way to reduce the carbon footprint of its facilities as early as 2021. It was the first Russian

company to install SIEMENS hydrogen powered turbines for power supply to its LNG plants[260]. NOVATEK strategy was to be world lowest carbon footprint gas supplier and YAMAL hydrogen cluster was part of that plan. Originally, hydrogen used was blue hydrogen - produced through steam methane reforming with CCS facility and storage in subsurface gas storage facility. Later, onshore wind projects and electrolysers were built to further reduce carbon footprint."

From Yamal, the tour along Northern route took us a to a nearby small harbour, connected to Norilsk[261], similarly to Murmansk an Arctic city. As my mind looks back to the cruise experiences, I started drafting again, busily remembering how Norilsk became a hydrogen hub.

Norilsk hydrogen hub

"Norilsk Nickel (world N1 nickel and palladium producers, and N3 global platinum producer) was one of the first companies to invest in hydrogen R&D program in Russia; first program was agreed with Russian academy of sciences in 2003.[262] Since 2003, the company has put significant efforts in both 1) decarbonising its own production assets and 2) developing one of the world largest clusters of hydrogen fuel cells manufacturing for heavy duty vehicles and railroad applications building on access to natural resources like palladium.[263] Large attention was also given to the development of innovative hydrogen storage solutions."

From Norilsk, back to the cruise ship, I remembered how the cruise boat arrived to Penzhin bay[264] passing the Bering Strait,[265] and then sailed further onto one of the harbours on Sakhalin islan[266] where the trip finished, and I flew back home to Moscow. I started scribbling presentation notes again, both on Penzhin bay and Sakhalin.

Kamchatka hydrogen hub – Penzhin Bay

" 'H2 Clean Energy' and RusHydro realised Penzhin Tidal Power Plant Project, which was originally developed in Soviet Union in 1980.

The tides in Penzhin Bay are 9 metres (30 ft) high, and reach 12.9 metres (42 ft) in the case of spring tides, which is the highest magnitude for the Pacific Ocean. As the area of the bay basin is 20,530 km^2 (7,930 mi^2), it corresponds to diurnal discharge of 360–530 km^3 (86–130 cu mi). This water rate is 20–30 times higher than that of the world's biggest river, the Amazon River. At the time, there was no demand for large-scale power generation in the region and long distance power transmission to export markets was not feasible. As a result, project was archived for over 40 years until 2020s, when export oriented hydrogen strategy was adopted by the Ministry of Energy.

The rise of demand for green hydrogen in South Korea, Japan and China created opportunity for electrolysis based hydrogen production in Kamchatka. By 2040 smaller project, North site with capacity of 21 GW electrolysis was launched and now bigger ones, with capacity of 87 GW electrolysis are in construction."

Sakhalin hydrogen hub

"Sakhalin hub was the final stop of the trip – far Eastern island of Sakhalin. In 2020, this was the first Russian region to declare goal of carbon neutrality (achieved in 2025) and launched an ambitious export-oriented hydrogen production program. Several hydrogen production projects were realised by consortiums of Russian and international players – SMR with CCS, pyrolysis (Rosatom, Linde, Gazprom[267]), wind-based electrolysis (Air Liquide, Rosatom,

Copenhagen Infrastructure Partners), biogas conversion to hydrogen from city waste, forestry production and algae. It was also the first region to build a greenfield "hydrogen city" – Ecopolis, where both transportation and utilities are hydrogen based."[268]

Conclusions. How carbon economy travelled to its decarbonisation through hydrogen

I was smiling. Life is good when you travel – albeit, it's even better if its hydrogen passion fuelled travel (Przevalsky didn't think of this.) It was going to be an interesting discussion at the workshop. I was looking over my notes on Russia's hydrogen economy development, and checking for any omissions. Yes, it needed some final thoughts. I felt that the magic rule of "3" key points could be appropriate here, as well. My pen started moving, and conclusions emerged:

- *"Hydrogen was a major driver of economic growth for several regions, helping the just transition across the economy and supporting economic development.*
- *Development of the hydrogen cluster in Sakhalin occurred ahead of other regions due to proximity to the key developing global hydrogen markets, which took 'technology agnostic' approach to hydrogen development (Japan, Korea, China), albeit later on pivoting more and more dominantly to low carbon hydrogen opportunities.*
- *Russian role in hydrogen economy is not only supplying low carbon fuel to the world but also supplying technology of low carbon hydrogen production and components to hydrogen equipment (e. g. electrolysers and fuel cells) on par with other leading hydrogen economies of the world."*

Uzbekistan, 2040

Author: Giuseppe Grimaldi

Pictures from Uzbekistan hydrogen economy in 2040

It is 20th of March 2040, we are in Tashkent the capital of Uzbekistan.[269] Colourful celebrations for Nowruz are underway at the main building of the National Research Institute of Renewable Energy Sources.[270] Many students, researchers and experts coming from all the corners of the most populous country in Central Asia are celebrating. The Institute is fully busy, as is the capital and the whole country, which gives a sense of mass gathering since more than 40 million people[271] are living together in Uzbekistan; almost seven millions more than in 2020.[272]

Nowruz (Uzbek: Navroʻz / Наврўз) is a popular festivity in Uzbekistan. It is the day of the equinox,[273] when day and night are equal. It marks the beginning of spring in the Northern Hemisphere. This day is widely celebrated across all the Central Asian countries, and in many places across the region it acquired some special features. When Uzbekistan was part of the Soviet Union, celebrations of Nowruz were generally

unofficial, and at times even prohibited. Despite the Institute frenetic activities, almost everyone paused working to celebrate this holiday. Even a group of young students, who are finalizing their working group assignment for the class of 'History of the Energy Transition' on the impressive transformation of their country from the legacy of old oil and gas assets to the ultramodern hydrogen and renewable assets era.

In this group seats Lola, a young girl in her 20s who has a genuine passion for her country and somehow for the energy sector. She is originally from Bukhara, famous for its historic sites.[274] She misses in the capital that feeling from Bukhara nature in the sunny days when you can enjoy the ancient signposts of the Silk Road shining in the light of the sun. In fact, the country solar irradiation levels are comparable in the South to the levels of Southern European Countries, such as Spain and Italy. And, when Lola travels back to her parents she crosses thousands and thousands of Solar PV panels which, like flowers, turn to the sun to catch the sunlight which will later become electricity, and then via electrolysis clean hydrogen to feed the spectacular lights of the cities.

In her research, Lola has discovered that her country looks quite different from the time before she was born. The energy sector is a good example of how Uzbekistan has evolved at fast peace achieving economic growth leveraging green technologies and international openness. In 2040 the total power generation installed capacity is 59 GW of which 12 are thermal capacity and the rest is renewables while in 2020 the total installed capacity was only 12 GW in total[275]. In the past most of the power generation assets were built during the Soviet times and relied on old technologies, all managed by the single state owned energy company Uzbekenergo, which was

unbundled in 2019 kicking off a rapid transformation of the whole energy sector in the country.

Lola's contribution to the working group assignment is the chapter dedicated to the power plant where her uncle used to work his entire life. It is located on a river, which has a special history in the story of these territories as in the past it was an important passage on the way out of the desert of Turkestan.[276] Her uncle was from the little town of Shirin, a few kilometers south of Tashkent.[277] The Sirdarya power plant is located roughly 1.9 km northeast of the city of Shirin, not far from the border with Tajikistan. Next to it, lies the local Museum of "The Turbine Hall" which has transformed the 3 GW oil and thermal power plant into a modern exposition space inspired by the similar old London predecessor. In 2020 ACWA Power[278] begun the construction of the 1.5 GW Sirdarya combined cycle gas-turbine (CCGT) power plant as part of the Uzbekistan Government's plan to improve efficiency and capacity of its electricity production, while boosting economic growth and reducing environmental impact. The project was transformational as it added 15% of Uzbekistan's power demand and 8% of its total installed power capacity. Built originally to run on natural gas, in 2040 the plant officially reached the target of 50% green hydrogen utilization and is on good track to achieve 100% green hydrogen for all its operations by 2050 in line with the Low Carbon Strategy of the government. Hydrogen is supplied both via local production, and via imports alongside Sir Darya river.

Sirdarya Combined Cycle Gas Turbines. Source

Reflecting on past and future

Lola is on her way home after the celebration. Tonight the streets are full of celebration ornaments but empty of people. Walking slowly to arrive to her appartment on time to admire the dawn from the room of her window, she starts thinking about the First Hydrogen Strategy of the country designed in 2021.[279] By 2050 all gas power plants are expected to be at the end of their technological lifetime, while some gas-fired power plants will be repurposed for hydrogen. The energy system will be operated on solar, wind, nuclear and hydropower, as well as decarbonized liquid and gaseous fuels. Already in the lift to her small student apartment, she remembers the first day at the Research Centre for Hydrogen Energy: The smell of the testing and certification laboratory for renewable and hydrogen which would later become the biggest department of the Institute.

Uzbekistan photo. Source: unsplash.com

* * *

It looks like the equinox-effect was not only in the first ray of light from the new day gently embracing the Institute and its scholars. It's almost like, on that day, the page was turning on the history of Energy in Uzbekistan, and a long period of fossil fuel economy was rapidly being substituted with a green new hydrogen technology that would light the future of the country as a regional leader for sustainable energy.

United Arab Emirates, 2040

Author: Robin Mills

His Plan: The OHEC Meeting of 14 September 2040

It was a pleasantly warm day in Neom,[280] just over 50 degrees Celsius. Ziad Al Shammary was there for action, not vacation, and his pilotless plane was first in the swarm. The followers buzzed near-silently over the hazy coastal plain as they delivered the constellation of Ministers and robot assistants[281] to the floating hotel. The fifth annual meeting of OHEC[282] was in session.

Ziad, only just appointed his country's second Hydrogen Minister, appeared more relaxed than he was, as he hopped out of the fuel-cell flyer and greeted his colleagues and rivals. Some seemed a little dismissive of the young man whose ability they had yet to gauge. He exchanged a few words with the unsuspecting representatives of Chile, Iran, Russia, Libya and Namibia. They murmured polite expressions, and he expressed a slightly naïve question or two to disarm them. He who estimates last, estimates best.

They'd given him the third most splendid suite in the hotel, walls in pastel blue and green, real glass windows, not electronic

projections, facing all four compass points. Sunsets are redder, more infernally magnificent than when he was growing up. The forest of wind turbines, solar panels and electrolysers to the East was only fifteen years old, but already seemed faintly antiquated.

He had visited Neom as a young engineer, when a choice of a career had been a gamble. *"Hydrogen"* his aunt had advised, and been proved right. In the 2020s, he had been looking for a way out of the disease, drought, depression, depopulation and dissension across South-West Asia. The primordial element had seemed an escape, not a return.

Westwards, the modern blades floating on the Red Sea, each towering twice a Great Pyramid,[283] were turning vigorously in the evening breeze, powering cavernous fans sucking a two-century carbon legacy back into the ground.

His robot parked itself unobtrusively in the corner of the room, taking his instruction on coordinating meetings. The Chief Hydrogen Buyers had come personally, the two-hour hyperplane hops still a remarkable concession in a near-virtual world. India, Germany, Korea, America, Bangladesh and other economic heavyweights. But they could sweat a little; he would see them later. Only the uncertain reaction of the Chinese delegate to his little coup worried him slightly.

But first, he had a few details to settle. He concentrated intently for a few moments so his neural circuit would make him appear in Sydney, just as the holographic projection of Savreen Kaur twinkled before him. In the Australian winter, she sat in front of a fireplace warmed by a near invisible blue flame.

"We will make hydrogen so cheap that only the rich will burn wood" - she commented drily. Indeed, the fireplace was an affectation.

Electric heat pumps instead of crude fuel heat almost every home around the world outside the chilliest northern climes these days in 2040s.

"If we still allowed burning wood, you know you're one of the few who could afford it" - he responded. Since their PhD days designing electrolysers in Cambridge together, they had stayed close. Scion of a wealthy Australian mining family, Savreen had hardly needed the qualification, but the knowledge she'd acquired had taken her from rich to true plutocrat. The historically wealthy figures, Rockefeller, Gates, Getty, Musk and the others, were quaint beside the hydrogen trillionairess.

"So our AI has okayed the legal code" - he told her. *"Our lawyers will approve the human language précis this evening, not that they'll find anything to object to. Tshwane has cleared the transfer of the platinum assets. Congress is holding up the photoelectrocatalysis IP, but they're shooting themselves in the foot if they deny its use in the US. I don't believe anyone else knows what we're up to, apart from the Russians. I'm just concerned about Mingxia's reaction."*

She arched her eyebrows. *"That is the one slight worry. It's only them, and your friends over there, that might get in the way. But I will handle Mingxia through the diplomatic channels. In the end, they won't dare risk their supply. Siberia isn't enough to replace the Gulf and Australia together."*

"I can handle the people here. They won't like it, of course, but they will go along for a cut of the pie." Indeed, a pie worth half a trillion a year, that would triple within a decade. And, more than the simple figures of euros, the electricity that kept nearly every vehicle droning down the world's roads and rails, the basic materials forging the new global economy, it was the control of the climate puzzle.

The next day, he rose before dawn and ran a virtual 5 km

along the beach. The nearshore green water over the dead corals gave way to the deeper blue offshore. The immersive reality could render the sounds and smells, the balance, and the rosy *vistas* of sea and mountains almost perfectly, but still not the feel of sand under your feet or dewy morning air in your lungs. Outside, the wake of the Jupiter was washing on the shore, as the world's largest hydrogen carrier ran silently west to Suez and eager customers in southern Europe. Close to the morning Venus, another bright star was probably the international space hotel.

He was first of the Ministers to the conference chamber, as his country was first to seize the potential of the first element. The others drifted in, expecting routine. They were served coffee synthesised from hydrogen and captured atmospheric carbon dioxide, a reasonable approximation to the bean version.[284]

First came the technical presentations. Strong demand to replace remaining fossil fuels, to make synthetic food, manufacture graphene for hyperjets and orbital vehicles, kept demand booming. Two more countries had reached net-zero this year, gearing up hydrogen purchases to keep their grids running through sweltering, stuffy, still weather. OHEC's low production costs gave them the edge over competitors.

But were they pushing H_2 and C prices too high? There was talk of new hydrogen manufacturing in the Sahara and the Gobi, and on giant floating islands, populist Chinese politicians promising to break OHEC. Maybe they could entice some competitors to join the organisation?

The Ministers' finance colleagues in Canberra, St. Petersburg and Isfahan were all itching to raise output, talking of hastening decarbonisation and releasing the brake on the global economy. But the hydrogen arbiters quickly reached agreement for only

a moderate boost in the 2040 targets. That seemed to conclude matters. But on the delegates' retinas appeared a new agenda item. Ziad spoke: *"Before some of us were hydrogen ministers, they were hydrocarbon ministers, and will know their history. Rockefeller controlled the transport of oil, and the club of Vienna controlled its supply. Eighty years on, we cannot repeat those approaches: the sun, wind and waves are everywhere. Last year the price was half what it is today. Next year, it may be half again or twice. This volatility is not good for those who rely on hydrogen for our economies, it is not good for consumers who need predictable affordability, and it is not good for anyone who desires a livable climate.*

We have a new vision, that will bring order to this chaos. When our system here writes the final communique, it will announce that my government is buying H To Mining and merging it with our hydrogen industry. The combination will control thirty percent of world hydrogen production capacity, a quarter of atmospheric carbon sequestration, seventy percent of the key catalytic metals, and, most of all, all the essential IP on ultra low-cost hydrogen manufacturing and conversion."

