CENTRE INTERNATIONAL DE FORMATION EUROPÉENNE
INSTITUT EUROPÉEN · EUROPEAN INSTITUTE

Master in Global Energy Transition and Governance

Academic year
2020 - 2021

HYDROGEN-BASED ENERGY STORAGE: A MAJOR PLAYER FOR DECARBONISATION?

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June 2021

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Abstract

The attention Hydrogen-based Energy Storage is receiving has intensified over the last two years. The energy carrier boasts an array of strengths that can have an unmatched contribution towards the necessary energy transition. It is in this context that the number of countries with polices that directly support investment in hydrogen technologies is increasing, along with the number of sectors they target. It is then by no means a coincidence that this ramped up hydrogen attention is unfolding alongside an increasing number of national commitments towards decarbonisation.

Just how big a role hydrogen-storage will have in contributing to national decarbonisation targets, and the factors that accelerate and/or inhibit this role, will be explored in this paper. A hypothesis is presented: That three core areas – policy, the role of the market, and civil society – are able to accelerate and/or inhibit Hydrogen-based Energy Storages' role in attaining decarbonisation targets. A two-part analysis will consider, firstly, the core challenges currently impeding hydrogen-storages' contribution to decarbonisation despite its growing attention, followed by a case study comparison of Japan and France to demonstrate the *how* of hydrogen-based energy storage by applying and comparing practical examples of its use.

It is found that the three themes mentioned each have the innate ability to both accelerate and/or inhibit hydrogen-storage deployment. Under these conditions considering each theme is an absolute necessity for ensuring hydrogen-storage has the optimal impact it can for global decarbonisation. At a time when the climate emergency has never been so urgent, a well-designed hydrogen market is needed, civil society engagement is essential, and policymakers must ensure that Hydrogen-based Energy Storage has as big an impact as possible.

Acknowledgements

Firstly, I would like to thank *Le Comité d'histoire de l'électricité et de l'énergie* and EDF for their research grant in support of this work. The funding provided me with flexibility, a greater research capacity and unrivalled motivation.

I further extend my thanks to those who offered their time to be interviewed. The insights provided helped enrich and shape this thesis for the better.

I would also like to extend my sincere gratitude to all those involved with this exceptional master's programme at CIFE; Dr. Rachel Guyet for her outstanding knowledge and infectious enthusiasm for the topic; Dr. Gilles Lepesant for his clear guidance, constructive challenges and constant motivation to dig deeper into areas of this thesis; and to Dr. François Bafoil and Dr. Laurent Baechler for their rich and stimulating classes. In a similar vein, I would like to extend thanks to all my classmates for making the academic year what it was both on and off the course.

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GDP – Gross Domestic Product
EV – Electric Vehicle
FCEV – Fuel Cell Electric Vehicle
HBES – Hydrogen-based Energy Storage
IEA – International Energy Agency
IPCC – Intergovernmental Panel on Climate Change
EEX – European Energy Exchange
JPEX – Japanese Energy Exchange
IRENA – International Renewable Energy Agency
ISO – International Standards Organization
GO – Guarantees of Origin
GHG – Greenhouse Gas Emissions
LDP – Liberal Democratic Party
LREM – La République En Marche!
EU – European Union
AFHYPAC – French Association on Hydrogen and Fuel Cells
HDF – Hydrogène de France
EDF – Electricité de France
ZEV – Zero Emission Valley
FC-CHP – Fuel Cell micro-Cogeneration Programme
FCH – Fuel Cells and Hydrogen Joint Undertaking
NHA – Neighbourhood Associations

"I believe that water will one day be used as a fuel, that hydrogen and oxygen, which constitute it, used alone or simultaneously, will provide an inexhaustible source of heat and light of an intensity that coal cannot have."

– Jules Verne. 1874. The Mysterious Land.

Introduction

The Role of Hydrogen-based Energy Storage for Decarbonisation

Ever since the Geneva conference in 1979 climate change has been globally recognised as an outstanding concern; this generation's defining puzzle. However, global mitigation progress is painstakingly slow, the climate crisis poses an ever-increasing threat to Earth's natural equilibrium. We are venturing into the unknown with our climate, and its associated impacts will be and have been devastating.

Climate change in general owes its increase in temperature to anthropogenic greenhouse gas emissions (GHGs). Consequently, Conference of Parties (COP) annual summits have shifted their focus onto significantly reducing these GHGs – most notably at COP3 in 1997, where the international treaty *The Kyoto Protocol* was signed, thereby committing over 190 countries to decarbonising. One of the most significant ways to reduce these emissions and stabilise global temperatures is by enhancing the efficiency of energy.

The climate change problem is principally an energy problem. As declared by a recent IPCC report on the impacts of global warming, "over two-thirds of global emissions stem from the energy sector."[1] Social scientists, such as Goodman and Marshall further stress this connection, highlighting the fact that climate change is induced by the patterns of production, politics, organisation and even technology of energy.[2]

As a result, it is acknowledged across the world that a fundamental change from a fossil fuel-based energy economy, which generates high levels of GHGs, to one based on renewable energy sources is required in little more than a single generation. This transition is not feasible without an easy and reliable method of storing energy, since renewables have daily and seasonal fluctuations.[3] With an increasing level of intermittent generation being put on the electricity grid, a greater level of balancing services is required, and hydrogen will play an important role here. Hydrogen-based energy storage's innate ability to convert energy from physical sources to chemical storage, seems to be a key player for global decarbonisation, allowing for the

[1] IPCC. 2018. 'Global Warming of 1.5 ^{o}C'. *An IPCC Special Report.* p.16.
[2] Goodman, J. and Marshall, J.P., 2018. Problems of methodology and method in climate and energy research: Socialising climate change? *Energy research & social science*.
[3] de Valladares, M.R., 2017. Global trends and outlook for hydrogen. *International Energy Agency*.

efficient maximisation of available energy. Hydrogen can – and will – constitute a key part of the solution to climate change through this complementary role.

A new era of energy policy is unfolding as countries respond to the COVID-19 pandemic, and hydrogen is playing a central role as a decarbonising agent. As showcased by the fact that the more ambitious a country's GHG reduction target, the greater the amount of hydrogen expected in the system.[4] Either the world fails to deal with the climate emergency or progressively decarbonises and the low and zero-carbon hydrogen market becomes an engine for change.

What is Hydrogen-based energy storage?

Hydrogen offers an elegant solution. As a highly flexible energy carrier, hydrogen delivers a holistic – clean, integrated and multi-sector – systems approach to energy, that will contribute decisively to securing Earth's energy future. Hydrogen being framed as the fuel of the future is not new though. In 1999, the *Economist* asserted, "after many false starts, hydrogen power is at last in sight of commercial viability."[5] Not quite. Two decades later and a new drive for hydrogen is emerging. In the backdrop of recent Electric Vehicles, Solar PV and wind energy successes hydrogen commitments are mounting. This recent hydrogen traction is unique; policy and technology innovation have now been seen to build global clean industries, and businesses and nations alike are in agreement that the same is needed for hydrogen.

Hydrogen is the most common element on earth, but it still must be produced as it exists only in combination with other elements. Multiple processes and energy sources can be used to isolate hydrogen, and to best understand all the different production means a colour coded nomenclature is commonly used – *Figure 1*. In all cases it takes energy to create pure hydrogen. For that reason, the climate change impact of using it depends on the carbon footprint of the energy used to produce it – sources with a lower GHG footprint are favoured for decarbonisation. However, for the purpose of this thesis a colour-blind approach will be chosen for ease of analysis across sectors and countries, and examples drawn from across the hydrogen rainbow. Hydrogen-storage has a role to play in decarbonisation and as the technology is still in its infancy looking at how to mature the technology and develop a market is the priority.

[4] IRENA. 2020. Green Hydrogen: A guide to policy making. Abu Dhabi. p.12.
[5] Economist. 1999. Stepping on the gas: After many false starts, hydrogen power is at last in sight of commercial viability. p.19-20.

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Figure 1. The Hydrogen Colour Rainbow. Source: Global Energy Infrastructure. 2021.

Once pure hydrogen is created, it is stored and can then be released over a multitude of time periods. This process is called hydrogen-based energy storage (HBES) where hydrogen is acting as a carrier of that primary electricity source. The produced hydrogen then covers an extremely large energy capacity when released, and in all cases, the only waste product when used is water vapor.[6] These aspects, coupled with the fact that hydrogen-storage is applicable at the community level, in the distribution grid and also at the transmission grid level, display an attractive level of flexibility and a promising future for the technology.[7]

As can be seen in *Figure 2* demand for hydrogen has grown more than 300% since 1975, and this trend continues to rise globally.[8] By 2023, industrial demand for hydrogen is expected to grow to $199.1billion.[9] The anticipated speed of growth for hydrogen, and in-turn HBES, is substantial. The technology is market ready, projects exist around the world and national

[6] IRENA. 2019. Hydrogen: A renewable energy perspective. Abu Dhabi.
[7] Wolf, E., 2015. Large-scale hydrogen energy storage. *Electrochemical energy storage for renewable sources and grid balancing* (p. 129-142). Elsevier.
[8] IEA. 2019. The Future of Hydrogen. p. 17.
[9] Market Research Future's. 2020. Hydrogen Generation Market Research Report: Global Forecast till 2023. Chapter 4.

hydrogen roadmaps are becoming commonplace. Yet a fully-fledged stable market – so far – does not exist for the technology, and for the first time in nearly a decade, annual installations of energy storage technologies fell year-on-year in 2019.[10] The anticipated effects of COVID-19 can only add to this staggered growth. HBES progression is still fragile and thus requires further investigation.

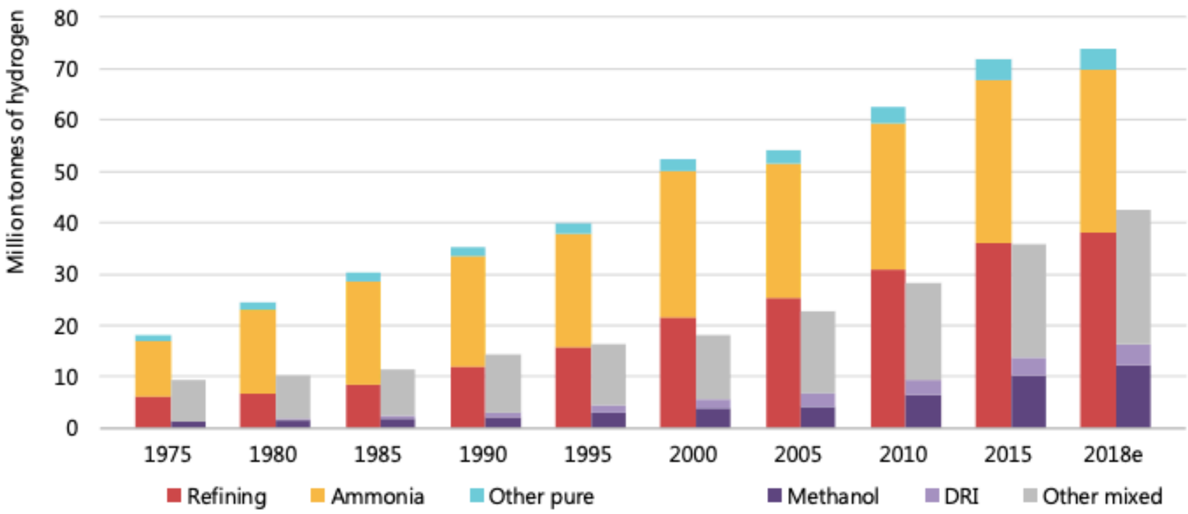

Figure 2. Global annual demand for hydrogen since 1975. Source: IEA. 2019. p.18.

Methodology

This master's thesis is consequently designed to explore the struggles of HBES, despite the inherent promise of the technology itself. To start, in chapter 1, this paper will explore the situation so far and what challenges currently face hydrogen as a storage medium. Then in chapter 2 a comparison of how the situation looks across Japan and France will be carried out. Finally, this paper will highlight the key findings, demonstrate how these can contribute towards hydrogen-storage for decarbonisation and make recommendations.

The situation in Japan and France is chosen for comparison in the second chapter. These countries were chosen as both have released hydrogen specific roadmaps within the last two years, although Japan hold a significantly stronger position in the global market. Each country's

[10] IEA. 2020. Summary Report: Energy Storage. p.1.

unique political and economic framework, alongside their dissimilar cultural normalities, allows for stimulating analysis, not just within each component, but also through the convergence or divergence of each sectors' support for or opposition to a HBES future. Clear comparisons can be drawn from this structure, by demonstrating what works well in one country and what does not work well in the other.

Three core themes will be used for a succinct analysis across this material: Policy, market and civil society. This format will allow a clear comparison of Japan and France, and enable the identified challenges and comparisons made to feed clearly into the suggested recommendations and concluding remarks for change. Examples from varied countries, organisations and sectors will also be used to support arguments and facilitate the discussion.

The methodology of the research will be predominately based on collating and analysing existing literature. Available data will then be complemented with four interviews, across industry players, policy advisors and academics. Each interviewee has their own expertise and insights on hydrogen-storage, with two more knowledgeable on Japan and the others on France. Literature based on the technological aspects and cost-effectiveness of HBES is growing rapidly, as engineers resolve logistical hurdles in the field. However, there is limited literature focused on the technology's adoption within the political, market and civil society sphere, especially within the last two years, since more hydrogen roadmaps have been released. This lack of available material, then, highlights the significance of this thesis.

Theoretical Framework

Transitioning towards hydrogen-storage is complex. It requires deep-structural changes and alterations in the overall configuration of the traditional operating framework across a range of actors.[11] This systemic change from one stable regime to another can be called a *socio-technical transition.* As conceptualised in *Figure 3*, the transition occurs when landscape pressures destabilise prevailing regimes, creating opportunities for promising niches.[12] It is traditionally argued that socio-technical systems are stabilised by regimes that coordinate actors through guiding principles. This stabilising force leads to inertia, lock-in and path dependence in

[11] Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*.
[12] Verbong, G. and Loorbach, D. 2012. Governing the energy transition: reality, illusion or necessity? Routledge. p.9.

existing systems. So, when asked how to transition to a new system you must look at how the existing regime operates and can therefore be changed.[13] To better understand this, Frank Geels' multi-level perspective (MLP) and socio-technical regime theory will be used.

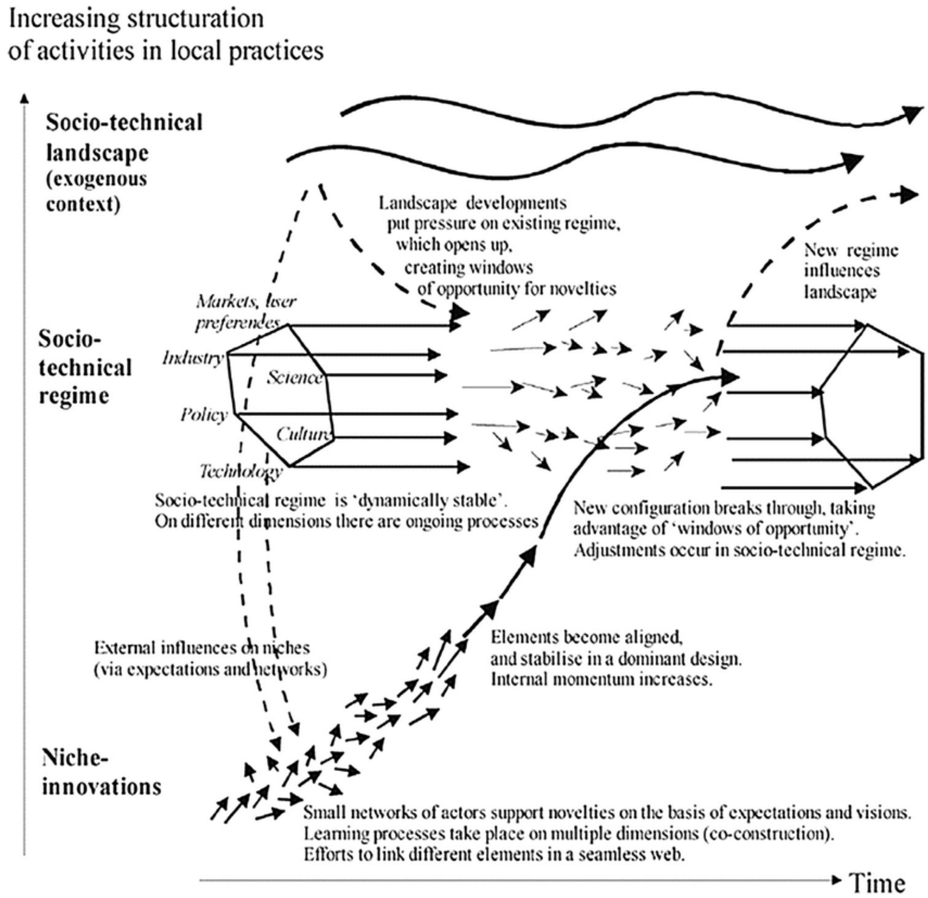

Figure 3. A dynamic multi-level perspective for technological transitions. Source: Geels. 2002. p.1263.

The MLP conceptualises transformations as the result of processes occurring at and between three interrelated levels: niches, regimes and landscape. The theory is an analytical tool to deal with the complexity and resistance to change. The model maps the participation of actors, focussing on how a system is organised and how decisions are made at the socio-technical regime level.[14] Thus outlining how elements of a socio-technical systems do not function on their own but are actively created and maintained by actors embedded within the six sectors seen in *Figure 3*; industry, technology, culture, science, markets and policy. Therefore, a socio-technical system is not only about the interactions between technologies and society but

[13] Geels, F.W., 2006. Multi-level perspective on system innovation: relevance for industrial transformation. *Understanding industrial transformation*. Springer.
[14] Ibid. p.170.

displays a network made of different groups of actors who interplay within a given field. It accounts for their varied interests (elaborated on in chapter 1) and competing visions for a niche-innovation. Most notably though, the MLP recognises that a niche-innovation can be socially controversial, prevented by current legislation, or have low market feasibility – aligning with the core themes of this paper.

The MLP framework acknowledges that for a niche-innovation such as hydrogen-storage to emerge conditions must align in the socio-technical regime, disrupting "business as usual" and forcing actors to realign themselves accordingly.[15] A technology can be seen to take hold in the unaltered niche-innovation bound of *Figure 3*, and progress until it influences the overarching landscape level – which traditionally accounts for exogenous concepts such as climate change or social values.[16] The MLP stresses the importance of each component of the socio-technical regime and the interactions across the structuration levels in order to seize a window of opportunity for regime change.

HBES has all the characteristics of a socio-technical niche: it is a combination of new and existing technologies, yet to be deployed on a largescale; it is supported by multiple actors and constituencies which show increasing interactions, and expectations; but the organisational field is not yet fully stabilised. The HBES niche-innovation is taking hold, its popularity mounting, and so this theoretical framework will be invaluable for guiding the analysis within this thesis.

Research Question

The objective of this thesis is to analyse the governance of HBES as the technology is emerging – how it unfolds and what barriers it is coming up against. The situation in Japan and France is compared and then used as a means to expand this analysis. These two separate components, hydrogen and storage, have separate roles to play and separate sectors to penetrate in order to help towards decarbonisation, but this thesis will look at the two combined and how this technology will impact global decarbonisation. Consequently, the following research question is proposed:

[15] Genus, A. and Coles, A.M. 2008. Rethinking the multi-level perspective of technological transitions. *Research policy*.
[16] Ibid.

What are the different factors that accelerate and/or inhibit the role of hydrogen-based energy storage in contributing to national decarbonisation targets?

In regard to this principal research question, a research hypothesis can be generated, coinciding with the three core themes mentioned. This paper hypothesises that three core areas – policy, the role of the market, and civil society – are able to accelerate and/or inhibit HBESs' role in attaining decarbonisation targets.

The main dynamic here is the political one. Transitioning hydrogen from a niche player to a widespread energy carrier will require an integrated policy approach to overcome initial resistance and reach a minimum threshold for market penetration.[17] Even so, as hypothesised, each theme has the power to inhibit progress and warrants investigation. A systemic perspective is necessary to understand both the problems involved and the interconnections between the various policy, market and civil society domains.

This research is significant, it will highlight the importance of each theme for hydrogen-storage deployment and support the technology's long-term contribution towards global decarbonisation. Policy gaps and opportunities will be presented which can enable countries to negotiate the barriers to reliable growth for HBES in the face of threats like climate change and COVID-19.

[17] IRENA. 2020. Green Hydrogen: A guide to policy making. p.18.

Chapter 1. Challenges Facing Hydrogen-based Energy Storage.

Despite the unprecedented attention hydrogen is receiving, several barriers are still impeding its full contribution to the energy transition. This chapter aims to explore these barriers in order to help optimise hydrogen-storage's contribution towards decarbonisation. By way of introducing this chapter a short state of play for the current hydrogen market will first be outlined. The four core challenges currently facing HBES will then be elaborated on; the path dependency from EV supply chains drawing resources away from HBES for the wrong reasons; uncertainties in the policy environment, most notably the lack of a clear regulatory framework; gaps in a potential hydrogen market which orientate around inadequate transparency; and the social acceptance hurdle for integrating hydrogen-storage into everyday life.

The State of Play

As more countries pursue deep decarbonisation strategies hydrogen will have an increasingly critical role to play. The fuel offers a versatile, clean, and flexible energy vector for the energy transition. While hydrogen is not the only decarbonisation lever, it is an essential lever among a set of other technologies. It makes the large-scale integration of renewables possible because it enables energy players to convert and store energy as a renewable gas, and hydrogen-storage's multipurpose nature allows various energy producing means to operate in conjunction with one another, further speeding up decarbonisation. Moreover, it can be used for energy distribution across a range of sectors and regions, whilst simultaneously acting as a buffer for renewable energy production. It can also provide a way to decarbonise segments in power, transport, buildings, and industry, which would otherwise be difficult to decarbonise; the '*hard to abate'* systems.[18] These unique strengths of hydrogen are gaining broad recognition across sectors, regions and governance levels, and in the face of the current climate emergency the necessity for hydrogen is mounting.

Hydrogen is gathering strong momentum as a key energy transition pillar.[19] The entire hydrogen value-chain is maturing, and an increasing number of actors are therefore interacting with the technology. As demonstrated by the near doubling of members of the Hydrogen Council – a

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[18] Reuters. 2020. Webinar: Fireside chat on the future of hydrogen productions and its role in renewable energy.
[19] Hydrogen Council. 2021. Hydrogen Insights Report. *Hydrogen Council, Mckinsey & Company.* p.iv.

global coalition of industry CEOs with a united vision and long-term ambition for hydrogen – from 60 to just over 100 members in the past year.[20]

Recognising the escalation in hydrogen actors is imperative for understanding how the technology will evolve, as well as the conflicting visions and interests that help explain the challenges studied later on in this paper. The eagerly anticipated ramp-up in the hydrogen market will require the engagement and coordination of not just industry players, but many heterogenous stakeholders,[21] and as a consequence *Figure 4* identifies those most relevant. Through a stakeholder mapping this paper aims to analyse stakeholders' interests and influence of power. The stakeholder mapping is derived from historical evidence of emerging niche technology, news articles, academic research and interviews. It is imperative to realise that not all stakeholders share the same vision for hydrogen,[22] and therefore, understanding the significance of these respective views is essential, as represented by the four coloured quadrants in the Key of *Figure 4*.

As seen from this overarching perspective of hydrogen stakeholders a lot of actors need to be accounted for, most notably: the national governments, who will be responsible for setting hydrogen strategies, a regulatory framework and can help incite investment; companies in the value chain, ranging from manufactures to producers these industry players are vital for innovation and implementation; associations or councils, these organisations will support other stakeholders, provide knowledge exchange, track progress and help facilitate the hydrogen dialogue; and broader civil society, often overlooked when it comes to a technology's development, civil society has a high influence and must be handled with care, as elaborated on later in the chapter. A paradox can then be seen; the high number of stakeholders currently engaging on the topic means there will be an abundance of opportunities in terms of synergies and cooperation, but similarly, just as many conflicts of interest and competing views will exist. This will generate a complex environment for the governance of a hydrogen economy.

[20] Hydrogen Council. 2021. Hydrogen Insights Report. *Hydrogen Council, Mckinsey & Company*. p.4.
[21] Schlund, D., Schulte, S. and Sprenger, T., 2021. *The who's who of a hydrogen market ramp-up: A stakeholder analysis for Germany* (No. 2021-2).
[22] Andreasen, K. P., & Sovacool, B. K. 2014. *Mapping and interpreting critical hydrogen stakeholders in Denmark. International Journal of Hydrogen Energy, 39(15), p.7634–7637.*

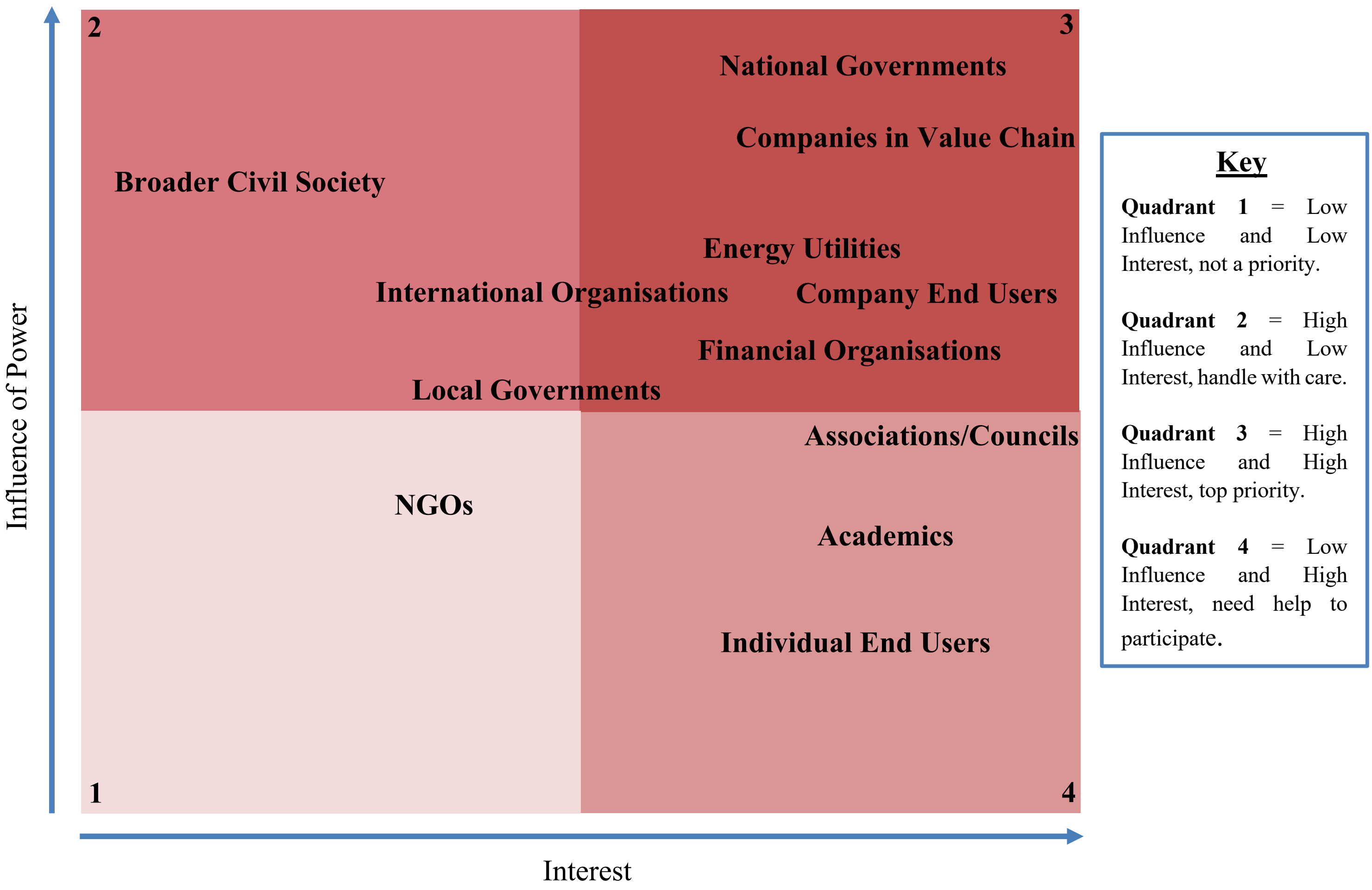

Figure 4. Stakeholder Mapping. Source: Author. 2021.

Even so, the extensive range of stakeholders engaged on the hydrogen topic is promising. Traction is undoubtedly growing for its use. However, as of 2020, the share of hydrogen in total global energy supply sat well below 1%.[23] To put this in perspective, the total global hydrogen market size is valued at $120.77billion,[24] whereas the market for natural gas distribution in the United States alone is valued at $155billion.[25] Despite hydrogen being a necessity for global decarbonisation with a diverse range of stakeholders contributing to its development, hydrogen asserts a negligible market share.

[23] IEA. 2020. Key World Energy Statistics. p.12.
[24] GrandViewResearch, 2020. Hydrogen Generation Market Size, Share & Trends Analysis Report by Systems Type, Technology, Application, Region, And Segment Forecasts, 2021 – 2028.
Online: https://www.grandviewresearch.com/industry-analysis/hydrogen-generation-market
[25] IBISWorld, 2021. Natural Gas Distribution in the US Market. Online: https://www.ibisworld.com/industry-statistics/market-size/natural-gas-distribution-united-states/

Consequently, this chapter will now turn to why this is the case and highlight what currently holds the nascent technology back. To realise the vision of a future global economy underpinned by hydrogen, the challenges currently facing the technology must be understood.

Emerging Path Dependency from Electric Vehicles (EVs)

It is increasingly common for academics to describe a process as path dependent. Traditionally used to grasp social and political processes, the path dependency concept is used as an organising tool.[26] It is sometimes not possible to uncover the logic (or illogic) of the world around us except by understanding how it got to be that way.[27] While many analysts now invoke the concept of path dependence, concrete definitions are rare. To establish greater clarity for this paper, the term path dependency will be used to cover the idea that:

> '*At every step of a process there are choices – political and economic – that provide real alternatives. Path dependence is a way to narrow conceptually the choice set, and link decision-making through time. It is not a story of inevitability in which the past neatly predicts the future*.'[28]

As the choices are narrowed, preceding steps in a particular process, say a technology's development, induce further movement in that same direction. To better demonstrate the notion of path dependency, a more specific concept can be used - increasing returns. In an increasing returns process, the probability of further steps along a particular path or process increase with each move down that path.[29] The relative benefits of the selected activity, or technology, compared with other possible options increase over time. An example of this is currently unfolding through the decarbonisation of the transport industry, as decision makers are faced with the choice of Fuel Cell Electric Vehicles (FCEVs) and traditional EVs.

Hydrogen has been a global commodity for decades and a robust hydrogen industry already exists. Used primarily as an input into oil refining and as an industrial feedstock, global demand

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[26] Ostrom. E. 1999. Institutional Rational Choice. p. 39–41
[27] David, P.A., 1985. Clio and the Economics of QWERTY. *The American economic review*, *75*(2), p.332-337.
[28] Kay, A., 2005. A critique of the use of path dependency in policy studies. *Public administration*, *83*(3), p.553-571.
[29] Pierson, P., 2000. Increasing returns, path dependence, and the study of politics. *American political science review*, p.251-267.

for hydrogen has reached 70million metric tons annually.[30] Less than 0.1% of the required 70Mt hydrogen is 'green hydrogen' produced from the conversion of renewable energy sources.[31] The future of hydrogen is therefore mapped from its historical use with fossil fuels. Alternatively, energy storage relies on another aspect of the energy market for most of its existing research and technological advancements – EVs. This formulates a challenge for the energy storage sector in terms of hydrogen. The market so far is largely reactive – responding to what works well and spills-out of the EV sector – rather than being proactive with research specific to how HBES would best benefit the sector. Given that the market for EV batteries is already ten times greater than for grid-scale batteries,[32] the indirect effects of innovation and cost reductions in application will be significant to the energy storage market as a whole. The IEA provide a clear example of these spill-over effects by showing that in 2019, "around 60% of grid-scale batteries are currently nickel-manganese-cobalt blends – the technology of choice in EVs."[33]

So, what opportunities are being missed due to EV batteries current dominance of the energy storage market? How is the path dependency from EVs in the storage market impacting HBES? To best answer this question FCEVs – EVs' main competitor – will be looked at in more detail. William Grove, in 1839, found a way to reverse the electrolysis process and generate electricity by combining hydrogen and oxygen to form water in what would be later called a fuel-cell.[34] Fast forward nearly two centuries and the technology's role is still growing.

FCEVs are widely recognised as being best suited for larger vehicles due to hydrogen's superior energy density in comparison to batteries, meaning an FCEV can drive further and transport more payload than traditional EVs. But the core infrastructure and refuelling station benefits of FCEVs are less familiar. As *Figure 5* depicts, hydrogen refuelling takes just one fifteenth of the time as fast-charging EV infrastructure, at a cheaper price to build, whilst also using about ten to fifteen times less space to fuel the same number of vehicles.[35] These are not only remarkable strengths of FCEVs, but they stress key areas that currently act as bottlenecks to the EV supply chain.

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[30] This hydrogen is predominately produced from natural gas and coal currently, and associated CO_2 emissions are therefore significant. IEA. 2020. Summary Report: Hydrogen.
[31] Nelson et al, 2020. Green Hydrogen Guidebook. *Green Hydrogen Coalition.* p.5.
[32] Ibid.
[33] IEA, 2020. Summary Report: Hydrogen. p.2.
[34] Olah et al, 2009. Beyond Oil and Gas: The Methanol Economy. Publishing: Wiley-VCH, p.144.
[35] FCH. 2019. Hydrogen Roadmap Europe: A Sustainable Pathway or the European Energy Transition.

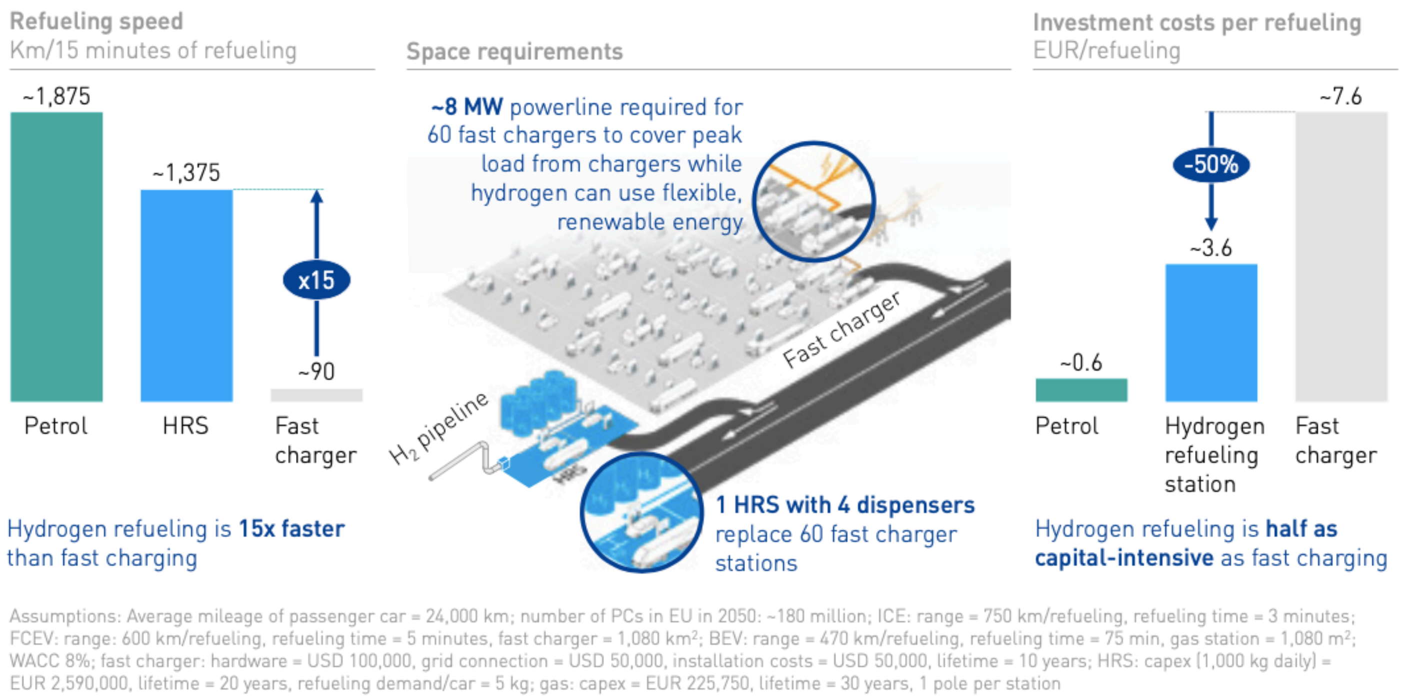

Figure 5. Implications of Refuelling Speed on Space and Requirements and Investments. Source: FCH. 2019. p.29.

When analysing the various battery storage styles, the end-goal of global decarbonisation must ultimately be the defining factor. In this long-term context FCEVs and hydrogen-based storage as a whole dominate again. Reinforcing the existing path dependency problem – investment is aimed towards EVs despite its inferior role for longstanding decarbonisation. The precious metals used in today's EV batteries come with high environmental costs, lithium, nickel or cobalt's presence in batteries all depend on extremely polluting mining activities. Processing just 1 tonne of these rare-earth metals can produce up to 2,000 tonnes of toxic waste.[36] The use of these precious metals is not sustainable long-term.

The current situation runs the risk of Technological Lock-in: the idea that there are significant increasing returns for the adoption of energy technologies, produced by economies of scale, learning and networks, which arise out of the integrated and systemic nature of development for these technologies.[37] Energy storage technology that was made financially viable extremely quickly, due to the EV market, is emerging as a technology that shows clear increasing returns, and the industry is only set to grow. The risk of being locked into the EV socio-technical regime is existing and rapidly mounting. Consequently, path dependency from the EV supply chains could mean that resources are drawn away from HBES, and for the wrong reasons.

[36] Edmondson, J. 2020. Will Rare-Earths be Eliminated in Electric Vehicles Motors? IDTechEx.
[37] Carillo-Hermosilla, J. 2006. A policy approach to the environmental impacts of technological lock-in. p.718.

Troublingly, the path dependency outlined is not just a threat to FCEVs. The entire hydrogen industry is at risk. Missed funding for the fuel-cell market means missed funding for hydrogen infrastructure that would strengthen the entire industry, no matter its end use. If the benefits are recognised here for transport, spill-over effects would occur for other aspects of hydrogen as the technology becomes more ubiquitous in terms of transmission and distribution, and its potential more widely recognised.[38]

The extent of this path dependency issue is evident in Europe. *Figure 6* clearly shows just how overshadowed FCEVs currently are in the European electric car industry. An alarming trend is shown for the future of fuel-cell technology, with very little growth anticipated over the next 5 years.