He had been waiting to be sure it came as a surprise, and his fellow Ministers were silent, hovering between the need to hear more, and their desperation to get out of the shielded room to communicate home for instructions: *"We prefer not to do this unilaterally. For true market stability, we need your cooperation, and you will all have the option to take a stake in the physical assets, the material synthesisers, the renewable energy fluxes, and, for those who want it, the oil and gas reformers and the carbon dioxide reservoirs."*

Mendeleyeva nodded a quick apology and slipped out, probably to broach a separate deal with Mingxia. That was expected. He watched the others in his peripheral vision, leaning back with half-feigned insouciance. Despite the conversation of

yesterday evening, he was not absolutely sure of the Chileans.

Nobody else moved, though, and he sensed some visible relief that they were not being cut out, some jealousy at being demoted to second place behind a young upstart Minister. That was the best he could have expected. The struggle of the 2020s, the cloudiness and false starts of the 2030s, had been replaced by hope, then clarity, optimism, perhaps now even a touch of hubris. For now, he had put his region firmly back in the global economy's nucleus.

Picture of Dubai. Source

Turkey, 2040

Author: Argun Karaçay

Izmir, a place for reflection on green hydrogen market evolution

It's a wonderful evening in Izmir, a city with thousands years of history,[285] and nice spring weather of May 2040 makes me enjoy my coffee. I am rocking in my chair, and remembering how hydrogen debates started in early 2020s, my mind wanders to my notes of the time:

2021. Prologue

"Turkey is one of the most dynamic regions in the world for renewables. Throughout last decade, Turkey has tripled its installed renewable capacity to around 45 gigawatts, and invested nearly USD 40 billion in renewable energy projects with different sources such as wind, solar, hydro, geothermal and biogas. The relative development in wind and solar energy is especially impressive as wind and solar installed capacities reached 10 GW and 9 GW, respectively. Building on this background, energy community started to discuss that the country had the opportunity, based on the track record, to take a

leading position in renewable energy transition.

In 2020, Turkey's Ministry of Energy and Natural Resources (MENR) published a 'white paper' in an effort to start formal discussions for determining Turkey's hydrogen roadmap. As a result, a fresh question started to emerge in 2021: Will Turkey be able to position itself as a pioneering country in green hydrogen?"

2040. Izmir as the multi-use case example for a diverse hydrogen economy

My mind jumps back to today in Izmir and my rocking chair (a spring day of May 2040) – I am reflecting on how hydrogen market has evolved, and with Izmir being a great example of this.

One of the ancient cities of Turkey in the pearl of Aegean cost, Izmir (Smyrna was its ancient name) has been a shining star within Turkey which inspired green transition for cities and achieved a far reached status with its vision. The city was the first one in Turkey to participate in EBRD's (European Bank for Reconstruction and Development) sustainable cities program two decades ago with a vision to be the pioneer in the green transition within the country.

As the city is hosting the vast majority of refineries and steel manufacturers, its position created a considerable momentum for Turkish industry's vision on the green energy transition. Today, the giant refineries located in the city (namely: Petkim, Star, Tupras) are running on 100% green hydrogen in their processes. The giant steel manufacturers also produce green steel. Of course, this achievement did not arrive in the blink of an eye. After grey hydrogen, blue hydrogen was used for some years until 100% green hydrogen utilization was achieved

through massive deployment of especially off grid wind and solar capacity dedicated to green hydrogen production.

Petkim plant. Open source

Izmir residents enjoy green hydrogen powered ferries when they are going to their offices in the morning and getting back home in the evening. The city is also home to bunkering business as well as green hydrogen exports through its 100% renewable powered harbors. Ships in the region use the city to fuel their engines with green hydrogen. Hydrogen bunkering became a big industry which employs thousands of Izmir residents. Of course, hydrogen export through hydrogen carrier ships is designated mainly for Asia as exports to Europe are usually sent through Southern gas corridor, which was used solely to transport gas in previous decades, but now is transporting biomethane and green hydrogen mostly.

The local gas distribution grid of the city was the first grid to supply 20% hydrogen blended gas approximately 15 years ago. Last year it has also been the first grid to supply 100% green hydrogen for heating purposes.

Izmir. Source: Author

The bus fleet of the city has also a colorful composition. 60% of the city busses are running of green hydrogen while remaining 40% is composed of 100% renewable electricity. Private car ownership has declined sharply to 30% within the last decade. Most of the city residents drive to supermarkets with hourly rented cars, of which most are running on hydrogen fuel cells. Of course, if you have specific tendency to old electric cars, you may choose them through your app's filter on 'preferred fuel'. Recent surveys of Turkish Auto Dealers Association showed

that almost 35% of the users above 50 tend to prefer electric cars over fuel cell cars especially for better acceleration.

* * *

As I am getting ready to go in town to meet some friends, my thoughts move to a broader question: *"Have we become one of the leaders in green energy and green hydrogen development?"* I tend to think so.

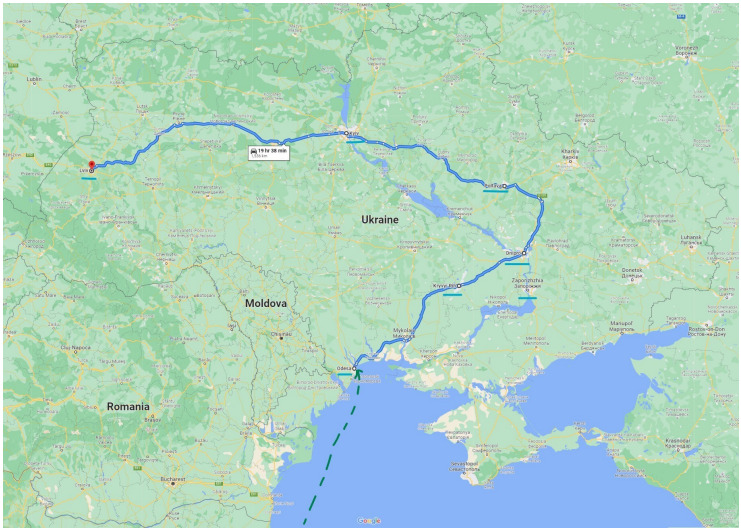
Turkey has achieved a landmark of installed capacity development in wind and solar during the last decade. 110 GW installed wind capacity and 150 GW installed solar capacity (which means approximately 13-fold growth within last two decades) has been achieved. The majority of this new capacity is coming from off grid plants which produce green hydrogen. Turkey also enjoys the benefit of having become a net exporter of green hydrogen. The country used to suffer from its budget deficits in the past most of which came from the bills of imported oil and natural gas. TANAP, which was used to transport Caspian gas to Europe, has now turned mostly into a green hydrogen export route to Europe from Turkey. Such transformation of the existing transmission and distribution grids of the country, and vast availability to construct renewables, opened a good window of opportunity for Turkey to become an important player in the global green hydrogen market.

Meanwhile, the beautiful city of İzmir continues to set a good example for the rest of the country on its way towards a green future. And I disappear into the night to enjoy it.

Ukraine, 2040

Author: Andrey Bondar

It's one of those rare occasions, when Edith – the young virtual-worlds architect working at one of the largest XR immerse-experience travel companies - decided to combine her dream vacation of taking a cruise with her new research project for a new chapter in the company's virtual worlds – Ukraine. To do so, she decided to board a cruise liner from Thessaloniki that stops in the Ukrainian biggest port city, Odessa. She takes a road trip around Ukraine to try and grasp the hyperbolic changes that have been happening here in the past decade. (See figure of the overall trip below.)



Overview of the trip. Source: Google maps

After passing Bosporus, the elegant cruise ship powered by green ammonia, with special safety precautions due to its toxicity,[286] headed North to Ukraine. It passed gigawatts of gigantic offshore wind farms that are coupled with offshore hydrogen- production purposed rigs, which are operated by Ukrainian and European energy companies. The cruise passes a busy sea route where barges with green ammonia and liquified hydrogen are headed to the Danube[287] for further export of the hydrogen upstream all the way to Southern Germany where it will be used to power European industry.[288]

Edith arrived to Odessa and took an evening walk through the local bars. The next day she rented out a self-driving car that will take her all the way to Kyiv with a couple of stops in Dnipro and Poltava.

On the way to Dnipro, she noticed the endless corn and wheat fields filled with wind turbines. Harvesters work diligently to collect the seasonal crops. The machines use hydrogen as their fuel,[289] and green ammonia-based fertilizers for soil productivity.

The fresh flour and sunflower oil are produced at factories where the primary source of energy and heat is generated with a mix of biomethane and green hydrogen. Biomethane plants are not uncommon, and became the supplement energy source for the agricultural sector.

The flour is exported around the world, including France where fresh croissants are baked from it for the guests and Delegation gathered to commemorate the Paris Climate agreement anniversary.

The car passed Kryviy Rig - an industrial city that transformed from one of the most polluted cities, into a city with clean air and opportunities for engineering talent. Here, along with Mariupol and Zaporizhia, the top-quality green steel products are manufactured.[290] Hydrogen is used both for the process of direct reduction of iron from local deposits, and as an energy storage[291] means to provide stable and dispatchable power from the surrounding solar and wind farms for the heavy but clean industry.

A major volume of low carbon, clean hydrogen is also produced with nuclear energy in this region, as local energy companies decided to make Small Modular Reactors another tool for their energy transitions, and to use the emissions-free energy for hydrogen production for the local market.[292] This nuclear technology, in combination with hydrogen ability to store energy long term, have helped Ukraine fulfill its promise to phase-out coal power by 2035.[293]

The steel is shipped to Western and Northern Europe where new wind turbines are produced. In some cases, those turbines end up back in Ukraine, and close the truly '*green loop*' of the energy with steel producing industries.

Nothing of the described would have been possible without the joint effort undertaken by Ukraine and the European Union. The deeper market integration opened opportunities for initial material funding that kick-started the transition which keeps contributing to the energy sovereignty and self-sustainability of the partners.

From the Dnipro region the road trip continued further North to Poltava, where the conventional gas producing industry has found the next big opportunity in producing low carbon and green hydrogen. All the way from Zaporizhia to Poltava GW scale H_2 factories produce the gas to be injected into a refurbished gas pipeline with several new H_2 dedicated routes.[294] Most of the hydrogen is then transported to the Western border to fulfill Ukraine's ambition of becoming an energy exporter utilizing its vast territories with great renewable capacities potential.[295]

Edith stopped in Kyiv to explore the city with all the historical sites and new architecture, to enjoy the fashionable restaurants and the local partying. Next stop was Lviv and the Carpathian Mountains.

In Kyiv she took the new, locally assembled hydrogen train,[296] and in three hours she arrived to Lviv, absorbing the unforgettable atmosphere of old streets and the smell of freshly roasted coffee. The city is home to many international trading energy houses branches. These companies want to be closer to the infrastructure that helps to plan for the winter period – the underground gas storage facilities previously were used for

seasonal gas storage, and are now used as a storage hub for hydrogen[297] from Ukraine and central Europe.

More than 30 bcm of hydrogen can be stored in the underground storages and freely traded by the companies according to the market demand. Another known location, which she did not visit, but had hear about, is the historical salt caverns near the Romanian border. Formerly a source of wealth for the Austro-Hungarian Empire – these salt caverns have been in part revived for a whole new purpose of hydrogen storage, while also being used for recreational services in the top-tier hotel chains located nearby.

Thanks to a group of enthusiasts that have embraced the blockchain technology for the energy sector, today every kWh of energy is being transparently traced from the primary source of energy – the Renewable Energy Sources, to its gaseous form of hydrogen or other green gas, so the traders know exactly what belongs to them in the underground storage, and are able to trace the origins of the hydrogen.

Furthermore, these certificates and blockchain deliver information on the exact source and emission content of every energy carrier all the way up to the final product, so that us – the consumers are aware of the emissions footprint of everything we buy. Moreover, it allows the financial institutions to have a clear picture of how to select their portfolios to meet emissions targets, enabled by the whole economy having its carbon footprint measured.

Edith took a last look at her watch, it was time to finalise her trip and go back to making the virtual world work again – she made a note, to underline the Ukrainian hydrogen economy in her design of that virtual Ukraine 2040.

Romania, 2040

Author: Lavinia Tanase

A great day of EU prize award in 2040

"A dystopia is an imagined community or society that is dehumanizing and frightening. A dystopia is an antonym of a utopia, which is a perfect society."- I read from a poster in the room. I was reflecting how Romania has become almost a 'utopia' in terms of being part of the global hydrogen economy and the energy transition. It was an important day in 2040.

Few hours left until the winner of the "2040 Race for Decarbonisation" is announced; until we learn whether Romania has won the competition with other EU Member States for fastest progress in decarbonisation amongst Eastern European States. "*We' re going to win, we must win",* I say to myself while I park my fuel cell car and start walking towards the "Constanta Casino", an architectural gem, at the seashore historical port city of Constanta.[298] My smart watch starts beeping announcing me that in 2 hours the winner will be known.

For the past 6 months, after we submitted our final application to the European Commission (EC), we have worked hard to organise a national event to cover the competition

and results. It's a high-stake event aimed at recording the progress from the past 20 years and inspire a push for the future. At the event we wanted to bring together all stakeholders that were deeply involved in the energy transition – from government to the ministry, regulator – Autoritatea Nationala de Reglementare in Energie (ANRE), national gas and electricity TSOs, DSOs, consumers authority, NGOs and associations, prosumers, producers, lenders; in short - everybody along the energy value chain, financing and acting in public energy policy was welcome. We have guests from the European institutions including ENTSOG, ENNOH, ACER, EU-DSO body, EU Clean hydrogen Alliance[299], EIB (European Investment Bank).

Me: *"Are you nervous?"* I ask my colleague, Andreea, as I enter the room. I see she is madly refreshing the competition's webpage, in hopes of an early announcement.

Andreea: *"I'm biting my nails, being nervous, of course. And you? How can you be so sure we even have a chance at winning?"*

While admiring the miniature model of the electrolysers plant built in the nature-rich Dobrogea region[300], close to the Black Sea's mammoth offshore wind park commissioned in 2030, I respond *"Well, how can they not? The criteria for the competition are very objective, and include target number of hydrogen valleys, material contribution to decrease of green hydrogen price and jobs. Romania is ticking all of those criteria. Look at this amazing piece of engineering of almost 4 GW electrolyser capacity built at large, in the Black Sea, somewhere between Constanta and Mangalia. It feeds itself with the wind electricity from the Black Sea windpark. And also, the prize award team and wider European institutions are aware of our progress, since they have been getting our reports every year. We have received close 20 billion euro[301] grants and loans to implement all changes to our energy system between 2021 - 2040.*

We have made sure to use these funds wisely building out the projects from plans to reality, we followed through. I mean, I'm surprised you ask yourself this question - you, as our creative director, helped us put all this in the speech that we have prepared for this presentation."

Andreea: *"Sure",* replied with an almost trembling voice, *"but we have begun to use the natural gas from under the Black Sea in 2026 from which we are still producing blue hydrogen with Carbon Capture and Storage (CCS);*[302] *we are not only producing green hydrogen. Do you think this can be a low scoring point for the jury?"*

Me: *"Good question, but remember that our initial National hydrogen Strategy that was issued in 2023*[303]*, and which is the basis for everything that happened afterwards, set some clear objectives for Romania, given its particularities and specifically mentioned that the hydrogen produced locally in the country, cannot only come from renewables, but also from gas, since we have quite some bcms under the Black Sea…everything unfolded after Romgaz took over the contract from ExxonMobil back in 2023...I remember the moment when together with OMV Petrom, the operator, they declared start of operations in 2026, as it was yesterday. That was a big win for us. If you well remember, in the National Energy and Climate Plan (NECP) of Romania (approved by the EC in July 2021) one of the objectives was for Romania to draft a piece of legislation that will promote investments in the Black Sea and modify relevant laws. And this happened soon thereafter."*

Andreea: *"You're diverging from the question"* she replies, *"we know all this, we inserted this in the application, but..."*

Me: *"Andreea, we do not have time to debate substantive things now, let's please go over the main points of the speech again"* - I interrupt her in an attempt to make sure that we practice delivering our speech impeccably, and thank everyone present for having made this energy transition possible.