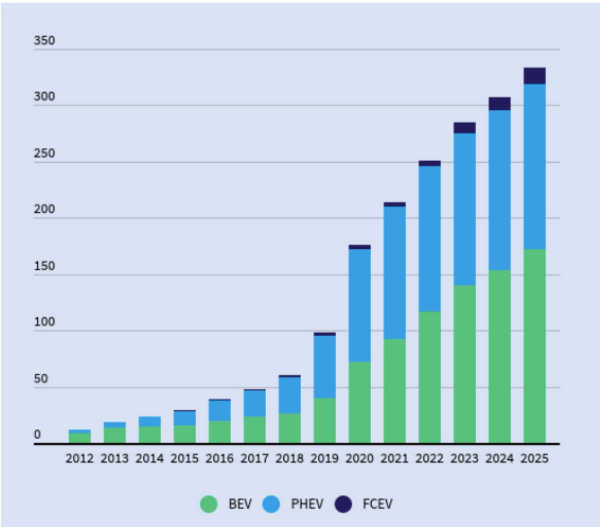

Figure 6. A bar graph to show the total number of EV models on the market in Europe. Source: Transport&Environmnet. 2019. p.11.

To tackle such an issue Europe must look to the word leader of renewable technology: China, where the path dependency issue is being tackled head on. In an attempt to avoid the danger associated with putting all eggs in one basket, Beijing has set an unprecedented target of having 1million FCEVs on the market by 2030,[39] double the EU target.[40] China has swiftly become a global leader in batteries and EVs, and fuel-cells and hydrogen may follow the same trajectory,

[38] Deloitte China. 2020. Fuelling the Future of Mobility: Hydrogen and fuel cell solutions for transportation. Online: https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf
[39] U.S. Department of Energy. 2020. Hydrogen and Fuel Cells Update. Online: https://www.energy.gov/sites/prod/
[40] Asif, U. and Schmidt, K., 2021. Fuel Cell Electric Vehicles (FCEV): Policy Advances to Enhance Commercial Success. *Sustainability*, *13*(9), p.5149.

due to acting proactively on the FCEV market and not leaving hydrogen-storage behind.[41] It is also important to highlight here that EVs are not displaced by this goal. They will undoubtedly have an enormous role to play in decarbonisation, especially for smaller vehicles, but China is acknowledging this alongside FCEVs; it's not a trade-off, and this is key.

This long-term favourability of FCEVs draws light to a thought-provoking aspect of the path dependency issue. If the currently favoured EVs mean that short-term decarbonisation issues, such as reducing transport emissions will be hit sooner, then surely the issue of path dependency should be disregarded?

Policy-makers must weigh up tackling transport emissions in the near-term with rapid investment and roll-out of EVs, against the issues of precious metals and infrastructure in the long-term where FCEVs are favourable. The current way of thinking is encapsulated here. FCEVs are overshadowed by EVs in sight of hitting decarbonisation as quickly as possible, threatening the HBES industry. As the path dependency concept dictates, switching technologies at a later date is costly, inefficient and extremely hard to manage. Essentially, favouring EVs diminishes the role of FCEVs for decarbonisation but most importantly this thinking is visibly unsustainable for concrete, long-term, decarbonisation.

HBES's increased power capacity, precious-metal free structure and storage durability – all of which will be vital for reaching and sustaining global full decarbonisation goals in the future – are evidently under threat from EV market path dependency. However, HBES's universal benefits are well known and documented, allowing for easy comparison to EV batteries. The technology's versatility and applicability are unparalleled, and this needs to be recognised across market players. The hydrogen-storage topic requires further investigation, despite the emerging path dependency element, in order to highlight gaps in the policy, market and civil society, that are currently failing hydrogen as an energy carrier.

The Political Environment

Climate change has put energy policy and the need for deep decarbonisation at the very centre of the political agenda. Even so, the best means to decarbonise remains a contentious topic and,

[41] Jianju. K. 2020. Prospects of a hydrogen economy with Chinese Characteristics. Etudes de l'Ifri. IFRI.

as seen with EVs, there is never just one option. However, as indicated by the IEA political momentum towards hydrogen has improved significantly in this context over recent years.[42] An increasing number of hydrogen-specific national strategies are being released, alongside growing attention from cities, utilities, and various energy related industries. It is now estimated that countries representing about half of the world's GDP have credible hydrogen strategies.[43] A number that rises to 70% once the U.S, Canada and Russia finalise their plans.[44] Agreement on hydrogen having a serious role to play in the future energy network is growing. The speed of transitioning to hydrogen will depend though on how quickly its production can ramp up, and on making it easily accessible where it's needed. Policy plays a key role here, and significant challenges still remain.

Strategies express a strong commitment by governments towards hydrogen and can trigger momentum within industry. But they are only the starting point. Political actors must translate their ambitious strategies into concrete measures. To do so, strong political action must be taken. The importance of this political action and the impact it can have on the demand for hydrogen is highlighted in the scenarios in *Figure 7*. The scenario depicting strong political action sees over three times as much demand for hydrogen in comparison to the weak policy scenario. Policy is not the be all and end all, but undoubtedly a core enabler of the niche HBES technology and therefore requires careful consideration. Policy mishaps, as seen with EV path dependency, run the risk of locking in slower technology or building towards less efficient pathways. Making the correct policy priorities is of the upmost importance.[45]

[42] IEA, 2020. Summary Report: Hydrogen. p.2.
[43] C, Ferreira Marques. Et al. 2020. The Missing Piece of the Hydrogen Puzzle.
[44] Ibid.
[45] This is also a point that cannot be know for sure. No way to guarantee you are making the right decision. IRENA .2020. Green Hydrogen: A guide to policy making

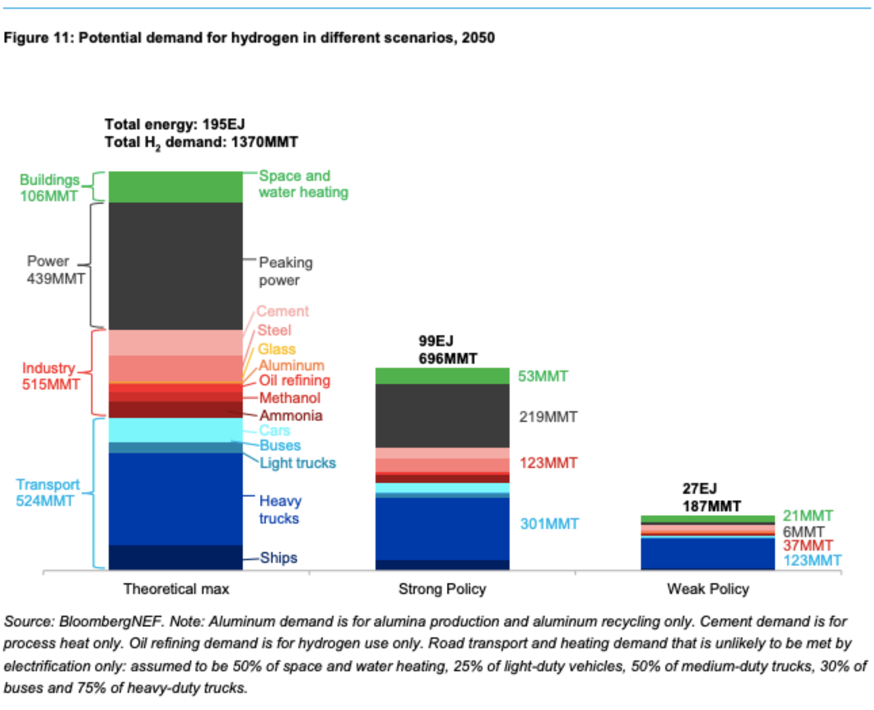

Figure 7. The Potential Demand for Hydrogen in Different Scenarios to 2050. Source: BloombergNEF. 2020. p.8.

The main policy challenges currently facing the hydrogen-storage sector orientate around regulatory barriers, ownership issues and risk mitigation. Policymakers' efforts in these areas can dictate industry players' role in the hydrogen supply-chain, levels of investment and social acceptance of the technology. Each challenge is important in its own right. For this section, however, the regulatory framework issue will solely be focused on.

The current lack of a clear regulatory framework acts as the single largest barrier for large-scale hydrogen deployment.[46] As with any emerging industry, developing a robust regulatory framework is a key hurdle that must be overcome to mobilise the private sector. Despite government commitments and long-term strategies, regulations can be slow to adapt. A survey by Baker Mackenzie revealed that unfit or outdated regulatory regimes were significant hurdles to smart power advancement, including HBES. Indeed, 77% of respondents from the industry said legal and regulatory frameworks are inadequate.[47] Generating an uncertain operating field for industry players, thereby isolating less established actors. Making clear and coherent

[46] Hydrogen Europe. 2021. The EU Hydrogen Strategy: Hydrogen Europe's Top 10 Key Recommendations. Online: https://hydrogeneurope.eu/hylaw
[47] Baker McKenzie. 2018. The Smart Power Revolution: Opportunities and Challenges. Online: https://www.bakermckenzie.com/en/insight/publications/2018/04/smart-power-revolution

regulatory decisions for the hydrogen industry is vital, as they will have a profound effect in terms of competitiveness for hydrogen in the future.[48] To better understand the prevalence of the regulatory framework challenge, it will be broken down into three core issues that currently threaten the industry: the lack of standards, guarantees of origin and trade issues.

The International Standards Organization (ISO) established a "Hydrogen Technical Committee" in 1990 with the objective of developing international standards in the field of systems and devices for the production, storage, transport, measurement and general use of hydrogen.[49] To date, seventeen ISO standards relating to hydrogen have been published.[50] These standards are vital for anticipating technical requirements of hydrogen-storage, whilst, also increasing both the productivity and efficiency of its use. But, so far, they are not extensive enough or internationally recognised, and subsequently a standardisation challenge remains. International standards mean that hydrogen end-users can have confidence that their products are safe, reliable and of good quality. Consequently, a uniform set of international standards for how the hydrogen value-chain should operate is imperative for the industry to grow and to be able to do so with the necessary level of social acceptance. The social acceptance aspect of HBES will be expanded on later in this paper.

Standards are established by consensus and then provide rules, guidelines or characteristics for the repeated use of an activity, aiming to ensure the optimum degree of order in a given context.[51] Without such a mechanism a project developer faces hurdles where regulations and permit requirements are unclear, unfit for new purposes, or inconsistent across sectors and countries. The lack of regulations act as an unnecessary barrier to investment and consequently stunts HBES growth and its ability to contribute towards decarbonisation.

Furthermore, a regulatory framework, including standards, would typically help define commercial deployment models, informing project budgeting. Subsequently, without clear regulatory frameworks to allow industry decision-makers to understand their cost and revenue basis, commercial projects will not be able to reach clear financial investment decisions.[52] A lack of political leadership creates an uncertain hydrogen market, as the required conditions to

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[48] FSR. 2020. Cost-effective decarbonisation study. European University Institute.
[49] Akin Gump. 2020. The Emerging Hydrogen Economy: Regulation, Policy and Industry Update Online: https://www.lexology.com/library/detail.aspx?g=e78409d9-bfcb-477a-ad85-15ea9698da39
[50] Ibid.
[51] European Committee for Standardization. 2021. European Standards. Online: https://www.cen.eu/work/products/ENs/Pages/default.aspx
[52] Isaac, T. 2019. Hydrogen: Deployment Barriers. Online: https://www.thechemicalengineer.com/features/hydrogen-deployment-barriers/

operate are not defined. A holistic picture of the technology's whole value chain's cost dynamics and interactions is lacking. [53] There is no broader perspective. The current unaligned policy framework adds redundant risk and is a key challenge for HBES uptake.

A lack of clear standards in the industry also threatens interoperability. Hydrogen-based storage's unique selling point for the energy transition is how, as we are moving towards a single distributed energy system, hydrogen can act as an intermediary between different energy sources and bring flexibility to the system. Without consistent standards this becomes a challenge. Existing firms struggle to exchange and make use of information, and simultaneously a barrier exists for entering the market, and with that, to the expansion of the hydrogen economy. Standards ensure compatibility and interoperability of hydrogen components, products and services. Clear definitions, certification schemes, and procedures are provided, allowing for different sectors, countries and businesses to operate with one another. Bringing benefits in terms of reducing costs, enhancing performance and improving safety.

The second challenge that stems from the lack of a regulatory framework for hydrogen is guarantees of origin (GO). In order to ensure that the use of hydrogen is in fact benefitting global emission levels, GOs must be used. A GO labels the origin of a commodity such as hydrogen, providing information to customers on the source of the product. It operates as a tracking system ensuring the quality of a product.[54] As it stands, worldwide, there is currently only one established GO program for hydrogen, Europe's CertifHy scheme. CertifHy was initiated and funded by the European Commission but was developed by industry.[55] Following the CertifHy scheme's success, momentum for similar GO schemes in other hydrogen hotspots is growing. Global standards are being called for in some countries in order to ensure competitiveness of commercial hydrogen facilities and to ensure that revenue can be maximised.[56] Undoubtedly, policymakers must act on GOs as they provide transparency to hydrogen end-users across all sectors and help create market pull for hydrogen, independently from production sites; utilising green credentials to maximise profits.

So, what is incorporated in a GO scheme? The information included in a hydrogen GO would cover the geographic source of energy used, whether it originates from renewable energy, the

[53] Hydrogen Council. 2020. Path to Hydrogen Competitiveness: A Cost Perspective. p.3.
[54] Bioenergy International. 2019. CertifHy launches Europe's first green GO.
[55] Grexel. 2020. Grexel to operate the first EU-wide GO market for Green Hydrogen. Press Release. Internal.
[56] Linklaters. 2020. Capturing the Hydrogen Opportunity. Insights, Thought Leadership.

emissions produced throughout its life-cycle and other relevant externalities.[57] As demonstrated in *Figure 8*, the GO system essentially allows you to track hydrogen production emissions and then value the lower GHG emissions used.[58] Informing not only customers on which type of energy they consume, renewable or fossil, but also, market players and governments on their carbon footprints in relation to hydrogen. Attaining and validating decarbonisation targets without such a system in place will be much tougher.

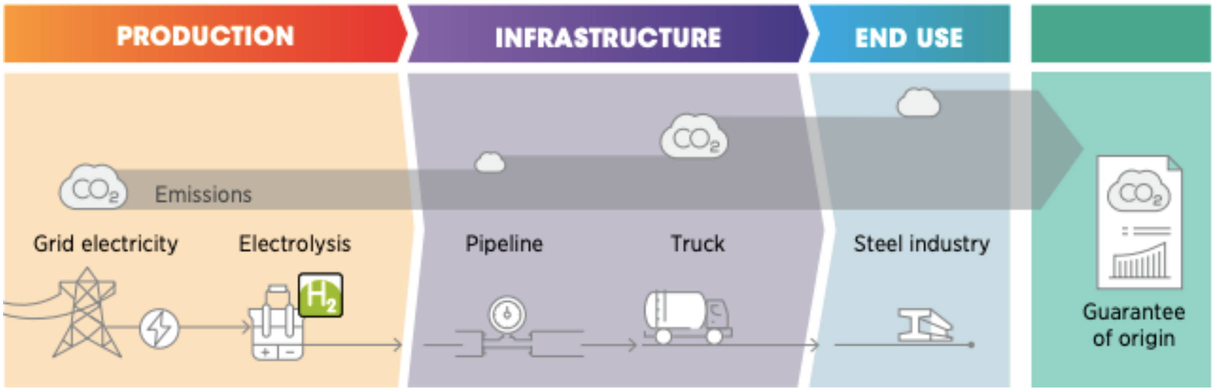

Figure 8. The intricacy of Guarantees of Origin lifecycle emissions. Source: IRENA. 2020. p.30.

Recognising the need for GOs for all forms of hydrogen on an objective basis will be imperative for facilitating informed, cost-effective hydrogen use. Hydrogen deprived of GOs will be dismissed much easier by members of society, as the HBES process is hidden from end-users. Implementing the GO system for hydrogen is consequently incredibly important for accelerating the industry's development. However, objectively documenting hydrogen's various production pathways, and accounting for its numerous end-uses is a real challenge for policymakers. For instance, with regard to the transport sector, hydrogen can be used directly in fuel-cells, or indirectly in the form of synthetic fuels. The latter requires a very energy-intensive process, as well as chemical compounds, the most common of which is carbon dioxide. As a result, emissions are produced, and these must be quantified for GOs. The final use of hydrogen determines its sustainability and therefore the GO system can become

[57] A, Piebalgs and C, Jones. 2020. Proposal for a Regulatory Framework for Hydrogen Guarantees of Origin. Online: https://cadmus.eui.eu/bitstream/handle/1814/68779/PB_2020_37_FSR.pdf?sequence=1
[58] IRENA .2020c. Reaching zero with renewables: Eliminating CO2 emissions from industry and transport in line with the 1.5°C climate goal. Abu Dhabi.

complex.[59] Policymakers face a significant, albeit important, challenge in establishing an effective, transparent and uniform GO regulatory mechanism for future hydrogen-storage use.

The previous two sub-challenges of the regulatory framework issue are important for their own reasons but the absence of standards and GO also directly feed into the final challenge to be mentioned: international trade. Today, hydrogen is still a very localised industry. Some 85% of hydrogen is produced and consumed on-site, mostly at refineries.[60] There is evidently a clear lack of international co-operation from policymakers. International co-operation – in the form of trade – is vital to accelerate the growth of versatile HBES around the world.[61] Since the costs of hydrogen production differ significantly between regions, long-distance transmission and international trade in hydrogen is an attractive option for governments. Enacting adequate trade policy is a key hurdle to overcome for unlocking the full potential of hydrogen.

The road to an integrated, well-functioning and clean global hydrogen trade network is fraught with uncertainty and risks. It could easily end up like natural gas – largely traded within countries or on fixed, long-term, bilateral contracts between countries, with little room for growth.[62] Although there is now a fully-fledged, flexible gas market, the road to this point was insecure, and this must be avoided for hydrogen. Any cross-border hydrogen trade that is established also has the potential to produce new dependencies between states. Hydrogen trade could thus add a new dimension to geo-economic rivalry amongst competing countries,[63] inciting potential conflict. The global map of energy trade, as we know it, could be completely reshaped by future hydrogen trade.

However, one of the key differences with trade in crude oil or natural gas, in comparison to hydrogen is that hydrogen trade will be less asymmetric. Hydrogen, technically, can be produced and consumed by every country, making numerous countries potential prosumers. This means that most trade partners hold a degree of bargaining power in future negotiations and that in theory the future energy network should be geographically more just. Even so, to ensure that international trade occurs in a non-exploitive manner it must be developed alongside fair, equitable standards and a clear GO operating system.

[59] ECOS. 2020. The challenges of Guarantees of Origin for Certified Renewable Hydrogen. Online: https://ecostandard.org/wp-content/uploads/2020/03/ECOS-BRIEFING-GUARANTEES-OF-ORIGIN.pdf
[60] IRENA, O. and DESA, U., 2019. A new world: the geopolitics of the energy transformation.
[61] IEA, The Future of Hydrogen. p.15
[62] Van de Graaf, T., Overland, I., Scholten, D. and Westphal, K., 2020. The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, *70*, p.101667.
[63] Ibid.

The aforementioned regulatory framework challenges currently limit the development of the HBES industry.[64] They are not mutually exclusive but multifaceted challenges that the political environment must tackle in unison. The challenge is immense. That being said, government support isn't everything for hydrogen. Having legislation in place since 2006 hasn't helped Argentina get far, and alternatively a lack of federal support hasn't stopped California from making significant progress.[65] Other components of the hydrogen economy evidently have an impact, and it is these that we will now turn to.

Gaps in the Market

Political traction for HBES is growing. Nonetheless, a stable market, so far, does not exist for the technology, and for the first time in nearly a decade annual installations of energy storage fell year-on-year in 2019.[66] With the anticipated effects of COVID-19 looming, a quick turnaround for the stagnating global energy storage market is not looking likely.[67] However, despite the field as a whole struggling, the global hydrogen-storage market was valued at $12.5billion in 2019, and is now anticipated to grow at a compound annual growth rate of 5.1% from 2020 to 2027.[68] One of the largest barriers to any new technology though – not just hydrogen – is the scaling-up process. Accelerating this process is fundamentally a market design challenge: how to best go from small-scale demonstrations of viability to large-scale industrial processing? This involves a transition from purely scientific and technological challenges to ones of logistics, economics and, above all, the challenge of ensuring market transparency.

As substantiated in David Mathis's near half a century old book, *Hydrogen Technology for Energy*, the traditional drawback of hydrogen has always orientated around costs.[69] For many years, hydrogen has been seen as a potential fuel of the future, while not being quite ready for economic implementation, and, despite the growing attention hydrogen is currently receiving, the technology is still not cost-competitive when compared to expanding renewable

[64] IEA. 2019. The Future of Hydrogen. p.14
[65] Ferreira Marques, C. 2020. The Missing Piece of the Hydrogen Puzzle. Policy Matters.
[66] IEA, 2020. Energy Storage.
[67] Ibid
[68] GrandViewResearch. 2020. *Hydrogen Energy Storage Market Growth & Trends.* p.1
[69] The book stresses the high cost relating to connecting to the grid and technology infancy at the time. Mathis, D.A., 1976. *Hydrogen technology for energy. etr.*

installations or incumbent fuels; undeniably, a major challenge for progressing the hydrogen socio-technical regime.[70] Financial gaps exist across its supply chain in terms of infrastructure, electrolysers, renewable energy and storage amenities, and these faults lie not with the technology itself, but rather the way the market currently operates. Components across the supply chain would benefit from clearer market leadership to increase cost-competitiveness.

Fortunately, the roadmap to cost-competitive low-carbon hydrogen is fairly set in stone. As demonstrated by IRENA in *Figure 9*. If electrolyser manufacturing continues to scale-up, and costs continue to fall, then renewable hydrogen could be produced at \$0.7 to \$1.6/kg in most parts of the world by 2050,[71] making it cost-competitive with natural gas on an energy-equivalent basis.[72] Consequently, the core gap in the market to be addressed in this section, although still cost related, lies more in the lack of financial transparency for hydrogen.

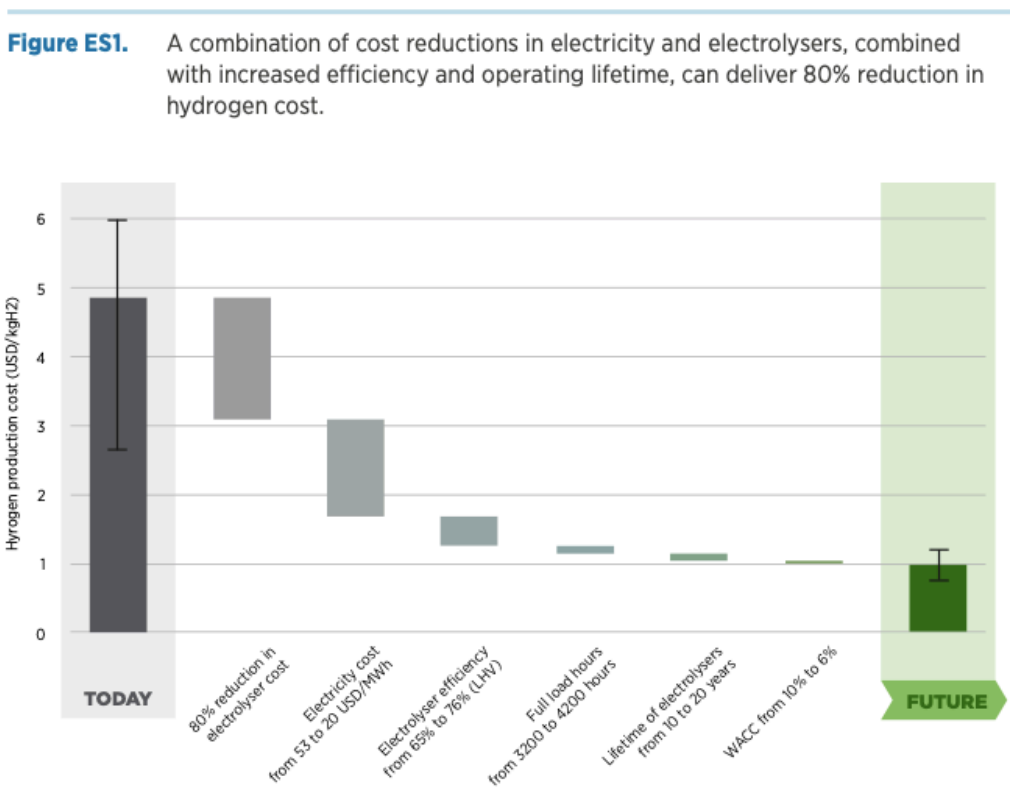

Figure 9. Green Hydrogen Cost Reduction Roadmap. Source: IRENA. 2020. p.3.

[70] Wan, L., Zhang, W. and Xu, Z., 2020. *Overview of Key Technologies and Applications of Hydrogen Energy Storage in Integrated Energy Systems.* p.4.
[71] BloombergNEF. 2020. Hydrogen Economy Outlook. p.2.
[72] The above calculation is equivalent to gas prices at \$6-12/MMBtu, making it competitive in India, Germany, China, Brazil and Scandinavia. Ibid. p.2.

As seen with the increase in national strategies, investment is on the rise, and this, coupled with the growing demand for hydrogen from industry players, means the hydrogen innovation tipping point looks near. Now it is a question of how best to utilise the growing market pull and government investment to best maximise HBES's potential for decarbonisation. The biggest threats to the market are seen here in terms of ensuring financial transparency and allocating subsidies.

Currently, market players are unable to operate on a level playing field, counterparty risk is prominent and there is no clear price reference for hydrogen use. These challenges are clearly summarised by Daniel Wragge, the director of political and regulatory affairs at the European Energy Exchange (EEX), when he states that "to have a market, one of the most important things you need is transparency."[73] A lack of transparency means that pricing and volumes of hydrogen are unclear. Under these conditions, access to the market is tougher, especially for smaller players, and the efficient use of hydrogen resources is not guaranteed.[74] For example, in 2017 a contract was signed for Air Liquide to supply hydrogen to Pemex's Miguel Hidalgo refinery in Tula, Mexico for a period of 20 years.[75] With a lack of hydrogen spot prices to base this contract off, clear risks for the market players existed and only big companies such as Air Liquide where able to handle these risks and the high upfront costs associated with them. Smaller market players where financially bullied out of the contract due to a lack of financial transparency. The current market model favours large companies who naturally seek to gain market share early on in HBES development. They do so even if at the expense of profits and uncertainties as it oppresses competitors.

Hydrogen use also comes under threat of being undervalued in these long-term contracts. They are not responsive to market trends and have no base price to build from, therefore the optimal pricing for hydrogen is not attained. The contract is not sufficiently informed. Under-pricing hydrogen in this manner directly threatens future development and market conditions inhibit HBES's role in attaining decarbonisation targets.

Whereas policymakers will have a greater role in preparing the legal and social framework for greater hydrogen adoption, private companies will be more responsible for providing the

[73] Wragge, D. 2021. *Interview on a hydrogen market.* Zoom with Toby Walker. 5th February 2021.
[74] EEX. 2020. Position Paper: Energy Trading Markets for Hydrogen.
[75] AirLiquide. 2017. AirLiquide signs a long-term contract with PEMEX for the supply of hydrogen to the Tula refinery in Mexico. Online: https://www.airliquide.com/sites/airliquide.com/files/2017/09/06/air-liquide-signs-a-long-term-contract-with-pemex-for-the-supply-of-hydrogen-to-the-tula-refinery-in-mexico.pdf

financial support to help these projects get off the ground.[76] But how can they be expected to invest without clear price signals from the market? Market places create a price reference, and these then signal to market players when is best to buy or sell. The lack of financial transparency, and missing market signals, therefore, stunt healthy competition in the market and this in-turn is detrimental to the development of a hydrogen market.[77]

Although competition may be lacking, individual hydrogen projects are on the rise. With over 126 hydrogen projects in Europe alone[78], and many more planned, having a sufficient overview of the market is therefore a challenge in itself. More importantly, there is a challenge in the fact that a lot of key developments in the hydrogen market must happen in unison. In order to fully establish the HBES market, adequate transmission, distribution and production are all necessary. HBES's ability to decarbonise multiple sectors at multiple scales can be seen as both its greatest asset and its greatest challenge here – primarily because the decisions that govern how the technology's benefits are to be compensated are disparate, falling under multiple jurisdictions, bodies, and regions. Purposeful and unified action in the field is consequently problematic, and only accentuates the need for transparency to be able to operate across all these different sectors and governance levels.

As shown, financial transparency is vital for a hydrogen market. However, the technology itself must first reach a point of being market ready. Here we then turn back to the initial financing for HBES. Clear subsidies are missing. Although it has been mentioned that costs are set to fall, and that investment is being mobilised, how should this investment be distributed? A huge challenge still remains in the form of allocating well-defined subsidies for the industry. As we have learned with the experience of developing the wind and PV markets, a key challenge to the cost-effective design of energy policy at the beginning of a new technology cycle is timing: getting the balance right between initial research and development to lower costs and creating demand through subsidies.[79]

Allocating a clear subsidy roadmap is vital for the future hydrogen industry.[80] Most renewables today are actively competitive in the market due to subsidies. Yet, it remains extremely

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[76] Casey, JP. 2021. A €100bn hydrogen industry? Challenges for the European Green Hydrogen Acceleration Centre. Online: https://www.power-technology.com/features/a-e100bn-hydrogen-industry-challenges-for-the-european-green-hydrogen-acceleration-centre/
[77] Wragge, D. 2021. *Interview on a hydrogen market.* Zoom with Toby Walker. 5th February 2021.
[78] Hydrogen Council. 2021. Hydrogen Insights Report. p.6
[79] FSR. 2020. Cost-effective decarbonisation study.
[80] Jammes, L. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 31st March 2021.

challenging to make an immature technology, such as hydrogen-storage, market ready through subsidies. The case of Germany's wind sector acts as a stark reminder on the importance of setting the right subsidy and for the right amount of time. Under Germany's Renewable Energy Act which took effect in 2000, renewable energy sources, including onshore wind turbines, secured priority grid access and guaranteed above-market payment for each kilowatt-hour delivered to the grid.[81] This subsidy in the form of feed-in tariff payments lasted for 20 years. Now, 21 years later wind energy production – as expected – has substantially grown. However, this growth has occurred alongside high electricity prices, which raises concerns that the transition cost towards a renewable energy system has been mainly borne by residential households and disproportionately by poor households.[82] Over 800,000 Germans have had their power cut off for being unable to pay their power bill.[83] Furthermore, as the subsidies ended last year, up to 4,500 turbines where rendered uneconomical without the guaranteed subsidy payments.[84] The subsidies acted as an unsustainable lifeline for the industry and lessons must be learnt for allocating hydrogen subsidies in the market. Inefficient public spending will take finances away from means to attain decarbonisation targets and must be avoided. This then brings us back to transparency, for any subsidies that are created, transparency around costs, conditions, contracts, and evaluation is critical to avoid overpayment and acting as a lifeline for the industry.

As shown in *Figure 10* HBES is a pre-cursor to optimal renewable energy use throughout numerous sectors. It is therefore imperative that this first stage is developed to its full potential. A virtuous cycle that ensures ongoing investment and further cost reduction must be achieved, and it is clear that to do so a financially transparent market is essential. If the above challenges can be stabilised and aligned there is clearly a real market for the nascent hydrogen technology to grow into. However, it is important to also realise that what is good for market players when addressing these challenges may not be in the best interest of the consumer,[85] as seen in the case of Germany and their wind turbines. Civil society's role in the development of the hydrogen market must therefore also be considered.

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[81] Gerdes. J. 2018. Germany Faces Giga-watt Scale loss of Onshore Wind Power. Online: https://www.greentechmedia.com/articles/read/germany-faces-a-gigawatt-scale-loss-of-onshore-wind-power
[82] Böhringer, C., Landis, F., and Reaños, M.A. 2017. Economic Impacts of Renewable Energy Production in Germany.
[83] Mraz, S. 2017. Germany's lessons in Windpower. Online: https://www.machinedesign.com/community/article/21835255/germanys-lessons-in-windpower
[84] Gerdes. J. 2018. Germany Faces Giga-watt Scale loss of Onshore Wind Power.
[85] Baxter, T. 2021. Why Hydrogen Energy has seduced a generation of politicians. TheConversation. Online: https://theconversation.com/why-hydrogen-energy-has-seduced-a-generation-of-politicians-157983

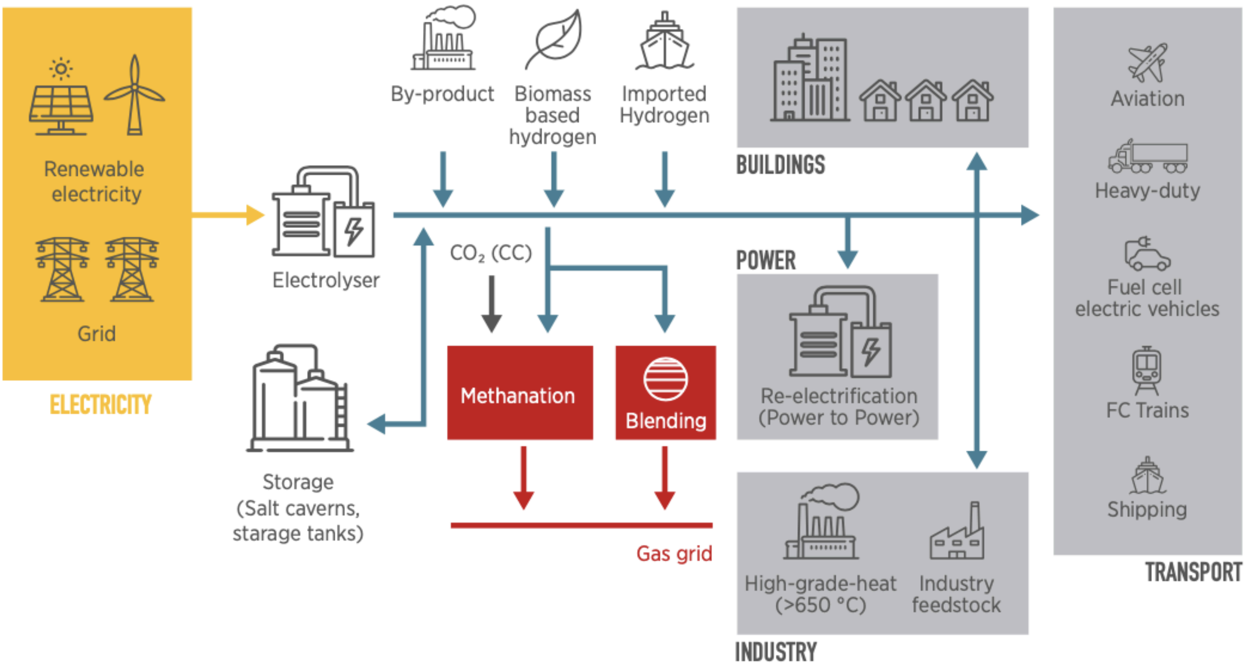

Figure 10. Integration of energy into end-uses by means of hydrogen. Source: IRENA .2018. p.16.

Social Acceptance

A transition of any kind calls for society-wide involvement.[86] A transition towards a HBES regime driven by the government or market alone will fail. The transition needs to be worked on by a variety of actors at a combination of levels.[87] An actor that has historically been overlooked in this respect is civil society. Naomi Klein neatly highlights this – and how it has united so many fateful policy errors of recent years – in her book, *This Changes Everything,* in which she uses the decision to frack natural gas as a bridge fuel as a rich example of how decision makers failed to notice civil society: "There were people on those lands who were willing to fight against the shattering of their territory and the poisoning of their water, thwarting progress."[88] Civil societies participation and acceptance of a decision, or technology, is evidently a contentious topic.

[86] Verbong, G. and Loorbach, D. eds., 2012. *Governing the energy transition: reality, illusion or necessity?* Routledge. p.323.
[87] Ibid. p.237.
[88] Klein, N. 2015. This changes everything: Capitalism vs. the climate. p.287.

The socio-technical regime (*Figure3*) accentuates this point by depicting culture as a key area to be addressed for a niche technology to progress. The culture surrounding hydrogen needs to be understood and to do this society's involvement investigated. The articulation of positive cultural visions is important to help legitimate innovations and attract further support.[89] Innovations may also be opposed by social groups who experience negative side effects or feel insufficiently consulted in decision-making,[90] as Klein demonstrated, and therefore hinder progress. Social acceptance can act as a powerful barrier to achieving decarbonisation targets, especially with emerging and less understood technology like hydrogen. Subsequently, in this section an understanding of the threat it poses will be developed.

Cultural and discursive struggles about the framing of hydrogen are expected. Social groups have different views and interpretations which find expression in contested public debates.[91] As seen with Carbon Capture and Storage, biofuels and large wind turbines, ignoring this can be a painful mistake. The gap between what is technologically feasible and socially acceptable is beautifully demonstrated by MacKay in his book on *Sustainable Energy – without the hot air*. After evaluating the potential contribution of renewable energy in the UK, MacKay concludes in 'when green ambitions meet social reality', that the UK renewable energy potential dwindles dramatically after public consultation.[92] If the framing and cultural vision of a technology is not communicated to civil society accordingly, the technology's full potential will not be reached; underlining the importance of social acceptance.

Leading academics in the field Wüstenhagen, Wolsink and Bürer,[93] introduce three core dimensions to better explain social acceptance; socio-political, community and market acceptance, as displayed in *Figure 11*. It is vital to realise that although these dimensions are introduced as three separate areas, they are equally interdependent on one another. For instance, within a country's political economy if the interests of different principal political actors do not align with one another over the topic of HBES, a lack of cohesive discourse will exist.[94] This conflict of interest at the socio-political level will then have consequences for social acceptance

[89] Devine-Wright, P., Batel, S., Aas, O., Sovacool, B., Labelle, M.C. and Ruud, A., 2017. A conceptual framework for understanding the social acceptance of energy infrastructure: Insights from energy storage. *Energy Policy*, *107*, p.27-31.
[90] Ibid
[91] Roberts, C. and Geels, F.W., 2018. Public storylines in the British transition from rail to road transport (1896–2000): discursive struggles in the multi-level perspective. *Science as Culture*, *27*(4), p.513-542.
[92] David, M. and Mackay, J.C., 2009. Sustainable energy without the hot air. *United Kingdom: UIT Cambridge.*
[93] Wüstenhagen, R., Wolsink, M. and Bürer, M.J., 2007. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy policy*, *35*(5), p.2683-2691.
[94] Ibid

at both the market and community level.[95] How will citizens know who to trust? How will consumers know what energy storage product is best to buy?

Figure 11. The Triangle of Social Acceptance. Source: Wüstenhagen, Wolsink and Bürer, 2007. p.2684.

This challenge is then the same within each dimension of social acceptance; a lack of cohesive discourse in one segment will incite uncertainty and apprehension in the other two dimensions, generating an overall lack of social acceptance for whatever topic is being discussed and as a consequence hinder progress. Therefore, to tackle the social acceptance challenge of hydrogen technology, conditions for determining acceptance must be set not uniformly, but across each one of the three dimensions introduced. This further emphasises the interlinked complexity of the challenge, not only do the values of each specific actor need to be understood, but also what motivates and concerns them in regard to hydrogen. Whilst ensuring that they do not contradict each other. Coinciding with Geels MLP framework, conditions must align for a new regime to be adopted.