My smart watch beeps at the right time – reminding me to go over the main points of the speech which we planned to deliver as a geographical travel through Romania and a time-lapse trip from 2021 until today showcasing the most important developments in hydrogen and for the energy transition…

And so, I begin repeating what I would actually say, about Romania's journey to be one of the leaders of the European hydrogen economy – the birth place to 1,000th hydrogen valley in the world:

"They say life is not about having, or doing but about being – in Romania, to the contrary, everything is about tomorrow, what will tomorrow bring and what can we do? Thus having worked hard to achieve a clean energy transition allows us to breathe and let the 'being' manifest itself, without worrying. We have moved from a country with very high potential (to do pretty much anything) to an actual decarbonisation hub in Southeast Europe. Please allow me for a time journey from 2021 to today.

*Back in 2021, we were off to a rough start – we did not have a clear strategy for hydrogen, we were lagging behind to a number of other countries globally. We did however have a National Energy and Climate Plan (**N**ECP) covering the period up until 2030.*

This NECP[304] *foresaw an important role for hydrogen in the transport, gas, and power sectors, without introducing clear plans and objectives for the future. We were missing a comprehensive framework for the use of hydrogen. In September 2021, the EC endorsed Romania's National Recovery Plan (NRRP) which outlined plans for the recovery of the country, in many areas (health, transportation, energy) following the disbursement of almost 29.2 billion EUR in non-refundable funds and loans. Only 41% - around 12 billion was targeted at enabling a clean energy transition and fostering green investments.*[305]

Unlike in the NECP, in the NRRP hydrogen's role was emphasised for the energy and transport sectors, with a clear goal "to accelerate the decarbonisation of the energy sector by phasing-out lignite and coal fired-power plants by 2032 and by facilitating the deployment of renewables and alternative energy sources, such as green hydrogen" - paraphrasing what the NRRP states.

What was very helpful to reaching this goal, and at the core of later success of Romania, was one of the clear objectives of the NRRP – so-called "Reform 4" - developing a favourable legislative and regulatory framework for future technologies, in particular for hydrogen and storage solutions and to remove any administrative obstacles to developing renewable hydrogen, with focus on transport, as well as on the gas and electricity sectors.[306]

The Reform 4 from the NRRP was the trigger for the emergence of the hydrogen Strategy in 2023. It was such a happy moment to have moved from a puzzle of fragmented initiatives to a unified hydrogen Strategy for our country – it was as if finally we nabbed our opportunity to make informed and comprehensive decisions regarding the future of hydrogen in the country.

Truth be told, we were a tad bit late to the 'momentum' that was already created starting with 2019-2020 when other European countries such as France, Germany and Norway had already published their national hydrogen strategies. And this delay was caused by the level of confusion among domestic actors on the role of hydrogen in a decarbonised Romanian economy. Even though a potent candidate for the energy transition among other energy vectors, hydrogen's advantages[307] *alone cannot yield a decarbonised economy: action must be taken at national policy level.*

And so, what happened after the Hydrogen Strategy was put in place in 2023, you may wonder. I will draw your attention to 9 key developments and will detail some of them:

1. The legal and political environment became steady and clear *which allowed for the Romanian energy landscape to become attractive for private clean energy investments but also for the exploitation of natural gas resources in the Black Sea (including required attention to mitigating carbon emissions and methane leakages.)*

2. We worked hard to arrange funding*, made projects submissions, received grants, and followed through with investments on the whole energy value chain to fulfill the national objectives on energy and climate change.*

In Romanian we have a saying "God offers you the means but does not put them in your bag" – and this time around we have not sat around waiting for our bag to be filled and miracles to happen, we have actually made them happen.

From the approximately 12 billion euros investments in the energy sector up to 2030, we have successfully used all the financial instruments that were available at EU level and obtained adequate allocations. We have invested massive amounts of Romanian and EU money in building new RES capacities (approximately 1 billion euros[308]*) and reinforced thus Romania's status as the country with one of the most significant renewable energy potential in the EU which may host the largest onshore and offshore wind parks. In addition, we have made investments in interconnections with our neighbours, both in gas and electricity and the level of electricity interconnectivity by 2030 increased with 17% and with 30% by 2040.*

3. We reinforced and modernised our power and gas (including hydrogen storage) infrastructure.

On 31 December 2021 the Government issued an Emergency

Ordinance indicating that the national gas distribution systems can be extended via investments from the distributors, third parties and local authorities.[309] *This had a major impact on how things later unravelled.*

We have invested in the modernisation of gas and electricity grids introducing more digitalisation, as well as additional distribution and storage systems.

Considering that Romania's natural gas transport system was arguably one of the oldest and least performing in the EU back in 2021, it was a widely known fact that reliance on the existing gas infrastructure was not sufficient and large capital-intensive investments needed to be deployed for new dedicated hydrogen infrastructure. The national gas TSO - Transgaz considered using the then existing methane infrastructure for hydrogen transport and planned to assess the economic and technical feasibility of injecting hydrogen and synthetic methane into the natural gas infrastructure.[310]

Storing and managing hydrogen flexibility was a key to resolve, and we did it. The availability of suitable formations to develop storage sites for seasonal hydrogen storage represents an opportunity for Romania and offers it a competitive advantage compared to other Member States. Romania has always enjoyed the perks of having a diverse geographical landscape, and in 2020 DEPOGAZ Ploiesti[311]*, the unbundled subsidiary of ROMGAZ,*[312] *the biggest Romanian national natural gas producer, was operating underground natural gas storage facilities which had the potential that on the medium or long term could be used for hydrogen storage.*[313] *Particularly Romania's inheritance of salt over 2000 years, offered opportunity for creating suitable saline storages for hydrogen – similar to the Netherlands and Germany.*[314] *That offered a critical differentiator and flexibility of easily accessible resource to Romanian hydrogen*

trading within Europe.

4. We have succeeded to create the 1,000th hydrogen valley in the world (I noted to stress this in the real speech)

As you may remember, at the 2021 EU Hydrogen Week the goal of having 1,000 hydrogen valleys by 2040 worldwide and a couple of hundreds in the EU alone was announced.[315]

We, Romanians, have materially contributed to achieving this goal: the 1,000th hydrogen valley in the world is Dobrogea![316] *Naturally, such an achievement comes with an increase in number of jobs and serious decrease of the production costs of green hydrogen.*

We made our bets on producing hydrogen in the country and transporting it to the EU either via the emerging European hydrogen Backbone, or via ships. As studies found,[317] *it was in some cases cheaper and more secure to produce hydrogen outside Europe and import it (this depended heavily on transport costs.) However, we aimed high and realized we can materially contribute to the production of hydrogen, as a country with a significant renewable energy potential in Southeast Europe rather than importing it from outside the EU. We started exporting hydrogen – to Austria and Germany and beyond, banking on our geography. In fact, the roll out of domestically produced renewable and low-carbon gases (in this case hydrogen) decreased the dependency of Europe on imports of fossil fuels, strengthening the resilience of the entire EU energy system.*

We were vibrant as a country and eager to elicit change. Hence, we became involved in a lot of EU IPCEI[318] *projects for EU funding for hydrogen.*

As an example, the 'Blue Danube' project was a real success, as around 1.5 GWh, or over 80,000 tons of green hydrogen/year are now produced in Romania at competitive prices and shipped to Austria

and Germany using Liquid Organic Hydrogen Carrier (LOHC) technology.[319] *Conventional inland waterway vessels, which used to load fossil liquid fuels, were very-well suited for the main logistic routes on the river Danube and could be re-used accelerating the energy transition.*[320] See figure below for an impression of the 'Blue Danube' project:

'Blue Danube' project overview. Source Verbund

This project was very impressive as it turned Dobrogea,[321] *one of Romania's regions close to the Black Sea and the Danube into a hydrogen valley. As a result, we have created around 80,000 jobs for Romanians from 2023 when the hydrogen Strategy was adopted until today ...and we will not stop here*[322]*. The real number is actually much higher if we consider the implications of the performant Romanian hydrogen economy for the EU contractors and subcontractors. This is important to mention as it was one of*

the criteria to potentially win the 2040 decarbonisation Race.

What is more, considering the high amounts of hydrogen that we started producing in Romania especially from 2030 in Dobrogea, we have enabled the achievement of the goal of creating liquid and competitive hydrogen markets in the EU. Even though the initial goal expressed by VP Frans Timmermans and Commissioner for Energy Kadri Simson to achieve liquidity by 2030 was a bit too ambitious[323]*, it was achieved later in 2035. We are now in 2040 and we are happy to say that we can trade hydrogen at TTF-hydrogen, NBP-hydrogen and SEEH (Southeast Europe hydrogen Trading Hub).*

5. We managed to contribute to reducing the cost of production of green hydrogen

When thinking of the cost of green hydrogen, the costs of renewable electricity must be taken into consideration, as the availability and cost of green hydrogen is dependent on renewable energy sources, their price and availability. Considering Romania's extensive local renewable energy potential, and the climate policies which determined increasing CO_2 costs and elimination of free CO_2 allowances allocation has established an environment whereby green hydrogen produced in Romania became more price competitive than grey or blue hydrogen (which uses fossil fuels instead of RES.)

Hence, starting already with 2030, in Romania hydrogen was produced for under 2 EUR/kg, in line with EC President Ursula van Der Leyen's statements.[324]

6. We stayed colour blind on clean hydrogen but aimed for netzero overall

In its hydrogen Strategy Romania did not formally move away from blue hydrogen, since it is the country with the biggest natural gas reserves and production in the EU, after the Netherlands.[325]

Albeit it did focus on green first. And even though it could provide a steady flow of hydrogen for the industry and all other demand areas, blue hydrogen at material scale required investments for CCS, whilst offering only 90% capture rates[326] *and it could have potentially rendered it non-economical in longer term due to high carbon costs as compared to green hydrogen. Nonetheless, blue hydrogen continued being produced in Romania making use of the sizeable natural gas reserves under the Black Sea from 2026 onwards, enabling top-up of flexible hydrogen volumes as green hydrogen was being scaled and became gradually competitive.*[327]

7. We managed to heat our homes with hydrogen and RES, while preserving our forests

I remember the day when in Romania the news of an EU Directive prohibiting the use of wood for home heating from 2023 onwards hit like a comet, as almost half of Romanians used to heat their houses with wood.[328] *After some research, it turned out it was fake news, however the NRRP did introduce (i) the extension of the gas network towards the rural areas with no access to any other source of heating and (ii) the plan to use other feedstock for heating and cooling rather than wood.*[329]

As a reminder, 2 decades ago, in the built environment of Romania, heating was primarily satisfied through biomass (forest) combustion and district heating, again mostly powered with fossil fuels. Next to wood, in Romania, natural gas accounted for over 40% for heating, hence hydrogen was a good alternative in some cases to electric heat pumps in housing: for example, for older housing stock – and could play a substantial role in decarbonising the heating and cooling sectors.[330] *To introduce hydrogen and renewable gases, the national gas distribution had been extended towards the urban and rural areas, with little to no access to energy, for heating, in a number*

of regions, including the Oltenia region.[331] *Initially, the NRRP provided for the building of almost 1900 km of gas distribution by 2026 transporting at least 20% green hydrogen produced from the electrolysers' capacities.*[332] *This network was envisaged to transport 100% green hydrogen by 2030, which started happening only from 2035 onwards.*[333]

Next to hydrogen, other energy sources played a large role in saving forest and greening the heating demand. Individual heating systems – using solar, wind power and geothermal had been installed. In addition, up to 4200 stationary capacities for high efficiency combined power and heat production (CHP) were switched to green gases, flexible to accommodate abated natural gas as well, in replacement of all lignite and coal capacities by 2026, providing green heating as well.

8. We left nobody behind and enabled a just energy transition in the coal-intensive regions of Romania, such as Valea Jiului

In the NECP, the coal-intensive regions have been at the core of the decarbonisation and just energy transition plans. Romania faced and had to tackle important challenges during the energy transition, especially in regard to the reconversion of mono-industrial and carbon intensive regions such as Gorj, Valea Jiului and Oltenia. The former was included in the European Platform for Coal Regions in Transition, and, as a consequence, a transition strategy had been developed. Furthermore, the Territorial Just Transition Plans that have been created for 6 of Romania's counties, Mures, Hunedoara, Gorj, Ploiesti, Galati, Dolj, provided for measures to reskill and upskill the workers in these regions.

Initially, the closing of coal plants was envisaged to happen until 2032, however the hydrogen Strategy in 2023 prompted this to happen much earlier, in 2026. In order to be able to rapidly replace

the closed coal power plant capacities, renewable energy, including hydrogen and related "just transition" jobs played a key role in supporting the regional decarbonisation targets.

Romania asked and received large funds from the EU Modernisation Fund to support this transition in the coal-intensive regions. Even to this day, there is still work to be done in these areas.

9. We focused on public and commercial transport as a means to launch hydrogen economy visibly to citizens every day. Constanta, Cluj, Timisoara, Bucharest – hydrogen buses[334]

Romania is a vast country with almost 240,000 km^2, hence the transport sector is very important.

An opportunity for hydrogen deployment was seen and used for heavy duty road transport[335] *and in the rail sector predominantly, since the maritime and aviation sectors represent only a relatively minor share of energy demand in transport sector in Romania.*

As for the passenger cars, hydrogen fuelled cars have been – despite international controversy on the subject – also deployed, since in Romania, the citizens need cars with large driving ranges - over 500 km. Currently, according to the estimations that have been done, the hydrogen refuelling station network in 2040 encompasses around 120 stations, with around 60,000 fuel-cell vehicles on the road.[336] *Back in 2021, we had very few highways connecting the country, however now we can drive on the highway from Bucharest to Cluj and Oradea – opening the roads for car and freight transport to the west (towards Hungary and further); we can also use the highway connecting Bucharest with Suceava, the north part of the country and we are now finishing a direct link to Serbia (Timisoara) with ample electric and hydrogen refuelling opportunity. I am happy to say that last week I managed to drive my fuel-cell powered car from Bucharest all the way to my parents' countryside farm, close*

to Iasi, in the north east of the country. There were 3 OMV Petrom refuelling stations on the way which allowed me to refuel my tank, however I did not need it as a full tank's range at steady speed of 90 km/h is 600 km.

In what concerns the railway sector, two decades ago, it was still largely dependent on fossil fuels for 57% of its energy use. It has been electrified in the meantime and there are now plans for hydrogen fuel cell trains – due to availability of competitive green hydrogen. I know I am excited to be travelling in the first hydrogen powered train from 2045 onwards.

Next to trains, steps were made on public transport buses. We have now 280 hydrogen buses in the country, spread between Constanta,[337] *Timisoara, Cluj, Iasi and Bucharest.*[338] *And isn't it fun to be able to travel around the cities in one of these modern miracles?"*

Dobrogea. What was the secret spice to the success? Seeking synergies and aiming high

I am pausing my practice of the speech and am reflecting on why we succeeded in turning Dobrogea into a hydrogen hub. My mind wanders.

"The hydrogen produced in Dobrogea using the renewable energy from the large onshore and offshore wind power plants is exported to Austria and Germany with inland vessels via the Danube, but also used to support Romanian industry (for example steel plant Liberty Galati and the cement factory LaFarge Medgidia).

In Romania, there are significant opportunities for the deployment of hydrogen across sectors, with the largest potential in industry and transport. The truth of the matter was that certain areas simply could not be decarbonised through electrification, and in 2021 the

largest demand for hydrogen was in the steel and glass sectors, as well as replacing fossil fuels for producing high temperature heat. An important principle that aligned us with the EU was a correct application of the principle of additionality in the hydrogen Strategy that we issued in 2023 in which it was stated that only new RES capacities that would not have otherwise been installed should be used for clean hydrogen production. This protected us from the so-called cannibalisation of renewable energy from the electrification purposes.