The social acceptance triangle is a useful tool for framing the problem. It can help understand what drives people to support or oppose a certain technology. Correspondingly, however,

[95] Hall, P.A., 1997. The role of interests, institutions, and ideas in the comparative political economy of the industrialized nations. *Comparative politics: Rationality, culture, and structure*, p.174-207.

identifying these three points of the triangle as voices with equal say in opposing a technology is dangerous. It risks missing inequalities in social acceptance issues. As academics on the energy transition Verbong and Loorbach stress "no one can single-handedly bring new understandings into being, but at the same time not all of those involved are of equal status."[96] Each Wüstenhagen grouping is an essential player for allowing hydrogen technology to develop but framing them as groups with equal status is misleading.

A more recent wave of research on social acceptance increasingly acknowledges and contests the fact that the deployment of renewable technology and associated decision making is often apolitical, unjust and undemocratic.[97] Take the example of hydropower dam projects in Canada, most notably Site C in British Columbia, where the market acceptance aspect evidently trumps the other two points. High returns on investment and consumer willingness for cheaper energy (market acceptance), overrides indigenous First Nation groups rights (socio-political acceptance), and for this to occur procedural justice in the decision-making process is evidently lacking (community acceptance).[98] The proposed equilateral social acceptance triangle is skewed. A better representation would resemble *Figure 12* for a hydropower project in Canada.

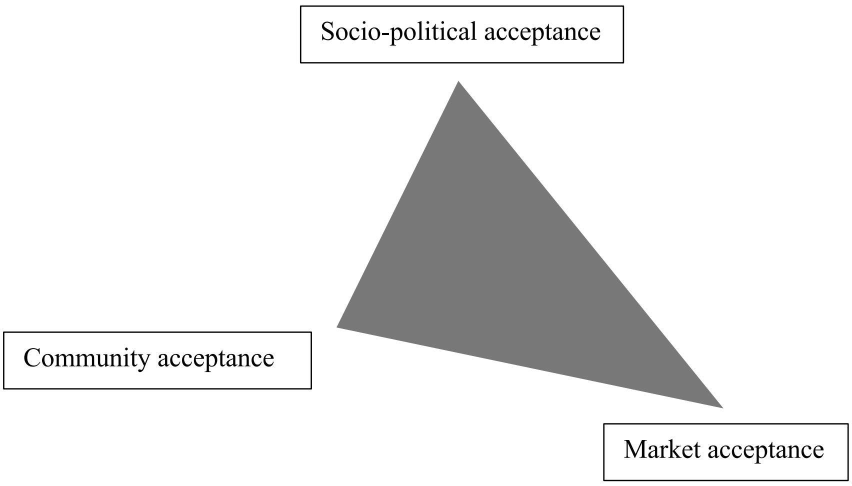

Figure 12. Triangle of Social Acceptance for Large Hydropower Projects in Canada. Source: Author, 2021.

This is important to acknowledge for the challenge of social acceptance, and unfortunately too often the norm. As a result, social acceptance for HBES must be acknowledged and examined

96 Verbong, G. and Loorbach, D. eds., 2012. *Governing the energy transition: reality, illusion or necessity.* Routledge. p.73.
97 Batel, S. 2020. Research on the social acceptance of renewable energy: Past, present and future.
98 Colton, J., Corscadden, K., Fast, S., Gattinger, M., Gehman, J., Hall Findlay, M., Morgan, D., Sayers, J., Winter, J. and Yatchew, A., 2016. Energy projects, social licence, public acceptance and regulatory systems in Canada: A white paper. *SPP Research Paper No*, *9*(20).

through not only a lens that aims to understand the values of the three Wüstenhagen labels, but also through a participation lens.[99] There must also be a focus on how best to devise ways to transform acceptance conflicts into practices, policies and regulations that give voice and reflect everyone interested and affected in a more equal manner.[100] The Site C project must act as a blueprint for what is to be avoided in the participation of HBES decision-making.

As markets for hydrogen-storage technologies develop, citizens will react in different ways to energy policies and local infrastructure deployed in their countries, regions and cities, and end-users will decide whether hydrogen fits their particular circumstances. Ensuring society participates in the decision-making process and fully understands what hydrogen is, how it operates and why it is being used is therefore essential for ensuring that citizens react in a positive manner. Positive salient discourses can enhance the cultural appeal and social acceptance of niche-innovations such as hydrogen, and as a consequence underpin stronger support policies[101] – necessary conditions for the acceleration of HBES's role in decarbonisation.

Further adding to the interwoven challenge that social acceptance poses, HBES can incite fear amongst members of society due to the perceived unknown risks it may pose to them. This is something which has been historically challenging for emerging energy technology such as wind, solar and particularly nuclear. Addressing this area of social acceptance can be crucial to a technology's success, and hydrogen is proving to be no different. The reality of this threat is plainly outlined by Ingaldi and Klimecka-Tatar, through their study to determine the opinions on hydrogen in countries where hydrogen energy is underutilised and where hydrogen infrastructure is under development.[102] The results indicated that society is not convinced that an adequate level of safety exists for energy derived from hydrogen.[103] It can be concluded that knowledge about hydrogen as an energy source, and the production safety and storage methods of hydrogen, is very low, and that this can act as a barrier for hydrogen development within these countries. Importantly, the study then went on to conclude that the social barriers mentioned could be adequately overcome with the help of various social engagement

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[99] Wolsink, M., 2018. Social acceptance revisited: gaps, questionable trends, and an auspicious perspective. *Energy research & social science*, *46*, p.287-295.
[100] Gehman, J., Lefsrud, L.M. and Fast, S., 2017. Social license to operate: Legitimacy by another name?. *Canadian Public Administration*, *60*(2), p.293-317.
[101] Geels, F.W., 2019. Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, *39*, p.187-201.
[102] Ingaldi, M. and Klimecka-Tatar, D., 2020. People's Attitude to Energy from Hydrogen—From the Point of View of Modern Energy Technologies and Social Responsibility. *Energies*, *13*(24). p.1.
[103] Ibid. p.13.

activities.[104] Although this is promising for the industry, it is important to stress that if gone unchecked social acceptance and hydrogen's perceived risks are a serious threat.

An example of where the safety record of hydrogen deployment shifted public perception and social acceptance of the technology can be found in China. After an explosion in Zhangjiakou in 2018 killed 24 people,[105] the Chinese media linked the accident to hydrogen. While it was later proved that this was just a rumour, the accident nevertheless caused widespread public concern about the safety of hydrogen utilisation, and calls were made for deeper assessments of infrastructure. Social acceptance was directly seen to slow hydrogen development, threatening its role for decarbonisation.

One way to better understand this aspect of social acceptance is by considering the political environment. How is the technology communicated and how much political support does it receive?[106] This component then links us back to the first challenge mentioned within this chapter. Policymakers need to think about all aspects that will influence hydrogen deployment and of the role that citizens and the market will play in its progress. Policymaker's must view citizen participation as being fundamental to a successful energy transition, especially given that it will require citizens to substantially modify their energy behaviour.[107] This sort of decision-making is currently missing across the world and poses an immense challenge for the future hydrogen economy.

The final aspect of the HBES social acceptance challenge to be addressed is the current lack of research. Despite there being a significant amount of research and information regarding the benefits of hydrogen energy, it creates considerable controversy in many countries.[108] The number of studies evaluating the public perception and social acceptance of hydrogen energy systems is scarce.[109] Progress on hydrogen technology is currently occurring without a sufficient understanding of the public's perception and values of hydrogen, in order to best

[104] Ingaldi, M. and Klimecka-Tatar, D., 2020. People's Attitude to Energy from Hydrogen—From the Point of View of Modern Energy Technologies and Social Responsibility. *Energies*, *13*(24). p.14
[105] Y. Zhang. 2019. 12 Convicted in Hebei Chemical Plant Explosion that Killed 24.
Online: www.chinadaily.com.en
[106] McPhail, S.J., 2020. Hydrogen energy: State of the art and perspectives. *Current Trends and Future Developments on (Bio-) Membranes*, p.3-19.
[107] Steg, L., Perlaviciute, G. and van der Werff, E., 2015. Understanding the human dimensions of a sustainable energy transition. *Frontiers in psychology*, *6*, p.805.
[108] Ingaldi, M. and Klimecka-Tatar, D., 2020. People's Attitude to Energy from Hydrogen—From the Point of View of Modern Energy Technologies and Social Responsibility. *Energies*, *13*(24). p.1
[109] Iribarren, D., Martín-Gamboa, M., Manzano, J. and Dufour, J., 2016. Assessing the social acceptance of hydrogen for transportation in Spain: An unintentional focus on target population for a potential hydrogen economy. *International journal of hydrogen energy*, *41*(10), p.5203-5208.

inform implementation and decision-making regarding hydrogen-storage this has to be addressed. The lack of research will threaten the sector. Understanding consumers decision-making is complex and therefore requires investigating. The same can be said for market players and socio-political actors, all three of these social acceptance players require examination that is currently missing.

As shown in this outline, numerous political, market and societal challenges need to be overcome to optimise HBES use. Each challenge has its own history and inherent complexities that warrant further examination. This master's thesis will therefore explicitly focus on these three components for further analysis, using Japan and France as practical examples.

Chapter 2. The Practicality – Case Studies.

This chapter will discuss the *how* of hydrogen-based energy storage by applying and comparing practical examples of its use. Cases of hydrogen practise can be seen across the world, despite this though, only two countries will be focussed on for deeper analysis in this chapter: France and Japan. Why these two countries are chosen will first be introduced. Followed by an analysis of the hydrogen policy, market and civil society settings. The challenges described in the first chapter will also be elaborated on in this context, with comparisons between Japan and France's best-case examples informing the discussion.

Japan and France: A Case for Comparison

As we have seen, there is a manifest enthusiasm for hydrogen and the race towards this kind of propulsion is well under way. Countries around the world are increasingly embedding hydrogen into their energy mix with ambitious strategies towards decarbonisation. The goal of each country is clear: mobilise investment, stimulate hydrogen production and use economies of scale to bring down costs to improve hydrogen's competitive profile. As the previous chapter outlined the road to realising this vision is not that straight forward. Clearly there remains a number of obstacles that warrant further investigation.

Fortunately, the observed momentum for hydrogen allows for an extensive catalogue of demonstration projects, policy interventions and market trends to exist. Facilitating a deeper analysis into the aforementioned challenges. According to the IEA's database, for green hydrogen production undertakings alone, nearly 320 projects have been announced worldwide with new projects being added on almost a weekly basis.[110] A comparison of some of these projects, their regulatory surroundings, market conditions and social setting is therefore important to optimise HBES development.

As a result, for the rest of this chapter an analysis of Japan and France will be carried out through the scope of these three themes. The two countries assert similar overarching climate and hydrogen goals, yet operate with remarkably different governance, market and societal spheres. By comparing Japan and France this paper will elicit the fundamental components of what work

[110] IEA. 2021. Hydrogen Projects Database.

and what does not for this aspect of the hydrogen economy. An analysis across the three themes will highlight elements that have aligned to stabilise the industry – allowing momentum to accumulate – whilst equally help to identify what has acted as a bottleneck for the niche-innovations role towards decarbonisation.

Both Japan and France aim to have fully decarbonised their respective countries by 2050, and under this precedence hydrogen's role is mounting. The size of the role that hydrogen is then anticipated to play in reaching national commitments will determine the technologies success.[111] Although Japan and France emphasise different aspects of the hydrogen economy, as will be alluded to later, both are betting big on hydrogen to meet their 2050 zero-emission targets, underlining why they are chosen for comparison.

To illustrate the commitments made to hydrogen in the two countries an overview of Japan and France's hydrogen timeline is displayed in *Figure 13*. Japan released their initial *Basic Hydrogen Strategy* in December 2017, the first country in the world to do so, six months later in June 2018 France released their *National Roadmap for Hydrogen* – with both countries simultaneously boasting to become world leaders in the field.[112] That being said, only one country has managed to follow through with this promise, Japan, making for an interesting comparison between the two countries into why this is the case.

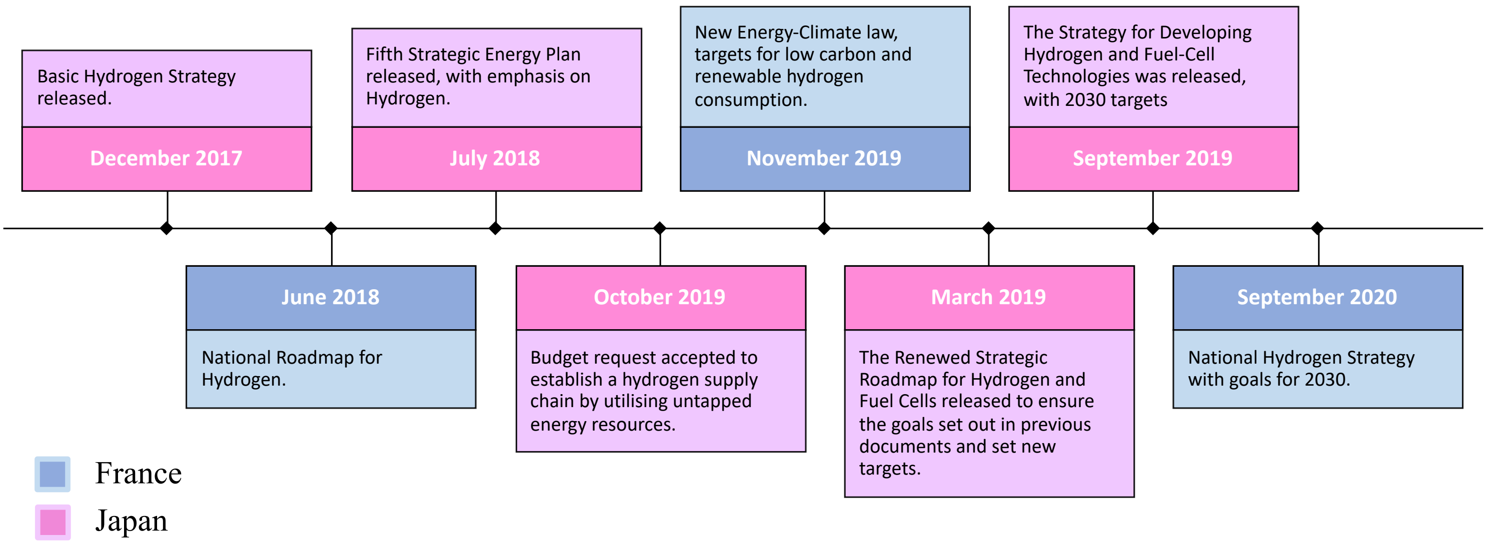

Figure 13. A timeline to show key legal, regulatory and policy developments in Japan and France for hydrogen. Source: Author. 2021.

[111] DNVGL. 2020. Webinar: Panel discussion - Developing efficient hydrogen infrastructure.
[112] BakerMckenzie. 2020. Shaping Tomorrows Global Hydrogen Market.

Equally as important as Japan and France's corresponding goals, are the countries differences. Considering geographical conditions alone, glaring dissimilarities can be seen. For instance, Japan has a land mass of 377,975km² with an enormous population of 126.5million,[113] whereas France, being the second largest country in Europe, has almost double the land mass but only half the population, at 643,801km² with just 67million people.[114] The priorities and flexibility of the two countries is therefore distinct and this must be considered.

Internal factors need to also be accounted for in terms of energy. Understanding each country's energy mix is important for clarifying why governments make certain decisions regarding hydrogen. *Figure 14* displays the respective energy sources of the two countries. As seen by the yellow colouring there is a clear dominance of nuclear energy in France (37%), and when comparing this to Japan it is obvious that the role of nuclear is switched out for fossil fuel use, predominately oil (40.5%) and coal (26.5%).[115]

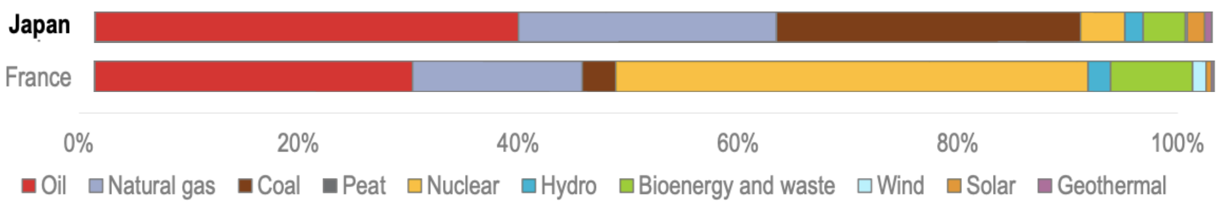

Figure 14. Breakdown of total primary energy supply in IEA member countries. Source. IEA. 2021. p.23

It is also important to note the role of renewable energy in each country. When considering the share of primary energy that comes from renewables Japan and France have fairly similar settings, with France only slightly leading with 11.7% and Japan close behind with 9.3%.[116] Both countries are pushing for more renewables but, alarmingly for Japan, their renewable potential is limited.[117] The IEA analysed the renewable penetration potential in Japan and found that the country has one of the lowest renewable energy potentials for electricity among

[113] The World Bank. 2020. Japan: Land Area and Country Profile.
Online: https://data.worldbank.org/indicator/AG.LND.TOTL.K2?locations=JP
[114] NationsEnclopedia. 2020. France: Location, Size and Extent.
Online: https://www.nationsencyclopedia.com/Europe/France.html
[115] Ritchie, H., and Roser, M. 2020. Energy. *Published online at OurWorldInData.org.*
Online: https://ourworldindata.org/energy
[116] OurWorldInData. 2020. Based on BP statistical Review of World Energy. Share of Primary Energy from Renewable Sources. Online: https://ourworldindata.org/energy-mix?country=
[117] Shiraki, H. et al. 2021. The role of renewables in the Japanese power sector: implications from the EMF35 JMIP. *Sustainability Science*, *16*(2), p.375-392.

developed nations due to its low grid strength, low coordination of flexible resource use, and 70% of land covered by mountains.[118] The implications of this is demonstrated by the 50-70% higher costs for renewable and hydrogen-storage resources in Japan as compared to other hydrogen producing countries.[119]

Japan's polluting energy mix and low renewable energy potential are inimitable. They rationalise the huge push for hydrogen, as a lack of alternative options for decarbonising the economy exist, and this allows for unique comparisons with France. The differences surrounding energy in the two countries is thought-provoking, and they help understand the respective framings of HBES. For more consequential and informative comparisons this thesis will primarily explore areas that can result in more actionable deductions. Japan and France function with unique political discourses, different energy markets and with stark cultural differences. The rest of this chapter will now shed light on why Japan has managed to bag the spot as the leading hydrogen nation, primarily with these more specific features in mind, as well as the challenges from chapter 1.