The Romanian steel sector, although relatively small, was still dependent on a conventional fossil-based steelmaking process. Up to 2030 and beyond, steel making at the Liberty Galati plant became a bit greener, and nowadays the plant uses half green, half blue hydrogen for steel production.

As the Energy Policy Group colleagues predicted back in 2021,[339] *I realize that indeed the green hydrogen from Dobrogea is used for feeding the municipal district heating systems (Constanța), with big plans to soon feed at large scale the maritime and aviation transport sectors – ships docking in Ports of Constanța as well as planes taking off from Mihail Kogălniceanu International Airport.*

The Port of Constanța is actually on the verge of becoming a portal for hydrogen export. Furthermore, the shipyards in Constanța and Mangaliaare actively contributing to transforming Dobrogea into a hydrogen hub as the local authorities, together with private companies have created here an extensive knowledge sharing hub and performant work sites where the building and retrofitting of ships that run on clean hydrogen can be done. A couple of days ago, the first long-haul transportation ship entirely built in the Port of Constanta shipyard was commissioned.

The vision of the Romanian decision makers of transforming Dobrogea intro a hydrogen hub happened thanks to the linkages

between the offshore wind parks in the Black Sea and the hydrogen value chains; and on the basis that Dobrogea, back in 2021, hosted most of the country's onshore wind capacities (around 3GW) and manifested the highest renewable energy potential (with an estimated total natural capacity of 94 GW.)[340] *By 2030 Romania already had 5 GW of electrolysers installed, and materially contributed to achieving the 2030 target of 40 GW electrolysers in the EU.*[341]

In has taken us almost 20 years to reach the stage where Dobrogea can be called a hydrogen valley, however in the longer term, I do agree that by tapping into Romania's affordable and significant renewable energy potential, Dobrogea can further develop into an even larger-scale, international and export-driven hydrogen valley,[342] *benefiting from the Port of Constanta, from the Danube Channel and from the country's natural resources and well-positioned geographical location."*

We really made great steps, I turn right back to the speech. It's time to rehearse the final words.

Final thoughts. Utopia became a reality

"*You see, things have changed, life has taken its course, but we made this transition happen and turned it to our advantage. Did I think back then that all this was a utopia? Yes, I did. I am happy to have been proven wrong.*"

This was the last line I repeated before entering the stage, we turned off the lights, turned on the big screen and waited for the results from Brussels to come in, any moment now… The public was nervous, but we were very hopeful to win.

Source: Author's collection

Greece, 2034

Author: Katerina Sardi

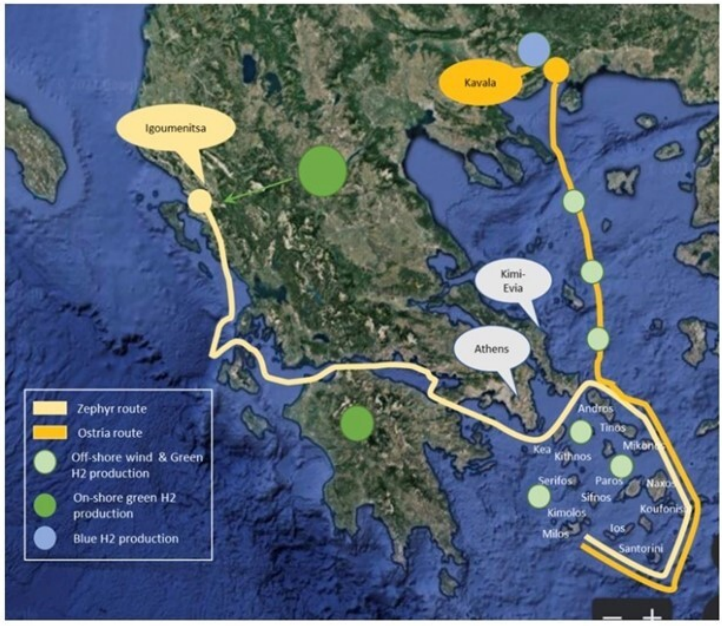
Hydrogen offset credits, Kasa's sailing trip in Greece

Tuesday 15 August 2034, somewhere in the Aegean Sea. A group of university students are on a sailing cruise. It is a group of 32; originating from different parts of South Mediterranean: Greece, Italy, Croatia, and West Balkans. It is the heart of the Greek summer. One of the student's is called 'Kasa.'

Kasa's trip was booked 7 months ago, through the specialised platform "#Collect4Green." This is the 6th year that Collect4Green offers trips to South Mediterranean views (as pictured below) and awards each traveler *'hydrogen offset credits'* (HOCs) to be used during the winter months to offset CO_2 emissions produced by household activities burning conventional natural gas (e.g., heating, cooking).

Views from Greece. Source: Shutterstock, Taiga

HOCs have been introduced at European level in the context of the 2030+ revision of the European Emissions Trading System (ETS), which extended the sectors covered by the system to households. HOCs are generated through carbon free leisure activities such as, for example, island hopping in Greece. One HOC equals 1 kWh of carbon free energy demand. The #Collect4GreenApp downloaded in the user's mobile phone tracks the HOCs generated throughout any linked trip. The trip was promising to be a great adventure. The map below shows the trip around the islands of the Cyclades complex. All islands are now interconnected to mainland Greece so that electricity demand is met by power produced mainly in the mainland and through wind and PV local production. Small electrolysers installed locally produce hydrogen as a fuel for ships and local heavy vehicle transport. (See figure below for seaborne trip overview.)



Trip overview. Source: Google Earth

The students, including Kasa, were now lying at the stern of two 50-foot Catamarans moored offshore, near the small island of Kimolos[343] at the heart of the Cyclades island complex. Kasa was enjoying a water melon cooled in one of the vessel's fridges, operating with electricity produced through a combination of PV power and fuel cells. Kasa loved technical details, and was mentally going through ship's fuelling and propulsion features. Each vessel comprises a mainsail of 120 m^2, a smaller auxiliary sail of 80 m^2, 3x 250 W solar panels, a 148 kW fuel cell operating on hydrogen (H_2) and a lithium-ion battery as propulsion back-

up. The on-board tank holds 600 litres of liquid hydrogen stored at a temperature just below -252,87 °C.[344] The tank capacity is enough for the ship to travel at its full speed of 35 km/h for 12 hours.[345] Thanks to advantages in technology, in part pushed by developments in aviation and developing space travel,[346] the cost of cryogenic components for H_2 containment and transport has substantially decreased post 2030 so that even comparatively lower budget cruise ships as the one in our story, were now equipped with liquid H_2 tanks. Both ships also have a 400-litre tank that can hold hydrogen in gaseous form, at a pressure of around 350 bars. This is enough for an additional 2-hour cruise in the absence of wind.

From former mining towns and ports to hydrogen hubs, sailing with Zephyr and Ostria. The hydrogen catamarans, co-powered by green and blue hydrogen

Kasa was reflecting on the trip of 2 Catamarans so far, and energy wonders that made it possible. It was amazing to be sailing between Greek islands, with occasional use of fuel, and to be offsetting emissions through HOC*s.*

The first Catamaran (Zephyr), named after Zephyrus, the Greek god or personification of the West wind, commenced its journey from the port town of Igoumenitsa[347] at the northwest of Greece 8 days ago, on 7 August 2034. It carried students from the West Balkan region and Italy who travelled from their hometowns with the relatively new hydrogen train speeding around the Adriatic Sea. Igoumenitsa is now a major hydrogen hub. The town receives green hydrogen in liquid form carried by trucks from the 'White Dragon'[348] hydrogen centre operating in Western Macedonia at the vicinity of the former

mining town of Ptolemaida.[349] This is the area, which hosted most of Greece's lignite plants until about a decade ago, and for more than 50 years had been a lignite mining community. Now it is home to a 5 GW electrolyser connected at the electricity transmission system, and receiving certified green electricity from around the country to feed the electrolyser for making green hydrogen from local water resources.[350] The produced green hydrogen is transported to various clients via dedicated transmission pipelines, operating as part of the European Hydrogen Backbone transporting hydrogen to the West part of Greece for consumption at distribution level, including fuelling sailing ships like Zephyr.

Naturally, Zephyr started the trip with a hydrogen full tank. She travelled southwards in the Ionian Sea between Italy and Greece, sailed through the Gulfs of Patras and Korinthos, and through the Korinthos Canal before entering the Aegean Sea. The weather was good so that wind and solar energy were adequate to power the trip. Any excess power was stored in the Lithium-Ion battery and subsequently used for charging various devices on board (laptops, phones). Household activities and appliances (hot water, cooking, and refrigeration) were powered through the PVs and the hydrogen fuel cell. Hydrogen propulsion was required only for a few hours, and this was rather fortunate as hydrogen refuelling stations around the Western part of the country are still scarce.

The second Catamaran (Ostria), commenced its trip at the Gulf of Kavala, at Northeast of the Aegean Sea. Ostria is named after a southerly wind in the Mediterranean Sea. As the Zephyr, Ostria uses hydrogen for propulsion when wind is not available as well as for powering appliances as a supplement to electricity produced from the PVs. Hydrogen for Ostria was supplied

from one of the nearby blue hydrogen plants (with improved capturing technology.)[351] CO_2 produced, as a by-product of blue hydrogen is stored at the dedicated underground CO_2 storage facility (UCO_2S) in the depleted oil fields of the Prinos complex located at the vicinity of the Kavala Gulf. The area has developed significantly over the past decade hosting not only the hydrogen production and liquefaction facility, but also green ammonia production used as fuel to large-scale ships. Vessels carrying liquid CO_2 from industrial facilities around Greece to be stored in the UCO_2S are seen as regulars in the Kavala Gulf.

Ostria travelled to the South, before meeting Zephyr at the Southern part of the island of Evia. Refuelling was necessary but this was no problem for Ostria. The island of Evia is hosting large-scale wind energy production for over 20 years. Comparatively small-scale electrolysers of a capacity of the order of 1,000 kW can be found in several locations across the island. They produce hydrogen from green electricity that would otherwise be curtailed, as the electricity grid in the area cannot accommodate large amounts of wind power at all times. There is no dedicated hydrogen network on the island yet so that hydrogen produced is typically used as a fuel for inland and seaborne transport. Cruisers typically stop at the port Kimi for refuelling with compressed hydrogen. Other refuelling options exist along the vessel's route to the South thanks to a number of floating wind parks equipped with small-scale electrolysers.

Today, on 15 August, the two ships met at narrow pathway between Evia and the island of Andros, the Northern island of the Cyclades, where the island-hopping adventure, including earning of HOCs, would continue.

* * *

Kasa ended her reflections, and turned the attention to the watermelon and her fellow green travelers. The sun was shining over the endless waters, and she felt the wind and water drops on her skin. What a wonder that water-contained hydrogen molecules that now helped to power the world including its leisure and tourism.

Italy, 2040

Author: Carlo Degli Esposti

My decarbonisation motorbike ride

This year I have crowned the dream of a lifetime: crossing the entire Italian territory riding my hybrid fuel tourer motorbike. I had been longing for it - it has been the chance to discover all those hidden corners of my country that I have not yet been able to visit in my lifetime. Now that I am reaching the end of my career, the bike allows me to visit those points where Italy has been able to achieve decarbonisation of its energy generation and consumption.

The engine mounted on my motorbike tells a lot about how things have been evolving in this country over the last 20 years, and what I have been able to see in person. There were, indeed, great expectations about hydrogen and the role it would have been playing in last 2 decades. Unfortunately, these have been only partially met, particularly after the pandemic time during the 2020s. I was very curious to discover in person *what* can be observed on decarbonisation while riding across the country.

From Alpine landscape to coast, good neighbours and importance of water

My trip began in the Alps, in the Western Alps, close to the large industrial cities in the North of the country: Turin, Milan and their main access to the sea, the city of Genoa. In this region, the power interconnection capacity with France has been further expanded via HVDC (High Voltage Direct Current) cables installed in road and railways tunnels.

I am meanwhile making a small mental side tour about the choices in energy policy that our neighbours have been pushing in the last years. Considering our never-ending dependence on energy imports, this is certainly still an important consideration to understand how the Italian energy landscape has come to the present status quo: *"France has indeed taken the wise decision of not abandoning nuclear power generation, but even deciding to reinforce it further. At that time, this decision went clearly against the "Energy taxonomy" presented by the European Commission in 2022,*[352] *and caused a lot of political debates between the conservatives and the green parties in Brussels and in every Member State. I remembered that the last, unexpected extended brownout that affected large parts of Europe, after a prolonged "Dunkelflaute" in January 2032, forced politicians to call for any available low-carbon resources back in service, nukes in particular. This was done to avoid the severe consequences that the series of power outages would have had on the society and on the relationships between Member States."*

My mind wanders back to Italian energy landscape of 2040.

Thanks to these power interconnections and the availability of a significant increase of stable energy supply from the French border, Turin and Milan have been going through a series of *'wise'* local administrations which have been supporting

significant decarbonisation of the heating and transport sectors, thanks to the increased production and use of green hydrogen.

Thanks to these power interconnections and the availability of a significant increase of stable energy supply from the French border, Turin and Milan have been going through a series of *'wise'* local administrations which have been supporting significant decarbonisation of the heating and transport sectors, thanks to the increased production and use of green hydrogen.

The increased interconnection with France has also allowed the installation of large seawater desalinization plants on the Tyrrhenian coast around Genoa. One of these plants is located in dismissed refinery area of Busalla, to satisfy the enormous increase in demand of demineralised water for green hydrogen production. This same plant supplies water to residential and agricultural users, not only in Turin and Milan, but all across the north western Po valley, as well. And this is where I have decided to go today. Leaving Turin behind me, crossing the sweet landscape of the Langhe, the region of the great red wines of Piedmont, and the narrow valleys of the Ligurian Apennines to finally reach the coast close to Savona.

Coming back to the water desalinization plants, the construction of these impressive plants has become a serious need over the last 15 years, during which extreme weather conditions have been repeating more and more frequently in the North of the country, with long draught periods alternating with catastrophic heavy rains and floods. All over this period, despite the evidence, the administration has been proving once again incapable to correct its plans, going on in disregarding the severe needs of water management works on its territory to comply with the measures indicated in the 'Water Framework Directive' and of the 'River Basin Management Plans.' The

economic losses, including that of lack of water resources, have been beyond imagination.

This is where I have decided to go today. Leaving Turin behind me, crossing the sweet landscape of the Langhe, the region of the great red wines of Piedmont, and the narrow valleys of the Ligurian Apennines to finally reach the coast close to Savona.

Savona. Source: Kayak

On to Milan and the story of mobility

I left the coast and the beauty of Genoa behind me to move again across the mountains and reach Milan. In the Italian economic capital, mobility and heating have been significantly transformed by the use of hydrogen.

My mind takes a minor detour: *"The use of electric batteries*

and vehicles for mobility has been slow due to the impossibility to implement charging points at scale: it was impossible to expand the distribution network to assure a sufficient number of charging pods in the historical city centre. This was a problem for Milan as for any other Italian urban conglomeration, whatever its size. It was expected that the increasing social awareness about the sustainability problems related to the extraction of minerals for production of batteries in poor countries like Bolivia and Democratic Republic of Congo (DRC) would have pushed the public opinion to refrain from purchasing electric cars, but the problem proved to be much more trivial. Due to the severe problems for distributors to develop their networks to follow the strong demand for new connections of car recharging pods, huge queues of cars were increasingly forming in front of charging stations due to the charging time being longer than expected, and battery efficiency much lower than foreseen. The hard crash on the reality of the charging process has slowly disincentived the choice of battery cars for private mobility (in favour of hydrogen ones).