Political Will: Japan Vs France

The current Prime Minister of Japan, Yoshihide Suga from the Liberal Democratic Party (LDP), assumed office in September 2020. The LDP has almost continuously been in power since its foundation in 1955, and although the LDP has not espoused a well-defined ideology – mainly due to its long stint in government – the party is traditionally associated with conservatism and Japanese nationalism.[120] The party has even been described as a 'catch-all' party due to its big-tent design but, ultimately, the LDP is a centre-right political party.[121] Alternatively, the current French President, Emmanuel Macron from the newly founded La République En Marche! (LREM) came into power in June 2017. LREM is described by Macron as a progressive party,[122] transcending the usual left and right divide, and intriguingly public perception on what type of party LREM actually are remains divided.[123] Nonetheless, the

[118] Energy, S.P., Power, C.S. and Cities, T., 2011. Harnessing Variable Renewables, A Guide to the Balancing Challenge International Energy Agency.
[119] BloombergNEF. 2020. Hydrogen Economy Outlook: Key Messages. p.4
[120] Ellington. L. 2009. Japan. Greenwood Publishing Group.
[121] Hook, G.D., Gilson, J., Hughes, C.W. and Dobson, H., 2011. *Japan's international relations: politics, economics and security* (Vol. 44). Routledge.
[122] Fejérdy, G. 2017. La première année du président Emmanuel Macron. *Vers une nouvelle Europe?*, p.97.
[123] FranceSoir. 2018. LREM: Macron'sparty is "right-wing" according to the French.
Online: https://www.francesoir.fr/politique-france/lrem-le-parti-de-macron-est-de-droite-selon-les-francais

LREM party is often associated with a liberal ideology, primarily across social and economic issues but similar to the LDP, the party is unanimously seen as a centre-right party. The countries not too dissimilar political positions are curious. Yet, the more liberal, modern, French approach as opposed to the traditional, conservatism, way of operating in Japan really sets the two nations apart. This divergence in political framings though, fails to separate the nations in terms of their political ambition for hydrogen.

The political will surrounding hydrogen has grown relatively fast over the last few years in France. Most notably, in his official speech on Bastille Day 2020, Macron stressed the support of the government for the development of hydrogen to catalyse the energy transition and create sustainable jobs.[124] A more symbolic demonstration of French hydrogen commitment occurred in May 2021, when renewable hydrogen was used to light up the Eiffel Tower for the first time.[125] French support has also ramped up in the form of strategies. As shown in *Figure 13*, just last year, after long speculation and controversy, a low-carbon and renewable hydrogen strategy was published; a key milestone for the country. France is also looking to become the first European country to decarbonise its economy, becoming the "carbon-free leader for tomorrow" with hydrogen touted as a core means to do so.[126]

Japan is also emphasising the role of hydrogen like never before. In the wake of the 2021 summer Olympic and Paralympic games in Tokyo, the Japanese government aims to showcase its world-leading hydrogen technologies. Japan intends to leverage the games to advance their large-scale hydrogen development efforts, with plans to make the athletes' village the world's first hydrogen-powered town, accommodating approximately 10,000 people.[127] FCEVs will also be used to ferry athletes around, with new filling stations already opening in the vicinity.[128] The most emblematic hydrogen effort though, is seen with the Olympic torch, hydrogen will be used for the first ever time to power the torch during its journey through Japan.[129] The Tokyo Metropolitan Government has declared that the games should leave a hydrogen society as a

[124] CliffordChance. 2020. Focus on Hydrogen: Time for new energy in Europe and France.
[125] SChipstra, A. 2021. LinkedIn: Last night for the first time in history… Online: https://www.linkedin.com/posts/afkenelschipstra_francerelance-hydrogen-hydrogaeyne-activity-6803349921425702912-JZfB/
[126] Barthélemy, C. 2020. Hydrogen Law and Regulation in France. CMS. Online: https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/france
[127] Japan Times. 2020. Hydrogen to fuel 2020 Olympic flame. Online: www.japantimes.co.jp/sports/2020/01/10/olympics/hydrogen-fuel-2020-olympic-flame/#.XqhUiWgzZnI;
[128] Ibid.
[129] Tarrant, J. 2020. Tokyo 2020 to power Olympic torch with hydrogen for first time. Online: www.reuters.com/article/us-olympics-2020-torch/tokyo-2020-to-power-olympic-torch-with-hydrogen-for-firsttime-idUSKBN1ZQ0D5.

legacy, just as the 1964 Olympics left the Shinkansen high-speed train system.[130] Thus signifying just how dedicated Japan is to the energy vector.

One of the most distinctive features for comparison between the two countries, in terms of political will, is that politically, Japan is currently situated within its "third wave" of hydrogen, with political support first getting started in the 1990s – due to a longing for energy independence from Middle East fossil fuels – and being rapidly accelerated after the 2011 Fukushima catastrophe.[131] This build-up of political will is invaluable to the industry, as stressed in an interview with a Japanese hydrogen expert:

> "Japan has been pursuing research on hydrogen for decades, but they've been fragmented across ministries, organisations and companies, and what the recent government hydrogen strategy did was pull all those effort into one concentrated push towards hydrogen."[132]

An environment has been formulated that allows for coordinated action on hydrogen to overcome the political challenges highlighted in chapter 1. With one clear narrative dominating the political discourse. The only real first political mention of hydrogen within France is much more recent. In 2015 French Law No2015-992 relating to the *Energy Transition for Green Growth* stated that the government shall establish a "development plan for the storage of renewable energies using decarbonated hydrogen,"[133] and since then the narrative surrounding hydrogen has fluctuated.

An example of how the less established political sphere is impacting the industry in France is drawn from June 2018, when then-Minister for Ecological and Inclusive Transition, Nicolas Hulot, vowed to make France a world leader in hydrogen as he unveiled a €100million investment plan. The public investment incentivised spending from the private sector, and Hydrogène de France's (HDF) outlined a €90million hydrogen project in French Guinea as a direct result.[134] The project was hailed as a means to revolutionise the energy sector, as it

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[130] Hydrogen Council. 2017. Hydrogen Scaling Up: A Sustainable Pathway, Global Energy Transition. p.74.
[131] Masaki, K., Niunoya, M., and Shima, M., 2020. Hydrogen in Japan. CMS.
Online: https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/japan
[132] Anonymous Informant #4. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 14th June 2021.
[133] Barthélemy, C. 2020. Hydrogen Law and Regulation in France. CMS.
Online: https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/france
[134] Deign, J. 2019.10 Countries Moving Toward a Green Hydrogen Economy. GTM. Online: https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy

coupled solar power with hydrogen-storage to supply clean power throughout the day.[135] Just two months after Hulot's announcement, however, he quit in frustration over sluggish progress on environmental policies in the face of powerful French lobbies.[136] Reuters described the resignation as a major blow to Macron's green credentials.[137] Following the resignation, the HDF project also went quiet. Evidently these events have not dashed the hopes placed on hydrogen in France, as seen from the surge of support over the last year, yet it does highlight the turbulent political footing surrounding hydrogen that categorically inhibits progress. The rollercoaster of political commitments and actors over recent years in France, then, emphasises the importance of a consistent, coherent, regulatory framework for hydrogen development.

As seen in chapter 1, enabling the hydrogen market requires a rigorous regulatory framework. A market based on competition between energy sources whose externalities [138] are accounted for. A key regulatory area to mention is guarantees of origin. GOs are consistently stressed as an important means to bring about the most cost-effective energy transition.[139] The GO European CertifHy scheme provides a clear label for hydrogen to increase consumer awareness and accurately describe the value of the commodity, helping to foster a hydrogen market in Europe.[140] GOs are evidently an area of expertise for the EU. As *Table 1* depicts three GO-type projects exist that stem from the EU. Within this setting The French Association on Hydrogen and Fuel Cells (AFHYPAC)[141] started work on their own GO mechanism for green hydrogen. Interestingly, the AFHYPAC stressed that a key aim of their scheme was to identify synergies between the French approach and the European CertifHy project.[142] From 30th June 2021, the French scheme will provide guarantees of renewable or low-carbon hydrogen origins as well as a traceability mechanism.[143] The push from the European Commission for EU-wide

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[135] Deign, J. 2018. HDF Energy Touts Big Promises for Its Hydrogen Project in French Guiana. GTM. Online: https://www.greentechmedia.com/articles/read/hdf-energy-unveils-ambitious-hydrogen-project#gs.95oqvo
[136] Frost, L and De Clercq, G. 2018. Popular French Environment Minister Quits in Blow to Macron. Reuters. Online: https://www.reuters.com/article/us-france-politics/popular-french-environment-minister-quits-in-blow-to-macron-idUSKCN1LD0K0
[137] Frost, L and De Clercq, G. 2018. Popular French Environment Minister Quits in Blow to Macron. Reuters. Online: https://www.reuters.com/article/us-france-politics/popular-french-environment-minister-quits-in-blow-to-macron-idUSKCN1LD0K0.
[138] Externalities in terms of what goes into the production of each energy source. The most notable information to be provided is GHG content. Transparency is key to allow for fair competition in the energy transition.
[139] FSR. 2020. Cost-effective decarbonisation study.
[140] Veum, K.C., Barth, F., Winkel, T., VanHoudt, W. and Altmann, M., 2019. Taking CertifHy to the next level; Roadmap for building a dual hydrogen certification.
[141] AFHYPAC association includes all major hydrogen industry stakeholders in France, such as Air Liquide, Alstom, EDF, Engie, and Total.
[142] AFHYPAC. 2017. L'hydrogène en France en 2017. Online: http://www.afhypac.org/documents/publications/rapports/AFHYPAC_Hydrogene-en-France-en-2016_web.pdf
[143] WatsonFarley&Williams. 2021. The French Hydrogen Strategy – A review.

standards in regards to hydrogen GOs facilitated the GO scheme development in France.[144] Europe are global leaders in terms of innovative policy[145] and, therefore, this supranational setting is an unparalleled benefit for France in terms of implementing a regulatory framework.

BODY	REFERENCE	THRESHOLD	QUALIFIED PROCESSES
AFHYPAC	None	100% renewable	All renewable-based solutions
Low Carbon Fuel Standard	Well-to-wheel emissions from new gasoline vehicles	30% lower GHG, 50% lower NO_x	Green hydrogen, catalytic cracking of biomethane or thermochemical conversion of biomass, including waste
CertifHy	Grey hydrogen	60% lower GHG than reference (36.4 gCO_2/MJ)	Two labels: • "Green hydrogen" if the hydrogen is made from renewable energy • "Low carbon hydrogen" otherwise Hydrogen must meet the threshold with 99.5% purity
TÜV SÜD	Grey hydrogen	35-75% lower than reference depending on process	Renewable electrolysis; biomethane steam methane reforming; pyro-reforming of glycerine
Clean Energy Partnership	Grey hydrogen	100% renewable	Renewable electrolysis; biomass
REDII[12]	Transport fuels	70% reduction	Renewable transport fuels of non-biological origin
Technical Expert Group on Sustainable Finance	None	5.8 tCO_2/tH_2 or 100 gCO_2/kWh used as input	Water electrolysis

Table 1. Examples of Guarantee of Origin schemes across Europe. Source: IRENA, 2020. p.29.

Japan on the other hand has no mention of GOs in their strategies. This brings us to an interesting comparison between the two countries. As indicated in *Figure 14*, Japan have a largely fossil fuel dominated energy mix. Resultingly, Japan opted to lead with grey/blue hydrogen for scaling up the technology, with very little mention of green hydrogen until 'phase 3' of their hydrogen strategy in 2040.[146] A pragmatic approach to hydrogen within their roadmap was smart for the Japanese hydrogen industry, albeit detrimental for any short-term climate goals. Something that France cannot replicate under the EU Green Growth attitude.

[144] EEX. 2020. Position Paper: Energy Trading Markets for Hydrogen.
[145] Material Economics. 2020. Mainstreaming Green Hydrogen in Europe.
[146] Ministry of Economy, Trade and Industry. 2019. Strategic Roadmap for Hydrogen and Fuel Cells. Online: www.meti.go.jp/english/press/2019/0312_002.html.

However, the lack of GO attention in Japan will be detrimental if left unchecked. The Japan Basic Hydrogen Strategy notes that imports will need to be 'carbon-free' from 2030 onwards.[147] To ensure these conditions an operating GO scheme is required. Numerous countries are set to engage with Japan on international hydrogen trade but relying on each separate country to develop their own GO scheme will lead to inconsistencies. A uniform GO scheme is needed that Japan can hold accountable and be sure to trust. A GO scheme would also help compare Japanese hydrogen projects and allow for an easier transition towards green hydrogen as planned. For Japan to hit future hydrogen and decarbonisation targets a GO scheme is necessary.

Although the EU may be seen as a hinderance, through their push for solely low carbon hydrogen production, their role is important for France's political will and guidance. As the MLP theory illustrates when a clear political landscape is set, windows of opportunity for niche technology are created, and the EU helps fulfil this role,[148] generating a dynamic multi-level governance setting. Knowledge transfer across the national and supranational governance levels is prominent in the EU (as seen with GOs) and also actively encouraged across member states, making for informed decision-making.[149] For instance, the Franco-German collaboration on Gigafactory projects over the last year, which help supply hydrogen to themselves and their neighbours.[150] Japan lacks similar opportunities. Although Korea and China are aiming for similar goals, and are located close by, the same regulatory or policy consultations are not present. This provides France, and Europe as a whole, with a unique advantage.

Where Japan lacks in terms of a cohesive political environment for points such as GOs, they make up for with their efforts on the international stage. In 2018, Japan held the world's first *Hydrogen Energy Ministerial Meeting*,[151] which now annually hosts over 600 participants from around 35 countries, regions and organisations. The meeting was held under the theme of "realisation of a hydrogen-based society", Japan situated itself as a leader amongst

[147] Ibid.
[148] Fuenfschilling, L. and Truffer, B., 2014. The structuration of socio-technical regimes—Conceptual foundations from institutional theory. *Research Policy*, *43*(4), p.772-791.
[149] Pandev, M., Lucchese, P., Mansilla, C., Duigou, A.L., Abrashev, B. and Vladikova, D., 2017. Hydrogen Economy: The future for a sustainable and green society. *Bulg. Chem. Commun*, *49*, p.84-92.
[150] Burke, F. 2020. Franco-German push for hydrogen is powering new EU drive for green energy source. ScienceBusiness. Online: https://sciencebusiness.net/news/franco-german-push-hydrogen-powering-new-eu-drive-green-energy-source
[151] Ministry of Economy, Trade and Industry. 2018. Japan Hosts First Hydrogen Energy Ministerial Meeting.

industrialised nations on how to integrate hydrogen technologies into various sectors.[152] This emphasised the country's political proficiency for hydrogen and made evident their ambitions.

Japan is well positioned to push for an internationally shared vision on making hydrogen a truly clean energy source with a comprehensive regulatory framework,[153] as seen by Japan's goal to establish an international hydrogen supply chain by 2030.[154] The *Hydrogen Energy Supply Chain* project is the first initiative globally to establish an integrated commercial-scale supply chain that encompasses production, storage and transportation. As a result, international trade projects are underway. Australia produces hydrogen through brown coal, then liquifies the substance and ships it to Japan.[155] Simultaneously, a pilot project to ship hydrogen produced from natural gas in Brunei to Japan began in 2020.[156] Japan is also in trade talks with both Norway and Saudi Arabia.[157] Japan is the only nation operating with such an international presence, situating them perfectly for seizing hydrogen opportunities.

Overall, international cooperation is crucial to scale-up developments, improve technologies and reduce costs. Moreover, a domestic scale up will have to be paired with an international push for hydrogen regulation, and this is where Japan's international presence will be truly beneficial. Currently Japan plays an important role in international energy markets, by bringing together energy producers and consumers to ensure stable supply at reasonable prices. Japan's efforts to promote a more liquid, regulated and transparent global LNG market are particularly commendable.[158] They spearheaded the markets development by emerging as the first big buyer and Japan's commitments to hydrogen imports show they are positioned to have the same commanding role for a global hydrogen market.[159] Japan continue to actively put hydrogen on the international political agenda.[160] Harmonising global standards, GOs and trade regulations naturally falls under their domain and is a clear goal of their strategies.[161] Although global regulations cannot develop in isolation, as a first mover, and with Japan's previous experiences

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[152] Ibid.
[153] IEA. 2021. Japan 2021 – Energy Policy Review.
[154] Ministry for Economy Trade and Industry. 2019. *The Strategic Road Map for Hydrogen and Fuel Cells*. Government of Japan. Online: https://www.meti.go.jp/english/press/2019/pdf/0312_002a.pdf.
[155] IEA. 2021. Japan 2021 – Energy Policy Review.
[156] Nagashima, M., 2018. *Japan's Hydrogen Strategy and its Economic and Geopolitical Implications*. p. 12-75. IFRI.
[157] Ibid.
[158] IEA. 2021. Japan 2021 – Energy Policy Review. p.17
[159] Van de Graaf, T., Overland, I., Scholten, D. and Westphal, K., 2020. The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, *70*, p.4.
[160] Ibid. p.129
[161] Ministerial Council on Renewable Energy, Hydrogen and Related Issues. 2017. Basic Hydrogen Strategy, METI. Online: www.meti.go.jp/english/press/2017/pdf/1226_003b.pdf.

and clear international willingness, they are in the best position to capitalise on any developments in the international market. Leaving countries such as France behind.

The final comparison to make between the two countries in terms of the political environment is the work of regional powers. France, similar to Japan, has distinctive regional hydrogen projects, depending on the area's geography and existing infrastructure. Unique to France; although regions receive support from the government,[162] regional hydrogen strategies are also adopted by local authorities.[163] Policy is enacted by regional and metropolitan authorities as part of a broader effort to attain carbon neutrality in their county.[164] Under this precedence, a variety of projects have been launched, but with certain regions more invested. For instance, as of December 2020, the Auvergne-Rhône-Alpes region was home to 80% of all hydrogen actors in France.[165] Amongst the various projects carried out in the region, Zero Emission Valley (ZEV) is most striking. The ZEV project finances a fleet of 1,000 FCEVs, 20 hydrogen refuelling stations and 15 electrolysers.[166] Another two ambitious regions are Brittany and Occitania, who have both published hydrogen strategies over the last few years, with aims of positioning themselves as leading regions.[167]

This varied sub-national hydrogen action then represents a politicised issue for France. As while the variety of projects reflect the diversity of hydrogen at the local level, they simultaneously stress the uncertainty that remains as to business models for production. Encouraging the pooling of uses is particularly welcome here, but it is complex to implement because the businesses can be so different in-between regions.[168] The regional challenge can then unfold technically speaking as well, once the diverse regional programs develop, France will suffer structurally from a lack of coordination between the implementation of the infrastructure and the potential users.[169] An uncoordinated, competitive, patchwork regime is unfolding due to the lack of direct national policy action and inhibits HBES's role for decarbonisation. Emphasising both the function of policy and a regulatory framework to standardise the various regions' way of operating, allowing for greater synergies, interoperability and progress.

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[162] Jammes, L. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 31st March 2021.
[163] RTE. 2020. The transition to low-carbon hydrogen in France: Opportunities and Challenges. p.31.
[164] Ibid.
[165] ADEME. 2020. A Regional Boost for Hydrogen. Republique Francaise. p. 2
[166] WatsonFarley&Williams. 2021. The French Hydrogen Strategy – A review.
[167] Bretagne. 2020. Deployment of Renewable Hydrogen: Brittany Roadmap 2030.
[168] I4CE. 2020. Hydrogen: France still has many challenges to face.
Online: https://www.i4ce.org/hydrogen-france-climate/
[169] Ibid.

Japan also struggle with regional differences, as seen with their fragmented electricity network; separated into many regional areas with limited interconnections, making it difficult to efficiently balance supply and demand.[170] However, their action on hydrogen is more coordinated from the national government, due mainly to their long history with the fuel and traditional political proceedings. Japan's strategy involves domestic and overseas industry and government stakeholders on a number of cross-sectoral pilot projects.[171] This fails to rule out the economic and technical challenges mentioned for France. But, nonetheless, the coordinated pilot projects, stemming from the government, do facilitate more harmonised action on integrating and mainstreaming hydrogen.[172]

Japan and France hold distinctive political footings. Each with unique regulatory expertise, ambitions and governance frameworks. Their traditional and modern political divide converges on a strong willingness for hydrogen use. Policy is undoubtedly the most important area for aligning elements of a hydrogen economy; as seen with both the French GO scheme catalysing hydrogen uptake and Japan's international hydrogen supply chain project positioning them as global leaders. Even so, a strong political willingness does not guarantee success. Other factors must be taken into account to help set the scene for optimising HBES potential.

The Role of the Market: Japan Vs France

According to the Hydrogen Council, by 2050, the market for hydrogen and hydrogen-related technologies is expected to draw revenues of more than $2.5trillion per year and create jobs for more than 30million people.[173] With Japan and France demonstrating clear commitments towards hydrogen, a large chunk of these benefits can be expected within the countries. Nevertheless, as stipulated in chapter 1, ensuring the right market conditions is complex, and further investigation is necessary. Japan and France will therefore be compared with references made to FCEV's, Fuel Cell micro-Cogeneration units and international trade.

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[170] IEA. 2021. Japan 2021 – Energy Policy Review. p.17
[171] Nagashima, M., 2018. *Japan's Hydrogen Strategy and its Economic and Geopolitical Implications*. p. 12-75. IFRI.
[172] Ibid. p.5
[173] Hydrogen Council. 2017. Hydrogen Scaling Up: A Sustainable Pathway, Global Energy Transition. p.8.

Before the potential hydrogen market can be analysed, a brief summary of the current electricity markets in the two countries is needed. The experiences gained from forming the current electricity market will be invaluable for supporting the growth of a hydrogen market.[174]

For the majority of civilisations' relationship with energy a centralised, closed, energy market has dominated the narrative.[175] France has historically possessed such a market, with EDF holding a monopoly over the provision of electricity for over half a century.[176] It was only in the late nineties that, in conjunction with European directives, the system began to change. French market liberalisation began, and the shift was completed by 2007, as residents had the choice between regulated tariffs or contracts at market price.[177] EDF no longer held a monopoly. Competition in the new liberalised energy market was formed, and today around 30 energy providers operate on the market.[178]

Alternatively, the Japanese market has been slower to change. Nine regional monopolies were created as assets of the state in the post-war fifties, and since then Japan has had a fascinating relationship with electricity.[179] Key steps towards change began in 2016. The electricity market was almost fully opened up, with any supplier allowed to sell electricity to the residential market for the first time.[180] Old regional monopolies' market share was being chipped away. However, a regulated market still existed for these companies to sell electricity on and stiff competition made numerous new entrants bankrupt.[181] It was only in April 2020 that the legal unbundling of the vertically integrated electricity companies (monopolies) occurred, and the Japanese Electric Power Exchange (JPEX)[182] fully took flight. JPEX followed a similar roadmap to the European Energy Exchange (EEX), by stimulating competition and putting a halt to monopolies. The Japanese market is a novel one, trading is not mandatory, and the country still has lots to monitor and learn. Cooperation with the EU could therefore be a useful means here for sustaining JPEX and establishing a future hydrogen market.[183]

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[174] BakerMckenzie. 2020. Shaping Tomorrows Global Hydrogen Market.
[175] Dahl, C., 2015. *International energy markets: understanding pricing, policies, and profits*. PennWell Books.
[176] KelWatt. 2021. The French Energy Market: History, Evolution and Providers in 2021.
Online: https://www.kelwatt.fr/en
[177] Deloitte. 2015. European Energy Market Reform Country Profile: France.
[178] Ibid. p.8
[179] Samuels, R.J., 2019. *The business of the Japanese state*. Cornell University Press.
[180] Reuters. 2020. TIMELINE – Japan's Electricity Market Reform.
Online: https://www.reuters.com/article/japan-power-idUKL4N2ID1NF
[181] Ibid.
[182] The Japan Electric Power Exchange (JEPX) was established in 2003 as a private and voluntary power exchange. It was designated a wholesale electricity market under the provisions of the Electricity Business Act in 2016, but its full operating capacity only came into action as of May 2020 when derivative contracts based on spot prices of electricity where released and foreign traders could join the market.
[183] Wragge, D. 2021. *Interview on a hydrogen market.* Zoom with Toby Walker. 5th February 2021.

The Energy Exchange's mentioned are important tools for future hydrogen markets. After the liberalisation of the energy market in Europe, energy commodities became tradeable on a multilateral, transparent, trading platform. Europe has since become a hotspot of electricity and natural gas trading, and Exchange operators have a rich build up in experience.[184] This will be instrumental for the future of hydrogen. Current Exchanges can act as a blueprint for a Hydrogen Exchange, which could then catalyse a hydrogen market.[185] As it stands no open market or Exchange for hydrogen exists. Hydrogen is only sold and moved through business-to-business transactions. The fuel cannot be bought in the same manner as other energy commodities such as electricity and gas, creating an environment that lacks financial transparency; as acknowledged in chapter 1. The role of a possible Hydrogen Exchange is therefore important to understand.

Within Japan and France, their respective Exchanges' operate in the same fashion: a spot market helps to ensure security of supply through balancing agreements and synchronising the production and consumption of the specified commodity for short-term optimisation; alongside a derivatives market that is based on robust and trustworthy spot market price benchmarks, providing hydrogen market participants with long-term investment signals and a secure fixed price level.[186] This sort of price hedging made available through an Exchange is appealing to parties as it allows for a clear, "right", price and will stimulate hydrogen demand.[187] Trades on these platforms are also subject to clearing and settlements. These settle financial flows, ensure physical settlements of the commodity and mitigate counterparty risk through providing financial margins that ensure payments and market stability.[188] The Exchange model essentially guarantees transparency. Purchasing hydrogen is more accessible through recognised reference prices and open market data. Clear market signals are provided, enabling competition and optimising hydrogen use. Both Japan and France's Energy Exchanges are a great footing to develop a Hydrogen Exchange, seize the benefits of financial transparency, incite competition with managed risk and establish a hydrogen market.

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[184] EEX. 2020. Position Paper. p.2
[185] Den Ouden. B. 2020. A Hydrogen Exchange for the Climate. Dutch Ministry of Economic Affairs and Climate Policy. Online: file:///Users/t.ob.y/Documents/A+Hydrogen+exchange+for+the+Climate.pdf
[186] EEX. 2020. Position Paper. p.3
[187] Den Ouden. B. 2020. A Hydrogen Exchange for the Climate. Dutch Ministry of Economic Affairs and Climate Policy. p.11.
[188] Ibid.

Although the Japanese electricity market is relatively new, their ambitions for a hydrogen market are long standing and far more advanced. The first aspect to look at here in terms of HBES, across the two countries, is the FCEV market.

Based on IEA projections and current development from auto makers such as Toyota and Honda, it is clear that Japan is expected to dominate this market.[189] By 2028, Japan is expected to host just shy of 600,000 FCEVs, as mapped by the blue line against the left axis of *Figure 15*, which also indicates their impressive 2030 target.[190] Japan boast similarly ambitious targets for their refuelling stations, as seen on the right axis, demonstrating a succinct market rollout. This coordinated momentum will be sure to catalyse the hydrogen industry. Alternatively, the French market only forecasts 52,000 FCEV vehicles for 2028,[191] over ten times less. As the market develops in Japan for FCEVs the benefits will then spill over into numerous other aspects of the hydrogen-storage sector further stimulating development and investment.

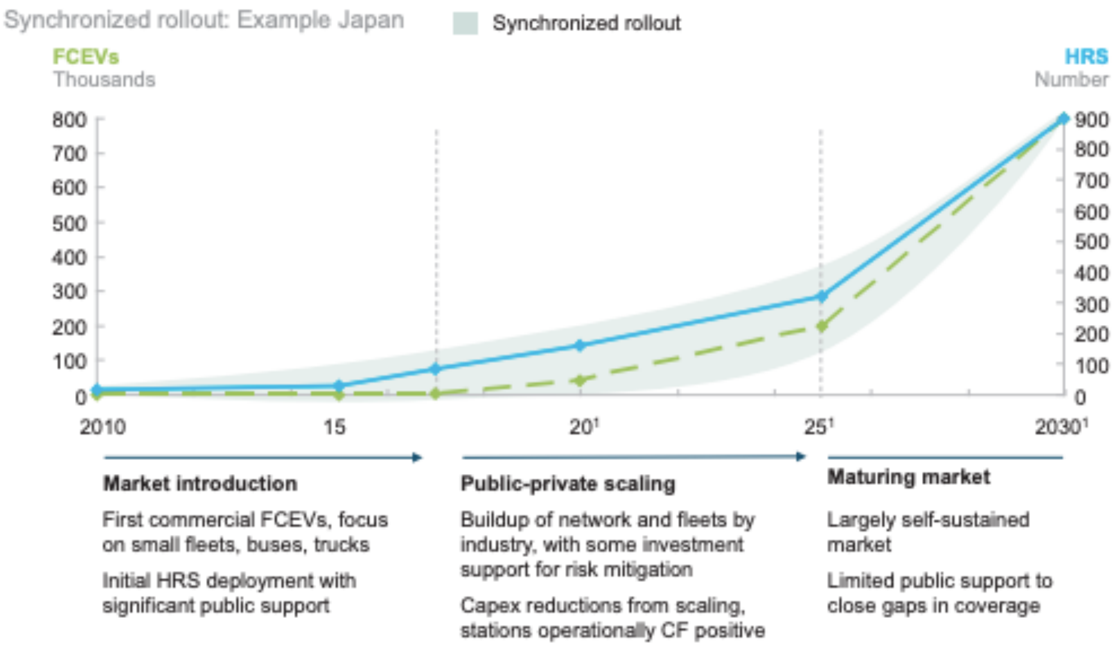

Figure 15. Japan's Synchronised rollout of FCEV's and Infrastructure in 3 phases. Source: IPHE, METI, Hydrogen Council. 2017. p.71

[189] IEA .2020. Hydrogen.
[190] Ministry of Economy, Trade and Industry. 2019. Strategic Roadmap for Hydrogen and Fuel Cells. Online: www.meti.go.jp/english/press/2019/0312_002.html.
[191] Mobilité Hydrogène France. 2019. Study for a Fuel Cell Electric Vehicle National Development Plan. Online: http://www.afhypac.org/documents/divers/H2%20Mobilit%C3%A9%20France%20EN%20FINAL%20UPDATED.pdf

Figure 15 provides a clear example of a socio-technical transition in action, demonstrating how a niche-innovation such as FCEVs can grow into an established market. It is important to discuss here the mention of public support, in other words, subsidies. For the FCEV market it's a what comes first problem, the chicken or the egg?[192] Do you first have the cars from industry, and then the infrastructure players think that it is an attractive opportunity to invest in stations? Or do you first build the stations that have no business case because they are not utilised?

Both Japan and France look to drive FCEV prices down for the consumer. Dissimilarly though they hold conflicting strategic approaches towards refuelling stations. The French strategy aims to support refuelling stations for captive fleets with predictable driving and refuelling patterns to address the lack of infrastructure.[193] Whereas Japan is targeting large cities and key public transit areas in their initial rollout of stations.[194] The French approach will make it difficult to transition towards a society-wade take-up of FCEVs. Focussing on business fleets will incentivise more companies but not individual consumers to enter the market, unlike the Japanese approach which targets residential areas. As the socio-technical transition model dictates an existing regime must be destabilised for a new sustainability niche to take hold.[195] In order to disrupt the existing regime in favour of FCEVs refuelling infrastructure must be ubiquitous for everyday consumers. The French approach fails to recognise this, and the immediacy of the path dependency problem mentioned in chapter 1.

Either way subsidies have a role to play in overcoming the industry stalemate that currently threatens the market. Clear market leadership and commitment is needed by a means of encouraging investment from other stakeholders. In Japan, the government has set aside ¥70billion ($643million) to promote hydrogen in the fiscal year starting April 2021, with ¥30billion allocated to purchase subsidies of FCEVs, and direct subsidies for the installation of charging infrastructure.[196] A clear subsidy roadmap is set for the sector facilitating the technologies initial growth.

[192] Anonymous Informant #3. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 20th April 2021.
[193] Mobilité Hydrogène France. 2019. Study for a Fuel Cell Electric Vehicle National Development Plan. Online: http://www.afhypac.org/documents/divers/H2%20Mobilit%C3%A9%20France%20EN%20FINAL%20UPDATED.pdf
[194] Nagashima, M. 2020. Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. p.18.
[195] Verbong, G. and Loorbach, D. eds., 2012. *Governing the energy transition: reality, illusion or necessity.* Routledge. p.147
[196] Ministerial Council on Renewable Energy, Hydrogen and Related Issues. 2017. Basic Hydrogen Strategy, METI.

Japan further flexed their subsidy expertise with a highly successful Fuel Cell micro-Cogeneration programme (FC-CHP). The project demonstrated how to deliver efficient and affordable fuel-cell heat and power units to buildings at a large scale. A digressive subsidy of more than $10,000 per FC-CHP was put in place in 2009, almost 200,000 units were then deployed in households by 2016.[197] Subsidies were gradually reduced as the industry matured and costs came down, similar to what is projected in *Figure 15* for FCEVs. Over the course of this period, costs decreased by 75%, enabling a self-sustained market by 2020 (for a total target of 5.3million FC-CHP units by 2030).[198] Over 50 countries have since benefitted from the cost savings achieved during the subsidised rollout, enabling them to reach self-sustained markets in much shorter periods of time by following the Japanese model.[199] Not only showing another clear subsidy success for Japan but their recognition as leaders on the global stage for hydrogen.

A key strength of the subsidy strategies mentioned is the interaction of government and industry players. As alluded to throughout this thesis, the themes chosen for analysis are not independent from one another; when they work in conjunction the best results are seen. As stressed by Mr. Tomohide Satomi, Deputy Director-General of the FC-CHP, when asked in an interview why the project was such a success, he put it down to "the extensive cooperation between the Japanese government and the FC-CHP industry, the financial support and impressive technological developments combining."[200] The same sort of relationship is then seen for FCEVs in Japan. As of late 2019, there were about 133 stations installed.[201] In 2018, a number of companies, infrastructure developers and investors founded the joint venture *Japan H2 Mobility* with a goal to build 80 new hydrogen filling stations by 2022, in co-operation with the government and direct subsidies.[202] The government revised regulation to accelerate the roll-out of infrastructure, including the modification of fire safety provisions to allow existing conventional gas station operators to integrate hydrogen stations. The market's development was actively encouraged through a strong political willingness.

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[197] Hydrogen Council. 2017. Hydrogen Scaling Up: A Sustainable Pathway, Global Energy Transition. p.49.
[198] Nielsen, E.R. and Prag, C.B., 2017. Learning points from demonstration of 1000 fuel cell based micro-CHP units-Summary of analyses from the ene. field project.
[199] Dodds, P.E., Staffell, I., Hawkes, A.D., Li, F., Grünewald, P., McDowall, W. and Ekins, P., 2015. Hydrogen and fuel cell technologies for heating: A review. *International journal of hydrogen energy*, *40*(5), p.2065-2083.
[200] PACE. 2019. Japan: A success story in deploying Fuel Cell micro-Cogeneration. Online: https://pace-energy.eu/japan-a-success-story-in-deploying-fuel-cell-micro-cogeneration/
[201] IPHE (International Partnership for Hydrogen and Fuel Cells in the Economy). 2020. Country page for Japan. Online: www.iphe.net/japan
[202] IEA. 2021. Japan 2021 – Energy Policy Review. p. 125.

France, similar to Japan – and any country looking to grow a nascent technology – pushes subsidies as a means to develop. In fact, the recent French hydrogen strategy encourages the development of hydrogen and fuel-cells by issuing tenders for projects, which if successful would qualify for a state subsidy. France has currently reserved €1.5billion in potential subsidies as of 2022.[203] In sync with the ongoing EU Important Project of Common European Interest on hydrogen. However, what is not clear in the French strategy is exactly how this investment should be distributed across hydrogen sectors. France acknowledge the need for subsidies but are failing to effectively guide the market.

So, why are subsidy schemes in France less successful? The same public-private partnerships are not seen, nor are clear targets seen with Japans' FC-CHP. In February 2021, the French government published the Ordinance No.2021-167, defining the future context of the low-carbon hydrogen market. The Ordinance introduces a subsidy mechanism for the production of hydrogen by electrolysis in the form of open calls for projects. The state offers contracts subsidising the investment and/or operation and will mainly focus on large-scale projects.[204] Large projects are focussed on, a timeline for subsidy phase-out is missing and sector specific targets are left out. The subsidy roadmap is undefined, especially so in comparison to the Japanese approach, and this is a key downfall of France. It will mean wasted spending and inhibit progress towards decarbonisation.

Even so, the amount of money France have at their disposal should not be underappreciated. Especially under EU taxonomy. For instance, the French COVID-19 pandemic recovery plan is worth €100billion, the equivalent of one-third of the annual state budget.[205] This is made possible as just over €40billion is provided by the EU through their Recovery and Resilience Facility, and a substantial chunk of this funding is intended for hydrogen.[206] Similar to the role the EU played in guiding French policy, they support hydrogen development with investment, and again Japan lack similar support. However, a number of lines can be drawn between the role of China-Japan and EU-France, both in terms of competition and cooperation. China's role in terms of hydrogen is mounting and the impacts for Japan are yet to be seen. *Figure 16* displays the growing government budget for hydrogen in China between the years of 2015-2018, a trend that is set to escalate. Coupled with the large-scale industrial capacity of China

[203] French Government: The National hydrogen strategy. 2020. p. 8.
[204] The Minister of Ecological Transition. 2021. Ordinance No. 2021-167, relating to hydrogen. Online: https://www.legifrance.gouv.fr/dossierlegislatif/JORFDOLE000043154425/
[205] Euronews. 2021. France aims to spend €30 billion on decarbonising its economy. Online: https://www.euronews.com/2021/05/07/france-aims-to-spend-30bn-on-decarbonising-its-economy
[206] European Commission. 2021. The Recovery and Resilience Facility.

the industry will inflate. Within this context, Nagashima stresses Japanese hopes for cooperation, to help scale-up and bring costs down for HBES in the Japanese market.[207] Chinese advancements may spill-over into Japan. Although not comparable to the EU-France direct funding, the dynamic has the potential to fulfil the role of cooperation the EU has for France.

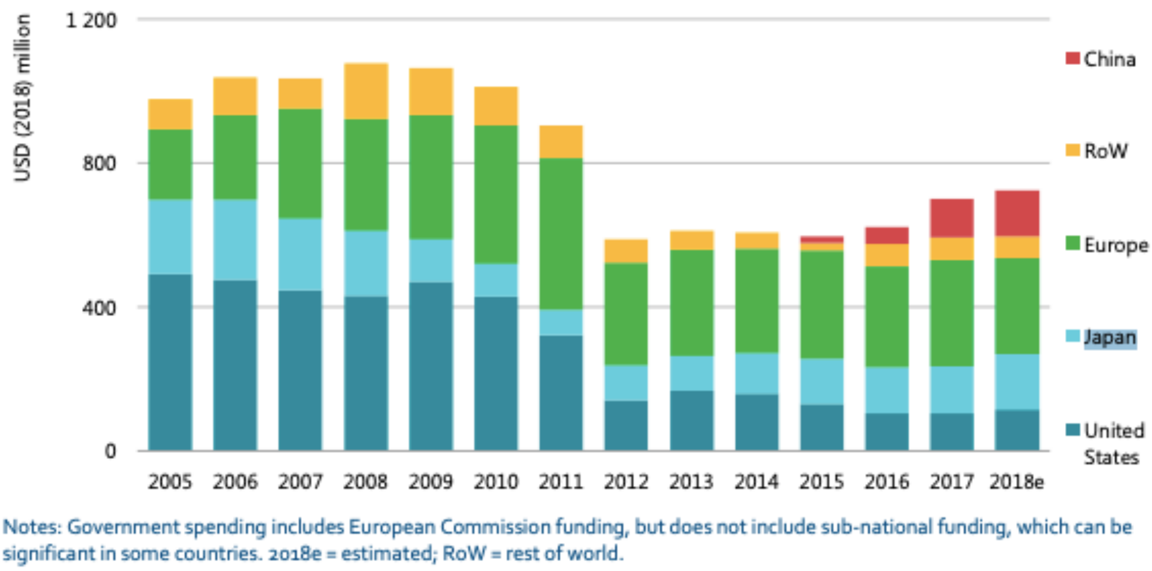

Figure 16. Government RD&D budgets for hydrogen and fuel cells. Source: IEA 2020. p.20

As shown, both financial transparency and subsidies are vital for ensuring the sort of regime change outlined by Geels' MLP towards HBES. Countries are set to spend an unprecedented amount on making hydrogen scalable. Ensuring it is optimally invested is then down to market conditions. The potential Hydrogen Exchange mentioned would help inform decision-makers in allocating subsidies.[208] Projects will become comparable with transparent pricing; the most cost-effective projects invested in and for the right duration.