In Milan, as in all other Italian cities, distribution operators had initially tried to deploy massive amount of 350 kW fast frequency charging stations.[353] *These fast chargers had been so stressing for the overall power distribution network that all required reinforcement to supply an adequate number of charging stations at peak time proved to be unrealistic. The conversion of existing tank stations into multi hub fuel suppliers has proven to be much easier: installing dedicated electrolysers producing hydrogen on spots, and leveraging the existing gas network to supply hydrogen from the city outskirts, was showing to be economic and doable."*

The landscape in Milan, and, more generally in the entire Po valley, has been tremendously changing.

Solar country side, slow growth, imports

I decided to leave Milan and to take the long drive towards the seaside on a route out of the mainstream travellers, moving along the highway. I have crossed Crema, Cremona, Mantua, Ostiglia and finally Ferrara, from which I reached Ravenna and its byzantine beauties.

All along the road, the countryside was no longer the blend of rural landscape and mid-size industry. The view was now showing large fields of solar panels at 4 meters above the soil, visible everywhere. Thanks to the strong push from the government and the regional administrations to launch a strong deployment of agrivoltaic plants,[354] the use of land has been significantly changing, moving from pure agricultural production to a mixed usage of agriculture with energy. A note of caution crosses my mind: we could have had more solar.

Across Italy, it had been estimated that it would have been necessary to install 75 GW of new solar generation capacity, corresponding to a surface between 600 and 750 km^2 of land surface, in order to cover with own renewable energy production the demand of green hydrogen by 2030, corresponding to slightly less than the 1% of the unused soil.

Unfortunately, these plans proved to be too ambitious. The growth rate would have been implying doubling the speed of new renewable capacity installation compared to the period from 2010 until 2020. This, combined with the scarcity of rare earths[355] on the markets in the following years, has been creating a structural shortage of raw materials supply for PVs and inverters[356] manufacturers, forcing the growth rate of renewable generation penetration, and of green hydrogen use, to significantly slow down.

This (the shortage of local clean hydrogen supply) has been partially mitigated by the conversion of a large part of natural gas transportation system into the main vehicle to convey a part of the residual demand in hydrogen from North Africa. I will be seeing the result of this major turnaround of the gas system later in my trip, once I arrive to the South (in particular in Sicily).

Clean air in Po valley

While driving, one upside of decarbonisation became evident. The strong decarbonisation of heating, transportation and industrial production has been clearing the air in the Po valley. Until 2030, the air quality was one of the worst in whole of Europe, costing several hundreds of deaths per year. One of the very few positive actions that has been undertaken by the regional governments of the North was to tackle this issue with *draconian* measures to promote the use of hydrogen for heating starting from 2026, when particular weather conditions, fully comparable to those of the 'Great Smog' of London in a 1952, have been saturating the intensive care of several hospitals in the dorsal region for entire weeks in a row. Hydrogen rescued air quality through its rapid uptake.

The initial estimates were foreseeing the need of a tremendous growth of the use of hydrogen, instead of heavy combustion oil and methane, between 2030 and 2050 (from 2% to 20% of the final primary energy consumption). The last estimates seem to confirm that the target of 20% clean hydrogen use in the final primary energy consumption will be reached already in 2044, thanks to the promotion of energy efficiency measures for buildings and, the increased hydrogen imports from North

Africa.

Refining sites transformed

The long trip across the Po valley has brought me on the sites of the former main refineries in Italy which were closed one by one all along the period between 2025 and 2040. Cremona, Mantua, Ferrara and Ravenna were largely dismantled or re-converted into green hydrogen production sites, with high concentration of electrolysers and fuel cells of the last generation (with nominal power of quite some hundreds of MWs). The significant amount of heat co-produced by the conversion process in electrolysers, has been allowing for the extension of centralised decarbonised heating and cooling networks covering large districts around these former refining sites.

Adriatic offshore wind to gas hubs

My trip continued along the Adriatic coast, in direction of Pescara. The landscape has significantly changed here. Despite all the talks until the end of the 2020s, the Adriatic sea revealed itself as an unexpectedly profitable location for the installation of new offshore wind farms, in particular leveraging the presence of dismissed gas extraction platforms all along the Italian coast.

These former gas sites have been re-converted in power-to-hydrogen hubs, connected by an efficient HVDC network which, besides granting a high load factor to hydrogen production, has helped to improve the overall security of supply for the Italian power system. 20 years ago, in 2020, there was no expectation that offshore wind energy, particularly in its

floating version, would have been so positively contributing to the decarbonisation of the Italian energy system. New types of wind turbines, based on cyclonic conveying of air into the turbine,[357] allowed the use of much lighter and irregular winds for the production of electricity in an area which is characterised by wind gusts, but no regular wind inflows.

After I had enjoyed a bit of views in Pescara, it was time to ride in the direction of Rome. My intention was to visit a couple of friends there who had been elected, at the last round of political elections, as Members of the Parliament. I was contemplating not to go. I was aware that they may not appreciate my concerns on completion of the last, crucial steps of the decarbonisation process of the Italian industry. Pleading for the re-introduction of nuclear energy in the Italian mix, relying on melted salt

reactors (which have been largely deployed in other parts of the world over the last 20 years, and became the most secure technology to provide large amounts of reliable supply of electricity) was certainly a debatable expectation.

To the South, the hydrogen hub for Mediterranean. Through Apulia, and Basilicata

There was one last step to complete my trip: the long descent southwards, towards Sicily, to visit what had been indicated by many stakeholders of the Italian and hydrogen energy markets over the last 10 years as the 'Hydrogen hub for the Mediterranean.'

Before getting there, two other stops were planned in: Apulia/Taranto and Basilicata. The regions host the highest concentration of renewables in Italy and the largest potential for oil extraction, respectively.

To my great surprise, the largest Italian steel production factory, based in Taranto, has been able to fulfill its plans, through the long and uncertain path, to cover entirely its needs of green hydrogen (approximately 300 kt/y) to decarbonize its production (6 Mt/y of steel).[358] The supply is provided by a large import terminal which allows ships carrying green hydrogen produced in UAE, to extract the hydrogen content from the liquid organic hydrogen carriers (LOHC) used for shipping the green hydrogen. This approach, combined with the local solar-supported supply of hydrogen, allowed the relaunch of the green steel production in what once was one of the most polluted industrial sites in Europe.

But what about Basilicata? Once I left Taranto and paused in the beauty of Matera, I arrived to the Agri valley, known

for decades as an unexploited "Italian Texas." The valley has been finally able to install sufficient 'carbon friendly' assets to increase its oil production, and to bring it close to its estimated potential of 150k barrels per day, after a long and harsh fight with local communities and environmentalists. Oil is refined locally in a new, dedicated cracking plant, combined with one of the most efficient carbon capture installations, and is used mostly for plastics (hence being allowed as use case), with carbon being used for other purposes on site (e.g. making of e-fuels).

The trip towards Sicily was almost completed. After the bike run across Calabria and the crossing of the Strait of Messina, I finally arrived to the end of my long trip.

Sicily is where, traditionally, energy has been arriving from Northern Africa. The gas and oil pipelines from Algeria and Lybia are now accompanied by a strong electrical interconnection with 10 GW of traditional and floating offshore wind installed in the sea between the island, Tunisia and Malta, interconnected by another meshed HVDC marine network that will soon stretch up to Greece eastwards and to Sardinia and the Balearic islands westwards. The deployment of these HVDC network allowed the installation of another farm of water desalinization plants on the southern Sicilian coast. This additional water production has allowed to install further hydrogen generation capacity by large scale electrolysers close to the former refinery locations in the region (Milazzo, Priolo and Gela), but above all has averted further desertification of the interior part of the island. Despite all improvements, the local water pipeline system, affected by losses for more than 50% of its capacity in 2015, is still undergoing a profound reinforcement process. The quality and efficiency in water supply have anyhow promisingly

improving.

The parallel reinforcement of the pipeline and electrical interconnections to the mainland and Sardinia is also still far from being completed, but it is increasingly supporting the rerouting of the excess volumes of hydrogen imported from North Africa (via the gas interconnector to Tunisia, and the one, launched in 2035, from Libya), or produced locally, towards the north of Italy and the rest of Europe, facilitating the access to clean hydrogen of other European landlocked countries.

Famous final words

Crossing the whole Italian peninsula has been a real adventure, but I am happy to have taken my hybrid (e-fuel and electric) motorbike and not my hydrogen fuelled car. Finding hydrogen fuelling stations further outside of the main highways and the main connection roads is still not that easy, but the construction of a HVDC power network dedicated to the supply of multi-fuel (hydrogen and syngas), and charging stations is underway. It is a promising step to bring the decarbonisation process for transportation close to full reality in Italy.

At the end of the motorbike journey across Italy, I feel comfortable in saying that Italy is on the right path to become a true example of how the transition towards hydrogen, as one of the vectors of energy transition, can be successfully achieved.

It is even more impressive how all this has been happening despite a never resolved issue with the complexity of the administrative and permitting burden, the chronical unpreparedness of administrators at all levels, hierarchically and geographically, to tackle energy related issues and, last but not least, the persistence of a fundamental idleness of the population in front

of the dramatic climatic changes in the Mediterranean basin, where prolonged periods of draught have becoming endemic.

Pushing decarbonisation to its extreme will require to walk few extra and (costly) miles. The decarbonisation of the last grey GWh will be a real challenge, but I have just received a call from Rome: *"Why have you not stopped over? We wanted to talk with you about those melted salt reactors you talked to us about to the point of boring... The Ministry wants to see you, she wants to take action!"*

Germany, 2040

Author: Konstantin Lenz

The snowy solar and heating

It is a cold morning, a real cold morning, tonight it was below minus 10 degrees Celsius. Looking out of the window I see a beautiful winter morning. The sun is shining on its deep angle, as it always does in January. The snow outside, which fell the last days, is still white and untouched, covering my small garden. And, magically there are some of these small ice crystals on the window. The prints of my footsteps in the snow are showing leading to the fire wood pile in the rear part of the garden. Modern heating systems can be so developed, clean and advantageous, but they will never be able to replace the cosiness of a fireplace. The view outside, on the street, is not so nice. The white virgin snow of the last days has meanwhile converted into a mixture of brown, grey and white mud. On city streets, some things never change.

My sight fell on the old oven in the living room with the ashes of the last evening. OK, I admit to myself, the need to clean it after every heating event is a clear disadvantage. And, the annual delivery of my local wood dealer delivering

some stacked cubic meters of wood, which has to be carried from the street into the garden, is always a welcome extra workout session. Moreover, a fireplace with a glass of red wine is unbeatable, but having it as the only heat source could be challenging – sometimes we can be happy to live in the 21st and not in the 19th century.

I look at the output of my rooftop solar installation. "Zero Point Zero" – of course it is zero, there is a lot of snow on it. Of course I could climb now to the roof and clean it, somehow it is similar to the efforts with the fireplace, but without the cosiness and the red wine. We live in a modern world – but still not in a perfect world.

Illustration of the snowy roof with solar PVs. Source: Shutterstock

Building the solar installation on the roof was a challenge. It is a flat roof covered with black tar paper. When I renovated

the tar paper in 2020, bringing up also an isolation on it, the roofer said that in the last 90 years the old tar papers were never removed and he suggested to put the fourth layer on the roof. Disposal of tar paper is horribly expensive, so people leave it where it is, so as I did. But this had some implications for the solar installation process on the roof; the roofer did not recommend to put solar cells with a steel framework on it. But some years later, there were these fantastic solar cells rollout layers available[359]. You roll it out on the roof, fix it on the tar paper, cable through the chimney to the basement where the electricity 'Headquarter' of the house is, and that's it. OK, the snow is still an issue – modern but not perfect. And no red wine bonus when consuming solar energy.

I have to get some stuff from the basement where I pass by the heating cube with its blue light which has to work hard at these low outside temperatures. This is the "*hottest*" device available in the market containing more computing power than Apollo 11 (but it doesn't fly me to the moon.) So what does it do? It's a hybrid heating system combining a heat pump with additional gas burning facility able to take natural gas or hydrogen or a mixture of both. It optimizes the relation of using electricity or gas depending on the actual market prices, the heating is integrated in a balancing energy pool. The display in the living room shows the outside and inside temperatures, the actual condition and running mode of the heating system, as well as current prices of natural gas, hydrogen and electricity. It also shows the current mixture of natural gas and hydrogen in the gas grid. The gas grid operators run the blending of hydrogen in the gas grid in a flexible way, optimizing price, carbon footprint and security of supply. Of course all this information is available on my smartphone.

Deeper dive on heating. From Bauhaus to hydrogen

The house in which I live is an old house, it was constructed around 1929 by one of these Bauhaus Architects, so today it is more than 110 years old. It is part of a larger ensemble of row houses in the South-Western part of Berlin, and the whole area is under monument conservation rules, so you are not allowed to change much.

A simple heat pump was not sufficient for such a house since due to the monument conservation it is not possible to isolate the façade. At these low outside temperatures, the radiators need 60 to 70°C inlet temperatures but a heating pump is only able to deliver 50°C, and the efficiency gets really bad at these low temperatures.[360]

Using hydrogen for heating purposes of private houses was originally not thought as an option in the beginning of the hydrogen economy, it was called the "*Champagne*" of the energy transition.[361] But reality turned out differently, as not only green hydrogen from electrolysis of water through renewable energy is produced today, but also turquoise hydrogen took an important role in the energy mix. Turquoise hydrogen is made out of natural gas using methane pyrolysis,[362] and the resulting products are hydrogen and solid carbon. The large amounts of produced solid carbon were a challenge at first as 2020s market for solid carbon was relatively limited.[363] However, once large amounts of "free material" was available, the chemical industry got creative, and this helped to create new materials, new sorts of plastics, as well as inputs for graphene batteries,[364] assisting the latter breakthrough.[365] Graphene batteries are made out of a single layer solid carbon; in general[366] they have no better energy density than other battery technologies which popped

up in the last 20 years, however, their price is very competitive since they don't need expensive raw materials. So a huge number of stationary graphene batteries, small and large size, were built, using e.g. former coal mines or coal plant locations, storing electricity in times of surplus and transferring it in times with a lower offering.

No speed limits on Vulcan. Driving towards the future

I am leaving the house feeling the breath of cold air on this sunny winter day. The cars on the street are partially covered with ice and snow. On the cars which are connected to the charging stations the snow has melted away on the windows, as the automatic heating systems in the cars take electricity from the grid in order to preheat them. Scratching windshields is a relic of the past, only with oldtimer cars you still have these issues, but usually people don't run them at this cold weather. And I was considering if to take my oldtimer for a ride, or my electric car. My mind briefly drifted away to reflect on the issue of oldtimers, loving them and fuels: *"How to continue operating oldtimers was and is still a big issue. Also I have one, 6 cylinders and 300 horsepower, nearly 40 years old now. Of course, it is in the garage and is used only if the weather is nice. But the sound of a real car is still an unbeatable joy.*

Have you ever considered why all the small kids love old steam locomotives, even if modern trains are much faster and convenient? I think it is due to their imperfection. Old trains are noisy, smell and they need love, and sometimes they are sick. They often have names and get with the age some kind of personality. Somehow it is the same with old cars, also they have a personality and many people give them names. Also my oldtimer cars had names. They were part

of the family and it was sad when they had to leave. Electric cars don't get names anymore, if they are broken, you give them away for circular re-processing. It is comparable with electric golf carts, have you ever seen a golf cart with a name? No, they only have numbers.

Producing synthetic, environmentally friendly circular fuels for oldtimers was a challenge, some automotive companies started these projects already in the early 2020s.[367] *For example, Porsche was in 2020s working on making e-petrol synthesised from e-methanol using green hydrogen and carbon-capture process.*[368] *They succeeded in producing e-gasoline and e-diesel using Fischer-Tropsch*[369] *synthesis with carbon made out of biowaste or direct air capture, but the main challenge for them was to gain trust from the owners to use these fuels. The car producers were forced to give wide guarantees to the owners for any kind of engine damage which might be caused by these synthetic fuels. Meanwhile, the gas stations changed their business, they have high voltage chargers which are able to fill nearly 1000 km range within 10 minutes. In addition they have still one or two fuel dispensers mostly used for oldtimers offering the e-fuels sorts like Super Fossi and Super Syn as well as Diesel Fossi and Diesel Syn. Super and Diesel Fossi is highly taxed, and often not available anymore but there is still a market for it (neighbors don't look kindly on such usage.) The synthetic fuels, or as we also call them e-fuels, are not highly taxed but are relatively expensive. All incentives are for citizens to drive mostly electric."*

My mind drifts back to sunny snowy reality. My oldtimer stays in its garage today, and I take a seat in my preheated electric Porsche Vulcan. Susi, the on-board computer, welcomes me. It knows already where I want to go, and the autonomous driving starts immediately. The streets' look did not change much in last 20 years - cars are standing on the sides, many of them connected with their charging stations which

you find every 10 meters along the street. The breakthrough of autonomous driving had an unexpected side effect - most people don't use public transportation anymore for short and medium traveling. Trains and buses are used only by people which can't afford to own a car or make use of car sharing. If the car leaves you at your destination, it automatically searches for a parking place, it tells you how far it is away from you and you call it to come when you want to go back home or to continue the travelling. Or you call via your smartphone a shared car. This is what many people do, especially in the city centers. In cities and on country roads you still have to be on the steering wheel controlling the computer driving. However on "*Autobahnen*" (highways) you are allowed to sit back, enjoying sleeping, reading, gaming, or whatever else you like. And yes, there is still no speed limit in Germany.

Speaking of speed, for long-range travelling, air planes are still the choice. Also their fuel is meanwhile to a very large extent based on clean hydrogen, or its derivatives.[370]

But my travelling today doesn't require an airplane. A new hydrogen production plant has been built on the outskirts of the city, and I was a part of this project. Today is the official housewarming party celebrating the start of the plant. It consists of several electrolysers of the newest generation with an efficiency of more than 80%, large scale graphene batteries to store the electricity and a connection to the district heating grid, where the waste heat is fed in and a private direct pipeline connection to a small refinery to provide clean hydrogen to produce synthetic fuels. The plant has a direct connection to the high pressure hydrogen pipeline grid where the produced hydrogen is transported to huge salt cavern storages along the shores of North and Baltic seas, to be further traded and

used across the European Hydrogen Backbone. The produced oxygen is used for different purposes. The water input for electrolysis is supplied from cleaned industrial waste water.

Driving to the new plant, one sees how cities have changed since 2020s. The buildings stayed look more or less unchanged, yet every spare space is covered with PV installations, especially the roofs, resulting in large amounts of renewable power produced during the summer, with excess renewable energy stored for the winter as hydrogen. Building all the caverns in the salt domes was a large investment and increased the salt level of the Baltic Sea significantly, which had fallen in the decades before. Yet, it did make Europe *nearly* independent from global imports of hydrogen. For the extreme cold peaks in our (abated) power generation, and for the making of turquoise hydrogen we still receive limited volumes of natural gas from pipelines and via global traded gas markets on LNG ships. Those gas volumes are taxed for carbon.

The hydrogen plant is surrounded by solar panels, and today most of them are covered with snow. Still not everything is perfect in terms of human ability to harness unlimited solar power – snow breaks that dream in this case. My mind drifts away again to future: *"The first commercial fusion power plants are under construction, having progressed since 2020s,*[371] *now way above time schedule and budget. Some things do never change. Policy makers are discussing already about flat rates for electricity as result of this progress. But this will probably need another 10 to 20 years. Within the life span of a human, we started with a world which was made to go round by oil, putting the first man on the moon.*[372] *We ended with a nearly fossil free economy in most of the industrial countries, with unlimited energy from fusion in visible commercialisation range, and with the first human steps on Mars."*

Notes

FOREWORD

1 IRENA (2022) Geopolitics of the Energy Transformation: The Hydrogen Factor. This is a conservative mid-range estimate – as IEA netzero analysis shows in "Announced Pledges Case" scenario a lower, and in "Net-Zero Emissions" scenario a materially larger hydrogen role in global energy use; IEA (October 2021) Netzero by 2050.

THE BEGINNING

2 See https://en.wikipedia.org/wiki/The_Mysterious_Island

NETHERLANDS, 2029

3 For those willing to take a listening detour on hydrogen 101, here are 2 podcasts of Switched On and Everything about hydrogen

4 See for what black-outs mean for example this article by BBC: What would happen in an apocalyptic blackout? - BBC Future

5 Invented name.

6 NortH2 | Kickstarting the green hydrogen economy

7 The qualification how sustainable hydrogen is in terms of climate impact and carbon footprint, further details e.g. in this hydrogen Council report - hydrogen-Council_Policy-Toolbox.pdf (hydrogencouncil.com)

8 It was connected to now world famous Dutch backbone including a developed network of salt cavern storages – see hydrogen backbone › Gasunie This operated in balance with powergrid, as was professed by study HyWay27

9 It's an invented name – however concepts are inspired by real life firm called - Spectral – Smart Energy Solutions

10 See Creation 'HyXchange' hydrogen exchange a step closer › Gasunie

11 Margin Call Definition (investopedia.com)

12 Air Company

13 See ZeroAvia | Rotterdam The Hague Airport | London

14 See hydrogen | Airbus

15 See A.P. Moller - Maersk accelerates fleet decarbonisation with 8 large ocean-going vessels to operate on carbon neutral methanol | Maersk

16 See for production methods Green Methanol | Power-to-X | thyssenkrupp (thyssenkrupp-industrial-solutions.com)

17 See Independent study on hydrogen production shows using nuclear will cut costs and emissions | News | Urenco

18 See e.g. Total joins HysetCo's fuel cell joint venture in Paris - electrive.com; see also hydrogen mobility pioneer, Hype, is entering a new phase with HysetCo's acquisition of major taxi firm Slota | Air Liquide Energies

19 Explanation on hydrogen colours: The hydrogen colour spectrum | National Grid Group

20 See Hyzon Motors | Accelerating the energy transition | hydrogen Mobility

21 See Nikola Motor Company

22 See e.g., https://fuelcellsworks.com/news/breakthrough-for-hydrogen-in-heavy-duty-transport-in-norway/

23 See https://hyundai-hm.com/en/

24 See TEVVA SECURES US$57 MILLION FUNDING TO PUT ELECTRIC & hydrogen TRUCKS ON THE ROAD IN 2022 - Tevva

25 See https://fuelcellsworks.com/news/gaussin-group-announces-an-initial-contract-for-hydrogen-powered-yard-trucks-atm-h2-with-plug-power/

26 See https://www.volkswagenag.com/en/news/stories/2019/08/hydrogen-or-battery—that-is-the-question.html#

27 See JCB signs green hydrogen deal worth billions - BBC News; see also Import of hydrogen | Port of Rotterdam

28 See The future energy system and the role of hydrogen - TenneT

DENMARK, 2030

29 https://index.goodcountry.org/ As of the time of writing (January 2022), Denmark is listed in number 2, just behind Sweden. Our neighbor to the north was the other country I was considering moving to after the UK.

30 https://bornholm.info/en/

31 https://www.euractiv.com/section/global-europe/news/denmark-delays-nord-stream-2-approval/

32 https://en.energinet.dk/About-our-news/News/2021/01/20/LoI-energy-island-baltic-sea

33 https://stateofgreen.com/en/partners/orsted-a-global-leader-within-green-energy/solutions/bornholm-can-become-the-worlds-first-energy-island/

34 https://portofroenne.com/press/2021/6/14/consortium-wants-to-make-bornholm-a-green-filling-station-for-shipping

35 https://stateofgreen.com/en/partners/state-of-green/news/denmark-wants-fossil-free-flights-by-2030/

36 Important Projects of Common European Interest (IPCEI) - https://ec.europa.eu/competition-policy/state-aid/legislation/modernisation/ipcei_en

37 https://www.cph.dk/en/about-cph/press/news/2020/5/leading%20danish%20companies%20join%20forces%20on%20an%20ambitious%20sustainable%20fuel%20project

38 https://www.h2-view.com/story/toyota-everfuel-drivr-partner-to-scale-copenhagens-denmark-taxis-to-more-than-500-by-2025/

39 https://scandinaviantraveler.com/en/aviation/sas-and-airbus-have-electric-dreams

40 https://www.powerlab.dk/

41 https://www.dtu.dk/english/news/nyhed?id=%7B15F143B0-1D6A-4C2A-BE6C-BF1D46FFB8C0%7D

42 https://www.windisland.dk/

43 https://ens.dk/en/our-responsibilities/wind-power/energy-islands/denmarks-energy-islands

44 https://www.dfds.com/en/about/media/news/hydrogen-ferry-for-oslo-copenhagen

45 See Proton exchange membrane fuel cell - Wikipedia

46 Power-to-X (P2X) is a key element of sector coupling. Most commonly, P2X stands for power-to-fuels or chemicals, where electricity production is typically via electrolysis converted to different types of end-products such as hydrogen, synthetic gases, hydrocarbons or chemicals.

47 https://investindk.com/publications/power-to-x-and-hydrogen-opportunities-in-denmark

48 https://fuelcellsworks.com/news/new-and-large-scale-hydrogen-hub-to-support-denmarks-green-transition/

49 https://www.everfuel.com/projects-archive/hysynergy/

50 https://reintegrate.dk/wp-content/uploads/2021/06/European-Energy-og-Reintegrate-vil-gore-Aalborg-til-metanol-metropol-1.pdf

51 https://www.ship-technology.com/news/maersk-reintegrate-e-methanol/

52 See Port of Esbjerg - Wikipedia

53 https://en.energinet.dk/Gas/Gas-news/2021/04/27/GUD-rapport

54 https://splash247.com/port-of-esbjerg-harnesses-offshore-wind-for-shore-to-ship-power/

55 https://energynews.biz/port-of-esbjerg-to-supply-ships-with-green-hydrogen-through-shore-power-plant/

56 https://www.rechargenews.com/wind/green-superpower-denmark-plans-second-gigascale-offshore-wind-to-hydrogen-plant/2-1-1060264

57 https://cipartners.dk/2021/02/23/cip-announces-plans-to-build-europes-largest-power-to-x-facility-with-the-support-of-market-leaders-within-the-agriculture-and-shipping-industries/

58 Author's estimate.

SWEDEN, 2048

59 See Gotland - Wikipedia

60 NB: This is mostly fiction. Even though Sweden do have import of LNG, it is not of a significant scale.

61 Inspired by Klätterverket (klatterverket.se)

62 See e.g. Sweden – a national strategy for green hydrogen – Enlit World

63 Swedish Energy Agency

64 Clean Energy for EU Islands Secretariat

65 Sverigeunikt projekt som kombinerar solceller och odling ökar skörden – Mälardalens universitet (mdh.se)

66 Road Runner | Looney Tunes Wiki | Fandom (looneytunes-fandom-com.translate.goog

67 Swedish Energy Agency

UNITED KINGDOM, 2035

68 Buzz Lightyear and his catchphrase "To infinity and Beyond". | Toy story buzz lightyear, Lightyears, Buzz lightyear (pinterest.com)

69 Useful read from 2021 on potential 'no regrets' hydrogen clusters A-EW_203_No-regret-hydrogen_WEB.pdf (agora-energiewende.de)

70 Less catchily known as the Integrated Rail Plan for the North and the Midlands Integrated Rail Plan for the North and Midlands - GOV.UK (www.gov.uk).

71 The 2035 carbon price has exceeded £400/tonne2021, the BEIS Green Book carbon values were projected to be between £151–453/tonne data-tables-1-19.xlsx (live.com).

72 Fizzy beer production typically requires purchase of commercial CO2, often a biproduct of fossil ethanol production. However, new methods, themselves pursued by Brewdog, reuse the CO2 generated in the early stages of the fermentation process. Are the bubbles in your beer made from sustainable CO2? | Greenbiz

73 Work that one out.

74 Continental Europe may refer to this as green methanol.

75 UK government electricity grid decarbonisation announcement Plans unveiled to decarbonise UK power system by 2035 - GOV.UK (www.gov.uk)

76 Reagan Joke — Soviet Union and Getting A New Automobile - YouTube

77 Author's views are valid.

78 Critics wary of Ryanair scheme to 'fully' offset flight emissions – EURACTIV.com

79 350 million trees in one day in 2019: Did Ethiopia plant four billion trees this year? - BBC News

80 Crickets are not strictly grasshoppers What's the difference between a cricket and a grasshopper? - Natures Home magazine uncovered - Our work - The RSPB Community

81 Game Zero: Tottenham 0-3 Chelsea achieves net-zero carbon emissions, according to Sky study | Football News | Sky Sports

FRANCE, 2040

82 https://en.wikipedia.org/wiki/Fuel_cell_vehicle

83 See, for example, https://www.iea.org/articles/proving-the-viability-of-underground-hydrogen-storage

84 https://gasforclimate2050.eu/sdm_downloads/european-hydrogen-backbone/

85 https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55

86 https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

87 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2

88 https://publications.jrc.ec.europa.eu/repository/handle/JRC126763

89 75% and 23% of the worldwide hydrogen production, respectively https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_hydrogen.pdf

90 The efficiency values point here to "primary heat to hydrogen", therefore taking into account the efficiency of the reactor producing electricity combined with the efficiency of the electrolysis cell. Reactors present typical efficiencies of around 30%, cells above 70%. Another efficiency measure frequently found in the literature is Power-to-H2-to-Power, nowadays estimated at around 25%.
https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx
https://librairie.ademe.fr/mobilite-et-transport/1685-rendement-de-la-chaine-hydrogene.html

SPAIN, 2035

91 https://www.fuelcellbuses.eu/wiki/fuel-cell-electric-buses-fuel-cell-electric-buses/about-fuel-cell-electric-buses

92 Antonio Machado was a Spanish poet and one of the leading figures of the Spanish literary movement known as the Generation of '98.

93 Author's translation. See "Los Olivos" poem: https://www.zendalibros.com/poemas-de-campos-de-castilla/

94 What is a lithium-ion battery and how does it work?

95 Based on Talgo's announcement in November 2020: https://www.talgo.com/-/talgo-tendra-listo-su-tren-de-hidrogeno-en-2023/

96 Formation Bureau Veritas: https://formation.bureauveritas.fr/formation/risque-industriel/hydrogene/7_235_6379_formation-h2-risk-safety-training-academy-%E2%80%93-niveau-2-.html

97 E-methanol is produced by combining green hydrogen and captured carbon dioxide from industrial sources. Source:https://www.freightwaves.com/news/e-methanol-missing-piece-to-shippings-decarbonisation-puzzle

98 Based on the announced project "SolarHy Córdoba": https://h2-project-visualisation-platform.entsog.eu/

99 *How to Avoid a Climate Disaster* by Bill Gates

100 EC COM (2020) 301 final

101 IRENA, "Geopolitics of the Energy Transformation - The hydrogen Factor" published 15th January 2022 (page 39)

102 "hydrogen Roadmap: a commitment to renewable hydrogen" published by the Spanish government in October 2020

103 A carbon dioxide equivalent or CO2 equivalent, abbreviated as CO2-eq is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent)

104 IRENA, "Geopolitics of the Energy Transformation - The hydrogen Factor" published 15th January 2022 (page 94)

105 According to Aurora Energy Research

106 https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-gobierno-aprueba-el-perte-de-energ%C3%ADas-renovables-hidr%C3%B3geno-renovable-y-almacenamiento-que-movilizar%C3%A1-una-inversi%C3%B3n-superior-a-16.300-millones/tcm:30-534032

107 See SUN2HY Project: https://www.h2bulletin.com/eu-approves-e122-million-for-decarbonisation-projects-including-hydrogen/

108 FuturEnergy Dec.21 - Jan. 22 issue (page 80)

109 https://www.bloomberg.com/news/articles/2021-01-20/madrid-brescia-rank-worst-in-europe-for-air-pollution-mortality

110 Nitrogen dioxide is linked mainly to traffic emissions, with older diesel models polluting more than gasoline

111 https://www.hydrogenfuelnews.com/fuel-cell-taxis-madrid/8547221/

112 More information: https://www.h2v.eu/hydrogen-valleys/green-crane-western-route

113 Author's own input.

114 IRENA, "Geopolitics of the Energy Transformation - The hydrogen Factor" published 15th January 2022 (page 87)

115 The Haber-Bosch process reacts atmospheric nitrogen with hydrogen to produce ammonia (NH_3), which is 17.8% hydrogen by weight (Source: AIChE)

116 More information: https://www.valenciaport.com/en/the-port-of-valencia-will-install-a-hydrogen-supply-station-in-january/

MOROCCO, 2029

117 References:

"lithub," [Online]. Available: https://lithub.com/how-does-it-feel-to-die-in-a-tsunami/

H. Azidane, "A Geospatial approach for assessing the impacts of sea-level rise and flooding on the Kenitra coast (Morocco)," Journal of Materials and Environmental Sciences, pp. Page 1480-1488, 2018, Volume 9, Issue 5.

118 "The Africa Report," [Online]. Available: https://www.theafricareport.com/124184/will-hydrogen-fuel-moroccos-industrial-projects-of-the-future/

119 H. Azidane, "A Geospatial approach for assessing the impacts of sea-level rise and flooding on the Kenitra coast (Morocco)," Journal of Materials and Environmental Sciences, pp. Page 1480-1488, 2018, Volume 9, Issue 5.

120 H. Azidane, "A Geospatial approach for assessing the impacts of sea-level rise and flooding on the Kenitra coast (Morocco)," Journal of Materials and Environmental Sciences, pp. Page 1480-1488, 2018, Volume 9, Issue 5.

121 "FEUILLE DE ROUTE HYDROGÈNE VERT, Vecteur de Transition Énergétiqueet de Croissance Durable," Ministry of Energy (Morocco), 2021

122 References :

"The Africa Report" [Online]. Available: https://www.theafricareport.com/124184/will-hydrogen-fuel-moroccos-industrial-projects-of-the-future/

"FEUILLE DE ROUTE HYDROGÈNE VERT, Vecteur de Transition Énergétiqueet de Croissance Durable," Ministry of Energy (Morocco),

2021.

"Global business outlook" [Online]. Available: https://www.globalbusinessoutlook.com/first-green-hydrogen-project-morocco-begin-production/

123 References: "FEUILLE DE ROUTE HYDROGÈNE VERT, Vecteur de Transition Énergétiqueet de Croissance Durable," Ministry of Energy (Morocco), 2021.

"Global business outlook" [Online]. Available: https://www.globalbusinessoutlook.com/first-green-hydrogen-project-morocco-begin-production/

IEA, "Global hydrogen Review," 2021.

"The Risks and Opportunities of Green hydrogen Production and Export From the MENA Region to Europe, Dii Desert Energy," Study on behalf of the Friedrich-Ebert Stiftung, November 2020.

NAMIBIA, 2030

124 hydrogen Fuel Cell Powered Rail - Hydrail | Ballard Power | hydrogen powered trains are poised to disrupt the rail industry as a cost-effective, high performing, zero-emission alternative to diesel

125 Republic of Namibia - Harambee Prosperity Plan II | http://hppii.gov.na/wp-content/uploads/2021/03/HPP2.pdf

126 Namibia: Nasdaq Welcomes Bank Windhoek to the Sustainable Bond Network | Namibia: Nasdaq Welcomes Bank Windhoek to the Sustainable Bond Network - allAfrica.com

127 Public-Private Partnerships

128 The World Wants Green hydrogen. Namibia Says It Can Deliver. - WSJ

129 Namibia Rated as Top Emerging Market Economy - allAfrica.com

130 The World Wants Green hydrogen. Namibia Says It Can Deliver. - WSJ

131 Namibia and Germany to form hydrogen partnership - ESI-Africa.com

132 A Perspective on hydrogen Investment, Deployment and Cost Competitiveness | hydrogen Insights 2021 - hydrogen Council

SOUTH AFRICA, 2044

133 See example here Kruger National Park - South African Safari and Lodging Guide (krugerpark.co.za)

134 See for detailed working of fuel-cell car, here: Alternative Fuels Data

Center: How Do Fuel Cell Electric Vehicles Work Using hydrogen? (energy.gov)

135 See Phalaborwa - Wikipedia

136 https://www.mining-technology.com/projects/palabora/

137 See Mokopane - Wikipedia

138 https://im-mining.com/2020/10/30/anglo-says-seven-mines-get-hydrogen-mining-truck-fleets-2030-rollout-40-mogalakwena-starts-2024/

139 https://www.dst.gov.za/images/2021/hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf

140 See Sasolburg - Wikipedia

141 https://www.sasol.com/70-years/celebrating-our-heritage

142 For comparison, in early 2020s whole of SA contributed about 1% of global emissions – see World's Top Emitters Interactive Chart I World Resources Institute (wri.org)

143 See Secunda, Mpumalanga - Wikipedia

144 https://www.bloomberg.com/news/features/2020-03-17/south-africa-living-near-the-world-s-biggest-emitting-plant

145 https://www.reuters.com/world/africa/south-africas-sasol-forms-consortium-produce-sustainable-aviation-fuel-2021-04-14/

146 https://www.sasol.com/sites/default/files/financial_reports/Sasol%20Climate%20Change%20Report_2021_22Sep21.pdf

147 What is a CSP?

148 https://www.energy.gov.za/files/IEP/2016/Integrated-Energy-Plan-Report.pdf

149 https://au.int/en/pressreleases/20210604/african-union-launches-worlds-largest-single-electricity-market-afsem

150 https://www.engineeringnews.co.za/article/worlds-largest-green-ammonia-export-plant-for-nelson-mandela-bay-2021-12-15/rep_id:4136

151 For impressions of industry plans in early 2020s please consult this public presentation available at: PowerPoint Presentation (ee.co.za)

URUGUAY, 2021 - 2031

152 Own calculations based on the Electric Market Administration Office (ADME) Annual Reports 2017-2019. Https://adme.com.uy/mmee/infanual.php

153 REN21 Global Status Report (2021) https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

154 World Energy Council (2021). World Energy Trilemma Index. Https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2021

155 Uruguay's National Energy Balance (2020). Https://ben.miem.gub.uy/descargas/1balance/1-1-Book-BEN2020.pdf

156 Gurin et al (2016) Complementariedad de las Energías Renovables en Uruguay y valorización de proyectos para el filtrado de su variabilidad. Https://www.gub.uy/ministerio-industria-energia-mineria/sites/ministerio-industria-energia-mineria/files/documentos/publicaciones/Complementariedad%20de%20las%20energias%20renovables%20en%20Uruguay.pdf

157 BID (2021) Hidrógeno Verde: Un paso natural hacia la descarbonización en Uruguay. Https://publications.iadb.org/publications/spanish/document/Hidrogeno-Verde-un-paso-natural-para-Uruguay-hacia-la-descarbonizacion.pdf

158 IEA (2021). Global hydrogen Review 2021. Https://publications.iadb.org/publications/spanish/document/Hidrogeno-Verde-un-paso-natural-para-Uruguay-hacia-la-descarbonizacion.pdf

159 Lantz, Hand and Wiser (2012). The Past and Future Cost of Wind Energy. Https://www.nrel.gov/docs/fy12osti/54526.pdf

160 Own calculations based on the characteristics of a Toyota Mirai. Https://h2.live/en/fahren/

161 See Water resources management in Uruguay - Wikipedia. We note that access to water is an advantage in Uruguay; globally some developers are looking at desalination.

162 See for global hydrogen market development overview, Executive summary – Global hydrogen Review 2021 – Analysis - IEA

163 See hydrogen Shot | Department of Energy; See also Opening keynote by the President: European hydrogen Week (europa.eu); Home - Green hydrogen Catapult (greenh2catapult.com)

164 See Gurin et al (2016) Complementariedad de las Energías Renovables en Uruguay y valorización de proyectos para el filtrado de su variabilidad. See also research by IRENA on global electrolyser costs reduction - Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5C climate goal (irena.org)

165 Ministry of Industry, Energy, and Mining of Uruguay and the Port of Rotterdam (2020). Uruguay – Port of Rotterdam – hydrogen Supply Chain. Https://www.gub.uy/ministerio-industria-energia-mineria/sites/ministerio-industria-energia-mineria/files/documentos/noticias/hydrogen%20-%20Uruguay%20%26%20Port%20of%20Rotterdam.pdf

166 IRENA (2020). Renewable Power Generation Costs in 2020. H ttps://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_Power_Generation_Costs_2020.pdf

167 See Ministry of Industry, Energy, and Mining of Uruguay and the Port of Rotterdam (2020). Uruguay – Port of Rotterdam – hydrogen Supply Chain.

168 See Gurin et al (2016) Complementariedad de las Energías Renovables en Uruguay y valorización de proyectos para el filtrado de su variabilidad.

169 See Gurin et al (2016) Complementariedad de las Energías Renovables en Uruguay y valorización de proyectos para el filtrado de su variabilidad.

170 See National Green hydrogen Strategy | Ministerio de Industria, Energía y Minería (www.gub.uy)

171 H2U Pilot Project outline

172 H2U Pilot Project outline: https://www.gub.uy/ministerio-industria-energia-mineria/sites/ministerio-industria-energia-mineria/files/documentos/noticias/Bases_dataroom_Proyecto%20piloto%20H2U.pdf

173 See eg. Joint statement of Uruguay and The Netherlands on collaboration in the field of green hydrogen import and export | Diplomatic statement | Government.nl

CHILE, 2030 - 2040

174 Load factors being discussed at: Individual news - ICIS Explore

175 Chile, National Green Hydrogen Strategy

176 https://www.mercurynews.com/2011/11/08/california-hits-renewable-energy-milestone-1-gigawatt-of-solar-power-installed-to-date/

177 See example of such exports plans in current world, at Ministry of Energy in Chile and Port of Rotterdam Authority sign MOU on green hydrogen | Port of Rotterdam

178 https://luxurylaunches.com/transport/the-worlds-first-hydrogen-powered-helicopter-might-be-the-answer-to-sustainable-air-travel.php

179 https://luxurylaunches.com/transport/the-worlds-first-hydrogen-powered-helicopter-might-be-the-answer-to-sustainable-air-travel.php

180 https://www.railway-technology.com/projects/santiago-metro-new-lines/

181 https://www.railjournal.com/in_depth/chilean-capitals-metro-network-enters-an-era-of-expansion

182 https://energystorage.org/why-energy-storage/technologies/hydrogen-energy-storage/

183 See for example of needed water for electrolysis, general article at: hydrogen production in 2050: how much water will 74EJ need? - Energy Post

184 https://pubs.acs.org/doi/10.1021/acsenergylett.1c01375

185 https://pubs.acs.org/doi/10.1021/acsenergylett.1c01375

186 https://www.iea.org/fuels-and-technologies/renewables

PERU, 2032

187 https://www.inaigem.gob.pe/glaciares/

188 These contributions represent the commitments assumed by the countries for the reduction of greenhouse gas (GHG) emissions and adaptation to climate change, in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

189 PASTORURI 40 años de estudios glaciológicos/ Autoridad Nacional del Agua. Área de Evaluación de Glaciares y Lagunas. 1a. ed. Huaraz: ANA, 2021.

190 https://viajes.nationalgeographic.com.es/a/ruta-cambio-climatico-por-glaciar-pastoruri-peru_13692

191 https://andina.pe/agencia/noticia-uni-apuesta-por-produccion-hidrogeno-verde-y-las-baterias-litio-este-2022-878814.aspx

192 See https://en.wikipedia.org/wiki/Department_of_Ancash#:~:text=The%20economy%20of%20Ancash%2C%20the,include%20potatoes%2C%20wheat%20and%20barley.

193 https://www.alpacacollections.com/vicuna-the-worlds-finest-natural-fiber

194 See on Alpaca's global relevance - https://www.zenger.news/2020/11/19/what-makes-perus-alpacas-so-special/

COLOMBIA, 2040

195 hydrogen fuel cell cars: everything you need to know

196 Aviation: Germany opens world's first plant for clean jet fuel

197 ZEROe: Towards the world's first zero-emission commercial aircraft

198 hydrogen-powered aviation: A fact-based study of hydrogen technology, economics, and climate impact by 2050

199 Carbón en contexto: más antiguo que la conquista

200 Cartagena: World Cultural Heritage Site

201 https://www.hydropower.org/country-profiles/colombia

202 Colombia's hydrogen Roadmap

203 Puerto Bolivar: coal export terminal

204 Lydia Oldendorff sets record at Puerto Bolivar and Antwerp

205 Possibilities of capture and geological storage of CO2 (CCS) in Colombia

206 Ecopetrol: technology and research

207 Colombia to offer tax breaks for carbon capture projects

208 Potential of carbon capture and storage-EOR in Colombia: study

209 Soplan nuevos vientos en la Guajira

210 La Guajira solar potential overview: Global Solar Atlas

211 Preliminary Analysis of Wind Power in 4 Colombian Cities

UNITED STATES, 2035

212 Equinor and bp achieve key step in advancing offshore wind for New York - equinor.com

213 US East Coast states to add more than 19,000 MW of offshore wind by 2035 | S&P Global Market Intelligence (spglobal.com)

214 Wind Turbines: the Bigger, the Better | Department of Energy

215 ZEROe - Zero emission - Airbus

216 20200507_hydrogen Powered Aviation report_FINAL web (ID 8706035).pdf (europa.eu)

217 Alstom to share its industry-leading expertise in green mobility with New York's Long Island Rail Road | Alstom

218 California Energy Commission Awards Funding to Demonstrate hydrogen Locomotive for Rail Applications in California • GTI

219 Hype – Première plateforme intégrée de mobilité hydrogène

220 Toyota Mirai : la nouvelle berline à hydrogène en détails (h2-mobile.fr)

221 Daimler Aims to Build hydrogen-Fueled Long-Haul Trucks - The New York Times (nytimes.com)

222 Economic Crossroads: Establishing a hydrogen Transportation Network for Long-Distance Transport in the Western US | Insights | Berkeley Research Group (thinkbrg.com)

223 Intro (archive.org)

224 hydrogen Shot | Department of Energy

225 Plug Power Inc. - Plug Power to Build North America's Largest Green hydrogen Production Facility in Western New York

226 Road+Map+to+a+US+hydrogen+Economy+Full+Report.pdf (cafcp.org)

CANADA, 2040

227 See e.g. Hydrogen | Airbus

228 hydrogen Strategy for Canada: Seizing the Opportunities for hydrogen, December 2020 https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_hydrogen-Strategy-Canada-na-en-v3.pdf

229 See for development path IATA - Sustainable Aviation Fuel

230 Ontario Low-Carbon hydrogen Strategy: Discussion Paper, 2020 https://prod-environmental-registry.s3.amazonaws.com/2020-11/Ontario%20Low-Carbon%20hydrogen%20Strategy%20-%20discussion%20paper%20%28November%202020%29.pdf

231 CCUS has become business as usual in early 2020s - CCS Facilities Database - Global CCS Institute

AUSTRALIA, 2040

232 https://www.minister.industry.gov.au/ministers/taylor/media-releases/australias-plan-reach-our-net-zero-target-2050

233 Vegemite

234 https://www.dfat.gov.au/publications/trade-and-investment/trade-and-investment-glance-2021#exports

235 https://whc.unesco.org/en/list/154/

236 https://www.woodmac.com/our-expertise/focus/transition/hydrogen-production-costs-to-2040-is-a-tipping-point-on-the-horizon/

237 https://www.abc.net.au/news/2021-08-26/states-push-back-angus-taylor-subsidies-coal-gas-power-plants/100410770

238 https://www.energynetworks.com.au/news/energy-insider/2021-energy-insider/where-do-you-put-five-million-tonnes-of-hydrogen/

239 https://www.shell.com/business-customers/aviation/the-future-of-energy/sustainable-aviation-fuel/synthetic-kerosene.html

240 https://www.energyvoice.com/oilandgas/north-sea/206114/dno-in-talks-to-reuse-uk-north-sea-platforms-to-support-wind-farms/

241 https://www.theclimategroup.org/media/12741/download

242 https://appea.com.au/wp-content/uploads/2020/06/Australia-Oil-and-Gas-Industry-Outlook-Report.pdf

243 https://www.premier.tas.gov.au/site_resources_2015/additional_releases/tasmanian_green_hydrogen_hub_project_submission

244 https://eternalisedofficial.com/2021/08/14/nietzsche-the-ubermensch-overman/

245 https://www.iea.org/reports/direct-air-capture

246 https://www.methanex.com/about-methanol

247 https://www.smithsonianmag.com/smart-news/green-steel-produced-first-time-180978550/

248 https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories

JAPAN, 2030 - 2040

249 https://www.iea.org/policies/13515-green-innovation-fund-meti-funds-hydrogen-supply-chain

250 METI uses the 3E + S framework to guide its development of the power system in Japan. This framework is intended to ensure that a balance between **s**afety, **e**nergy security, **e**conomic efficiency and **e**nvironment is maintained when changes are made to the power system.

CHINA, 2030

251 Compound Annual Growth Rate (CAGR)

RUSSIA, 2040

252 See Nikolay Przhevalsky | Russian explorer | Britannica

253 https://1prime.ru/energy/20211130/835370528.html

254 Kalininggrad's part of *"Western hydrogen cluster"* of Russian nuclear conglomerate Rosatom, which also included EV batteries manufacturing and recycling plant. Originally built as an export-oriented facility, this plant later was extended to supply the needs on Russian north-west industries and transport (https://tass.ru/ekonomika/12681009).

255 See Nevsky Prospect - Wikipedia

256 See *https://teknoblog.ru/2021/08/03/112946*

257 See Murmansk - Wikipedia

258 See https://www.kommersant.ru/doc/4654965

259 See Yamal Peninsula - Wikipedia

260 See https://www.kommersant.ru/doc/4606242?from=doc_vrez

261 See Norilsk - Wikipedia

262 See https://www.ng.ru/science/2003-12-24/12_future.html

263 See PGM-Based Fuel Cells: Applications for Industry – New Age Metals Inc.

264 See Penzhin Tidal Power Plant Project - Wikipedia

265 See Bering Strait - Wikipedia

266 See Sakhalin - Wikipedia

267 See https://oilcapital.ru/article/general/09-09-2021/vodorod-na-sahaline-laboratornaya-rabota-ili-imidzhevyy-proekt

268 See https://sakhalinecopolis.ru/

UZBEKISTAN, 2040

269 See Tashkent - Wikipedia

270 https://kun.uz/en/news/2021/04/09/uzbekistan-to-develop-hydrogen-energy

271 Source Worldometer

272 https://commons.wikimedia.org/wiki/File:Boukhara_4654a.jpg

273 https://en.wikipedia.org/wiki/Equinox

274 See Bukhara - Wikipedia

275 See https://minenergy.uz/en/news/view/612#:~:text=Uzbekistan%20plans%20to%20develop%20alternative,electricity%20with%20low%20carbon%20emissions.&text=This%20aims%20to%20deploy%20up,3%20GW%20of%20wind%20energy

276 See eg The Syr Darya River - the Queen of Central Asia (people-travels.com)

277 See Shirin, Uzbekistan - Wikipedia

278 See further broader plans, and source here: Saudi Arabia's ACWA Power, Uzbekistan Ministry Of Energy & Air Products Sign Deal On hydrogen - FuelCellsWorks

279 See Presidential Decree formalises Uzbekistan hydrogen energy strategy (powerengineeringint.com)

UNITED ARAB EMIRATES, 2040

280 See NEOM: Made to Change

281 See context for rapidly developing robotics - 27+ Robotics Industry Statistics To Show You How Big It Is In 2022 (techjury.net)

282 This organisation, with a name left for reader to guess, is at present a fiction for avoidance of doubt, yet a plausible fiction – see Opec member urges oil producers to focus more on renewable energy | Fossil fuels | The Guardian

283 See Pyramids of Giza | History, Location, Age, Interior, & Facts | Britannica

284 See Finland serves coffee in machine powered by the air we breathe at Expo 2020 Dubai (thenationalnews.com)

TURKEY, 2040

285 See İzmir - Wikipedia

UKRAINE, 2040

286 See for ammonia promise for shipping, for example: https://spectrum.ieee.org/why-the-shipping-industry-is-betting-big-on-ammonia

287 See VERBUND hydrogen project Green hydrogen Blue Danube

288 See High-level delegation visit to Ukraine led by State Secr | (energypartnership-ukraine.org)

289 See for example: Why are some betting on hydrogen power for ag? | AGDAILY

290 Example of use of hydrogen in steel industry - hydrogen in steel production: what is happening in Europe – part two - Bellona.org

291 See for example, hydrogen Energy Storage - Energy Storage Association

292 See NuScale SMR under consideration for Ukraine : New Nuclear - World Nuclear News (world-nuclear-news.org)

293 See EHB_one-pager_210624.indd (gasforclimate2050.eu)

294 See The promise of Ukraine's unprecedented coal phase-out (energymonitor.ai)

295 See e.g. Renewable energy – UkraineInvest

296 See e.g. Future of mobility: what is known about hydrogen trains in Germany | RailTech.com

297 See Underground hydrogen storage - Wikipedia

ROMANIA, 2040

298 https://en.wikipedia.org/wiki/Constan%C8%9Ba

299 See European Clean hydrogen Alliance (europa.eu)

300 See DOBROGEA Region, Romania - Travel and Tourism Information (romaniatourism.com)

301 This is an author's estimate; readers are welcome to challenge. The author based this on augmenting projections of support by EU beyond 2030, using double digits of billion EUR support which Romania can receive under the recovery funding until 2030 (both grants, and competitive loans). See further discussion in the chapter.

302 See https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/06/Blue-hydrogen-as-an-enabler-of-green-hydrogen-the-case-of-Germany-NG-159.pdf

303 The hydrogen strategy is being developed (Jan 2022 status). So here and further statements in regard of strategy are an author's assumption for purposes of storytelling. See disclaimer. See hydrogen law and regulation in Romania | CMS Expert Guides; See https://www.energetika.net/eu/novice/articles/romania%E2%80%99s-hydrogen-strategy-to-be-ready-by-early-202

304 Romania NECP

305 Commission endorses Romania's plan (europa.eu)

306 NEW CID ANNEX ROMANIA RRF 13 09 2021 (gov.ro), Reform 4, Page 158.

307 See e.g., IRENA. Hydrogen: A renewable energy perspective (irena.org)

308 Romania's NRRP, as approved by the EC, provided that the country will receive 29.2 bln EUR for all sectors. 41% of this amount to be targeting

a clean energy transition, while only approximately 1 bln EUR will be dedicated for clean energy production component. Https://balkangreenenergynews.com/romania-allocates-eur-3-9-billion-from-eu-recovery-funds-to-zero-carbon-railway/

309 https://e-nergia.ro/prosumatorii-vor-avea-parte-de-compensare-cantitativa-oug-adoptata-azi-ce-a-comunicat-ministerul-energiei/?fbclid=IwAR3FfSPamQslJsP_1S75SZMbLLMGbV2twkSUaXfi08BGsfLr0nW5dmT_FM8

310 Authors remark - In Romania, about half of the distribution network was made up of polyethylene, this distribution part could be relatively competitively converted to hydrogen (as e.g. UK research experience showed - Conversion of the UK gas system to transport hydrogen - ScienceDirect).

311 https://www.depogazploiesti.ro/en/about-us/profile

312 https://www.romgaz.ro/explorare

313 See e.g. slide 4, PowerPoint Presentation (unece.org)

314 See (PDF) hydrogen underground storage in Romania, the potential, actors and relevant circumstances (researchgate.net)

315 https://www.fch.europa.eu/event/european-hydrogen-week-2021#:~:text=The%20second%20edition%20of%20the%20European%20hydrogen%20Week%20will%20take,and%20the%20FCH%20JU%20Awards

316 See e.g. H2Valleys | Mission Innovation hydrogen Valley Platform

317 https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_11_H2_Insights/2021-11-18_Slides_Agora_12_insights_on_hydrogen.pdf

318 What is an IPCEI?

319 See: https://www.hydrogenious.net/index.php/en/references/blue_danube/

320 https://www.verbund.com/en-at/about-verbund/news-press/press-releases/2020/11/17/greenhydrogenbluedanube

321 Dobrogea, polul de energie regenerabilă al țării. Cum poate câștiga pariul pe hidrogen verde | Digi24

322 The IEA estimates that 7.2 jobs are created for each EUR million spent on investments in the hydrogen value chain.

323 As mentioned by Kadri Simson, Commissioner for Energy DG Ener on 15 December 2021 https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_21_6910

324 https://www.euractiv.com/section/energy/news/lets-reach-for-the-stars-eu-aims-for-green-hydrogen-below-e2-kg-by-2030/

325 https://www.romania-insider.com/ro-second-biggest-gas-producer-eu-aug-2020

326 IRENA 2020

327 https://www.euractiv.com/section/energy/news/romania-will-start-extracting-gas-from-black-sea-in-2026-minister-says/

328 Component 6 Energy, Section F.3, Reform 6 'Increase in competitivity and decarbonisation of the heating-cooling sector' https://mfe.gov.ro/wp-content/uploads/2021/09/e6f28710212d5a2d963ba440ce587a99.pdf

329 https://romania.europalibera.org/a/lemne-de-foc-interzise-ue/31614058.html

330 https://www.euractiv.com/section/energy/news/heating-homes-with-hydrogen-fails-on-economic-and-climate-merit-report/ ; https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

331 Component 6, Reform 6, Investment 2 – page 189 NRRP

332 Author's note on context. In 2020, in Romania, only one out of 3 homes had access to the gas distribution network: out of 320 cities, only 246 have access to the national gas distribution network, whereas out of almost 2600 communes, only 675 enjoyed access to this infrastructure.

333 Component 6, Investment 2 of NRRP https://mfe.gov.ro/wp-content/uploads/2021/09/e6f28710212d5a2d963ba440ce587a99.pdf

334 Dobrogea, polul de energie regenerabilă al țării. Cum poate câștiga pariul pe hidrogen verde | Digi24

335 In 2021, Romania´s road transport sector was strongly dependent on fossil fuels and hydrogen seemed one of the solutions that could be deployed to decarbonise energy use in this sector, especially in heavy-duty road transport, which represented approximately 34% of the energy use in road transport.

336 The initial NRRP estimations were 30-80 stations for 19 000 - 41 000 fuel cell vehicles on the road, by 2030.

337 https://www.g4media.ro/autobuz-cu-hidrogen-in-teste-la-constanta.html

338 Opportunities for hydrogen energy technologies considering the National and Energy Climate Plans – Romania, Fuel Cells and hydrogen Joint Undertaking, Jul 2020.

339 https://www.enpg.ro/2630-2/

340 https://www.enpg.ro/2630-2/

341 As per EU's hydrogen Strategy from July 2020.
This is an incredible achievement, as the NRRP in 2021 portrayed as an audacious plan to install green hydrogen production capacities (electrolysers) of at least 100 MW, producing at least 10,000 tonnes of hydrogen from renewable sources by 31 December 2025.

342 As p*er the EPG study* Clean hydrogen in Romania Elements of a Strategy, Dec 2021

GREECE, 2034

343 See Kimolos - Wikipedia

344 For detail of storing hydrogen in liquid form, see How is hydrogen stored ? | Air Liquide Energies

345 For energy density of hydrogen, please consult Fuels - Higher and Lower Calorific Values (engineeringtoolbox.com)

346 For detail on space and aviation developments, see "Space Applications of hydrogen and Fuel Cells | NASA"; https://www.nationalgeographic.com/magazine/article/50-years-after-apollo-11-moon-landing-new-age-of-space-travel-is-coming; https://www.nasa.gov/centers/kennedy/pdf/167433main_Propellants08.pdf;
IATA on liquid H2:https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/fact_sheet7-hydrogen-fact-sheet_072020.pdf

347 See Igoumenitsa - Wikipedia

348 More information: "White Dragon" proposal submitted for IPCEI hydrogen Important Projects of Common European Interest - DEPA COMMERCIAL S.A.

349 See Ptolemaida - Wikipedia

350 See Towards a sustainable water resources management in post-lignite era: the case of Western Macedonia, Greece - cest (gnest.org)

351 See Towards a sustainable water resources management in post-lignite era: the case of Western Macedonia, Greece - cest (gnest.org)

ITALY, 2040

352 Author's estimation of the debate outcome on EU energy policy – see https://ec.europa.eu/commission/presscorner/detail/en/ip_22_711

353 Fast Charging Station: A fast charging station saves energy when supply exceeds demand. More information: https://www.sciencedirect.com/topics/engineering/fast-charging-station

354 Agrivoltaic Systems, A Promising Experience.

355 Rare-earth elements

356 What is an inverter?

357 Cyclonic-flow wind turbine with statoric and rotoric elements

358 https://hydrogen-central.com/nextchem-maire-tecnimont-acciaierie-ditalia-feasibility-study-taranto-steel-plant-hydrogen/

GERMANY, 2040

359 We see examples of such innovation today - SunRoof enters the German market - pv Europe

360 For example of discussions on heat pumps see Heat Pumps: Myths and Facts - Stiftung Klima (stiftung-klima.de); German 2030 power use forecast up due to heat pumps, e-cars and hydrogen | Clean Energy Wire

361 Some early experiments were and are being conducted in UK, Netherlands and Germany for example. See here: BDR Thermea joins pioneering test of hydrogen energy in Germany (bdrthermeagroup.com)

362 See work done inter alia by BASF - New technologies (basf.com)

363 See Global Carbon Black Market Size Will Grow to USD 22.5 (globenewswire.com)

364 See Fraunhofer flagship research on Graphene and its applications - New study predicts increased market penetration for graphene-based applications by 2025 - Fraunhofer ISI

365 See for current research on using carbon in batteries - Energies | Free Full-Text | Applications of Carbon in Rechargeable Electrochemical Power Sources: A Review (mdpi.com)

366 See broader research on graphene batteries - German Energy Solutions - New generation of supercapacitors to challenge lithium storage

(german-energy-solutions.de)

367 See e.g. discussion on research lead i.a. by Porsche for legacy car market - Will synthetic fuels ride to the rescue of classic cars? | Hagerty UK

368 See Press releases: Porsche and Siemens Energy, with partners, advance climate-neutral e-fuel development - Newsroom & Press - About Porsche - Dr. Ing. h.c. F. Porsche AG

369 *Fischer-Tropsch process*

370 See for detailed discussion on hydrogen in aviation, predicted to reach 40 mtons/year by 2050 https://www.fch.europa.eu/sites/default/files/FCH%20Docs/20200507_hydrogen%20Powered%20Aviation%20report_FINAL%20web%20%28ID%208706035%29.pdf

371 See e.g. Bill Gates-backed nuclear fusion pioneer: 'We can fill the gaps left by wind and solar' | Recharge (rechargenews.com)

372 See How Much Fuel Does It Take To Get To The Moon? | OilPrice.com