The final aspect to look at for the role of the market is the value-chain framing of the anticipated market in Japan and France. What is expected in terms of jobs and economic benefits from the expansion of hydrogen?

In both Japan and France hydrogen is seen as a tool for tackling climate change, increasing energy sovereignty, and hitting decarbonisation targets. More specifically, in France the

[207] Nagashima, M. 2020. Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. p.21
[208] Bridle, R. 2021. Should Governments Subsidise Hydrogen? Global Subsidies Initiative. Online: https://www.iisd.org/gsi/subsidy-watch-blog/should-governments-subsidize-hydrogen

hydrogen and fuel-cells market is predicted to create an industry with €8.5bn in revenues and 40,000 jobs by 2030, countering the risk of job losses that currently faces the automotive industries,[209] with revenue increasing to €40bn and jobs to 150,000+ by 2050.[210] The domestic Japan market is expected to reach similar revenues; the nationwide market for hydrogen technologies is expected to grow 56-fold by 2030.[211] Unsuspectingly though, across the Japanese strategies, there is not a single mention of jobs and the employment opportunities attached to this growth. This is a missed window of opportunity for the Japanese socio-technical regime.

Further damaging to the future Japanese market is their goal to export hydrogen. Japan is one of the few countries currently involved in international hydrogen trade. Although Japan is currently importing, as Nagashima declares, Japan is also "nurturing an export market" for hydrogen.[212] Correspondingly, international trade barely receives a mention in the French hydrogen roadmap, with the word "international" only being mentioned twice.[213] In Japan, whatever queries stakeholders may have with hydrogen for its use within the country, will only be exacerbated if market benefits are being redeemed outside Japans' borders.[214] The framing of the hydrogen value-chain is a delicate manner when it comes to exporting.

The market has a clear role to play in terms of providing wider societal and economic benefits. In this context, France are framing the hydrogen market in a more positive light than Japan and the ramifications of this are yet to be seen. What these comparisons do highlight though, is that across the value-chain framing of a hydrogen market, the issue of social acceptance is important. The social acceptance lens would call for some caution with regard to ideas of propagating international trade. Even if a market is developed through optimal subsidy use and then operational with full transparency under an Exchange, the framing of the market can encumber progress. This cross over with the role of the market and social acceptance is thought-

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[209] AFHYPAC. 2018. Developing Hydrogen for the French Economy. A prospective study. Online: https://www.afhypac.org/documents/publications/rapports/Afhypac_Etude%20H2%20Fce%20GB_def.pdf
[210] French Government. 2020. Draft: National Strategy for the development of decarbonised and renewable hydrogen in France. BDI.
[211] Makino, H. 2020. Japan, The New Hydrogen Nation – Global Opportunities. Swiss Business Hub Japan. Online: https://www.s-ge.com/en/article/global-opportunities/20201-c5-japan-hydrogen-market
[212] Nagashima, M., 2018. *Japan's Hydrogen Strategy and its Economic and Geopolitical Implications*. p. . IFRI. p.7
[213] French Government. 2020. Draft: National Strategy for the development of decarbonised and renewable hydrogen in France. BDI.
[214] Wüstenhagen, R., Wolsink, M. and Bürer, M.J., 2007. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy policy*, *35*(5), p.2683-2691.

provoking. The social acceptance issue and role of civil society is evidently important and will now be discussed in more detail.

Civil Society: Japan Vs France

The energy transition is a major societal issue to which hydrogen energy is going to make an important contribution. As stressed in chapter 1, a key enabling dimension of an energy transition is civil society. If the technical aspects of HBES seem paramount, it is equally as important to focus on civil society and end-users. Civil society plays an important role in the success of an energy system: they may not accept it, they may not use it as intended or they may even act as a source of innovation.[215] The role civil society plays and the level of societal engagement occurring for hydrogen's complex supply chain warrants further investigation.

The civil society term initially became popular during the 1980s when it was used to identify non-state movements against authoritarian regimes.[216] Today, however, the term is defined more broadly, and civil society encompasses a wide and vibrant range of organised and unorganised groups. For the purpose of this section the term civil society will refer to the non-state, non-market sector of society. That means it comprises almost any actor not aiming for profits in the market or control of the government.[217]

Nowadays the importance of understanding civil society's role, especially for emerging technology, is growing. *Figure 17* shows the increase in publications addressing the human-technology relationship over the last three decades for hydrogen-energy systems. Fascinatingly, addressing the human-technology relationship even became a more dominant theme to study in comparison to the core hydrogen-energy theme from 2012-2018.[218] We are of the age where the technology is market ready, but we must figure out how best to integrate it into society. Accentuating the need to better understand civil society's role.

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[215] Martin, A., Agnoletti, M.F. and Brangier, E., 2020. Users in the design of Hydrogen Energy Systems: A systematic review. *International Journal of Hydrogen Energy*, *45*(21), p.11889-11900.
[216] Jezard, A. 2018. Who and what is 'civil society?' *WeForum: World Economic Forum.* Online: https://www.weforum.org/agenda/2018/04/what-is-civil-society/
[217] Pekkanen, R. 2011. Grassroots Democracy and Civil Society in Japan. *Education About Asia. Volume 16:3 (Winter 2011): Food, Culture, and Asia.*
[218] Martin, A., Agnoletti, M.F. and Brangier, E., 2020. Users in the design of Hydrogen Energy Systems: A systematic review. *International Journal of Hydrogen Energy*, *45*(21), p.11889-11900.

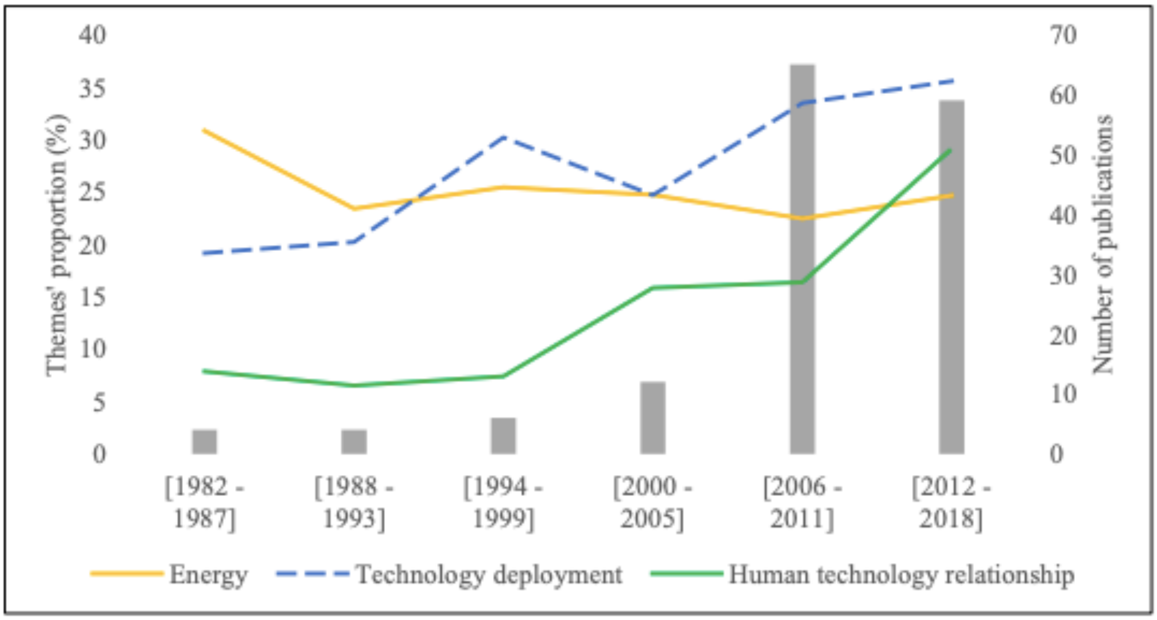

Figure 17. Hydrogen Energy Systems publication themes and amounts evolution over time. Source: Martin, A., Agnoletti, M.F. and Brangier, E., 2020. p.11.

A Japanese hydrogen expert declared that "civil society, have a very different standing in Japan than they do in Europe,"[219] and it is this distinctive role of civil society mentioned here that will now be investigated further.

For a comparison of civil societies, one has to tote up the social framing in one country and then examine the corresponding setting in the other. In this context, the most noteworthy societal norm is age; Japan has the highest proportion of elderly citizens of any country in the world.[220] Japan is also one of the only large countries with a shrinking population. Japan's population is expected to drop from 127million in 2015 to 88million by 2065.[221] A demographic crisis is underway due to the combination of a high life expectancy and low fertility rate. France is also home to an ageing society, albeit with only 20.39% of their population being aged 65+ in comparison to 28% in Japan.[222] This stark ageing characteristic must be kept in mind when addressing civil society in Japan. It comes with prominent socioeconomic issues such as a

[219] Anonymous Informant #4. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 14th June 2021.
[220] OECD. 2019., OECD Economic Surveys: Japan 2019, OECD Publishing, Paris. Online: https://doi.org/10.1787/fd63f374-en.
[221] Ibid. p.9
[222] D'Ambrogio, E. 2020. Japan's Ageing Society. *European Parliamentary Research Service.* p.2 Online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659419/EPRS_BRI(2020)659419_EN.pdf

declining number of young in the labour force, lack of savings in the country and an increase in government spending on pensions.[223] In a sense, a more passive, dependent society exists as opposed to a more fast-paced, engaged French one.

In terms of civil society Japan boasts a distinctively varied network of local civil society organisations, most notably their prolific neighbourhood associations (NHAs).[224] Despite this, Japan has a small professional component. The share of people making their living through civil society is negligible.[225] Scholars have posited an array of explanations for this weak professional civil society. With the majority pointing to society, arguing that Japanese citizens do not seek solutions to common problems through grassroots initiatives, they instead turn to the state for guidance.[226] This explanation also ties in with the traditional LDP stable governing narrative; one sturdy governing party that society has historically depended on and trusts in. Japanese civil society is therefore viewed as more docile, subservient, to the operating corporations and government.[227] Even Makido Noda, chief program officer at the leading research institute on Japan's grassroots organisation, says, "Japan did not have a civil society until recently, and our civil society remains weak."[228] Therefore in terms of the centralised roll-out of hydrogen technology in Japan, less backlash is typically expected, accelerating the role of hydrogen for decarbonisation.

France have a more impactful civil society. Especially so in terms of professionalism. French civil society is a major employer, accounting for 8% of the total full-time workforce.[229] Higher than both transport and construction in the country, and throughout this decade employment in the non-profit sector continues to expand, at a pace twice that of the public and business sector.[230] There is evidently a greater emphasis put on civil society in France and their role is a much more active one. Similar to Japan the number of organised civil society participants is growing. Dissimilarly though in France this comes with a demand to access the decision-

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[223] Ibid. p.5

[224] NHAs are small, local groups, representing around 100 families each. Historically formed by ordinary people to defend homes from bandits centuries ago. The government also pushed for an increase in NHAs in the twentieth century as they are seen as a useful organisation tool.

[225] Pekkanen, R. 2011. Grassroots Democracy and Civil Society in Japan. *Education About Asia. Volume 16:3 (Winter 2011): Food, Culture, and Asia.*

[226] Ibid.

[227] Hirata, K., 2002. *Civil society in Japan: The growing role of NGO's in Tokyo's aid and Development policy*. Springer.

[228] Ibid.

[229] Archambault, E., 2018. French Civil Society: Historical Background, Present position and Major issues. *Voprosy Statistiki*. p.4.

[230] Ibid. p.8

making process.[231] This distinctive disparity for the two countries is then better expressed in terms of culture.

As demonstrated by the MLP's socio-technical regime (*Figure 3*), understanding culture is important for grasping what external pressures can be put onto a niche technology. As such it is vital to examine what the aforementioned civil society settings mean in terms of culture. Japan's weak civil society is derived from traditional cultural aspects of Japan.[232] In particular, three aspects of Confucian tradition that remain prolific in Japanese culture deserve attention: (1) respect for hierarchy and authority, (2) emphasis on conformity to group interests rather than individual needs, and (3) emphasis on order and stability.[233] These values legitimise state authority and most importantly mean that Japanese citizens embolden a greater sense of citizen duty as opposed to believing that they possess the right to make demands on authorities. Alternatively, the French culture is more assertive. There is a much bigger tendency in France for organised civil society to protest and bring together individual citizens to represent their interests directly.[234] For example, the *ni ici, ni alleurs* civil society led anti-fracking movement. The undertaking demanded reform from the national government and just one year after creation parliament passed a law for an outright ban on fracking.[235] France holds the second-largest shale gas reserves in Europe but became the first country to enact a ban on hydraulic fracturing,[236] exposing the influence of civil society in the country.

So, what are the implications of these cultural contrasts for hydrogen in decarbonisation? The more individualist culture of France[237] means that civil society has a greater role to play and a deeper means of civil society engagement is necessary. French civil society can directly influence national decision-making and inhibit HBES use (like with fracking). The same cannot be said for Japan. The social hierarchy and state authority in Japan emphasise citizens' obligations and responsibilities rather than their individual rights and deters challenges from

[231] Saurugger, S., 2007. Democratic 'misfit'? Conceptions of civil society participation in France and the European Union. *Political Studies*, *55*(2), p.384-404.
[232] Ogawa, A., 2009. *The failure of civil society? The third sector and the state in contemporary Japan*. SUNY Press.
[233] Hirata, K., 2002. *Civil society in Japan: The growing role of NGO's in Tokyo's aid and Development policy*. Springer. p.37
[234] Saurugger, S., 2007. Democratic 'misfit'? Conceptions of civil society participation in France and the European Union. *Political Studies*, *55*(2), p.398
[235] Smith, A., 2012. Civil society in sustainable energy transitions. *Governing the Energy Transition: reality, illusion or necessity*, p.180-202.
[236] Weile, R., 2014. Beyond the fracking ban in France.
[237] HofstedeInsights. 2021. Country Comparison: France.
Online: https://www.hofstede-insights.com/country-comparison/france/

civil society.[238] The lack of opposition means that project implementation is more straightforward, acting as just one of many reasons why hydrogen is more advanced in Japan. Even though intervening is deterred, civil society is not passive in Japan and its role is still fundamentally an important one.

This point is stressed in Japan, despite their more subdued civil society. As Mr Eiji Ohira,[239] a key industry player emphasises "we must establish social implementation by not only envisioning hydrogen use, but how we will integrate it into the fabric of society."[240] While Japanese policy and market conditions will turbocharge Japan's ambitions to become a hydrogen-powered society, promoting awareness and participation throughout this process is integral. This recognition coupled with the cultural and social proceedings in Japan accelerate deployment.

Whilst civil society is always an important presence in socio-technical systems and their transformations, it is important to remember that it is never a singular, manageable presence.[241] Therefore, governments must aim to make as wide-ranging and impactful engagement action as possible. To overcome the social acceptance issue stressed in chapter 1 and accelerate the take-up of hydrogen. Examples of such action within the two countries will now be looked at.

An imperative point to discuss in regard to social acceptance of HBES is the role of the 2011 Fukushima nuclear incident in Japan. Energy has been at the forefront of Japanese resident's mind, with many having to face energy poverty as a direct result of the incident.[242] The disaster did, however, provide positive transition pressure on a regime change towards a low carbon society which incorporates greater energy-efficiency, renewables and hydrogen.[243] As such, Japan is currently labelled as one of the lowest energy intensive economies as well as one of the most energy conscious populations among developed countries.[244] A greater recognition of

[238] Hirata, K., 2002. *Civil society in Japan: The growing role of NGO's in Tokyo's aid and Development policy*. Springer.
[239] Director general of Fuel Cell and Hydrogen Technology at the New Energy and Industrial Technology Development Organization in Japan.
[240] The Economist. 2020. Japan eyes a hydrogen-powered future, n.d. Japan Goes Green. Online: https://japangoesgreen.economist.com/japan-eyes-a-hydrogen-powered-future/.
[241] Smith, A., 2012. Civil society in sustainable energy transitions. *Governing the Energy Transition: reality, illusion or necessity*, p. 202.
[242] IEA. 2021. Japan 2021 – Energy Policy Review. p. 15.
[243] Chapman, A.J. and Itaoka, K., 2018. Energy transition to a future low-carbon energy society in Japan's liberalizing electricity market: Precedents, policies and factors of successful transition. *Renewable and Sustainable Energy Reviews*, *81*, p.2019-2027.
[244] Slusarska. D, and Orlando. F. 2016. Shifting Geopolitics of Energy Winners and Losers: Japan. *Friends of Europe. Geert Cami* p.5-10.

the value of energy is embedded within their culture which is invaluable for society recognising HBESs' potential for decarbonisation.

A strong apprehension for nuclear energy arose from the disaster, and alternative pathways of sourcing energy are consequently more readily supported.[245] An example of this is the Kitakyushu Hydrogen Town, the world's first community-level hydrogen demonstration project, 2011-2014. The project ran alongside regular meetings with residents to ease any concerns and utilised HBES throughout the community's energy network. The project was labelled a great success and its use acts as an important blueprint for other projects. Furthermore, in 2017 the city announced the *Kitayushu City Vision for Hydrogen Society*, which aims to establish a hydrogen supply chain by 2030 in the region to further lower hydrogen prices.[246] The project combined a centralised ambitious hydrogen project with consistent civil society engagement.

Discourse and narratives were also important here. The socio-political framing of these projects was integral. Especially as one of the most serious challenges post-Fukushima was that policymakers and energy industry players lost public trust.[247] The framing of HBES was extremely innovative for Kitakyushu. They tested the ability to use hydrogen-storage as a backup in case of a power shutdown. Power outages are common since Fukushima, and so hydrogen stored in an FCEV was introduced as a medium to power a house, as seen in *Figure 18*.[248] The socio-political framing of the hydrogen-storage technology encouraged social acceptance. The technology became desirable as it catered for civil society's needs.[249]

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[245] McLellan, B.C., Zhang, Q., Utama, N.A., Farzaneh, H. and Ishihara, K.N., 2013. Analysis of Japan's post-Fukushima energy strategy. *Energy Strategy Reviews*, *2*(2), p.190-198.
[246] City of Kyushu. 2017. Kitakyushu City Hydrogen Society Vision.
[247] Suzuki. T. 2017. 6 Years after Fukushima, Japan's Energy Plans Remain Murky. *The Conversation*. Online: https://www.scientificamerican.com/article/6-years-after-fukushima-japans-energy-plans-remain-murky1/
[248] Jammes, L. 2021. Will hydrogen be the energy vector of the future? CIFE Presentation. April 23 2021. by Laurent Jamnes
[249] Martin, A., Agnoletti, M.F. and Brangier, E., 2020. Users in the design of Hydrogen Energy Systems: A systematic review. *International Journal of Hydrogen Energy*, *45*(21), p.11889-11900.

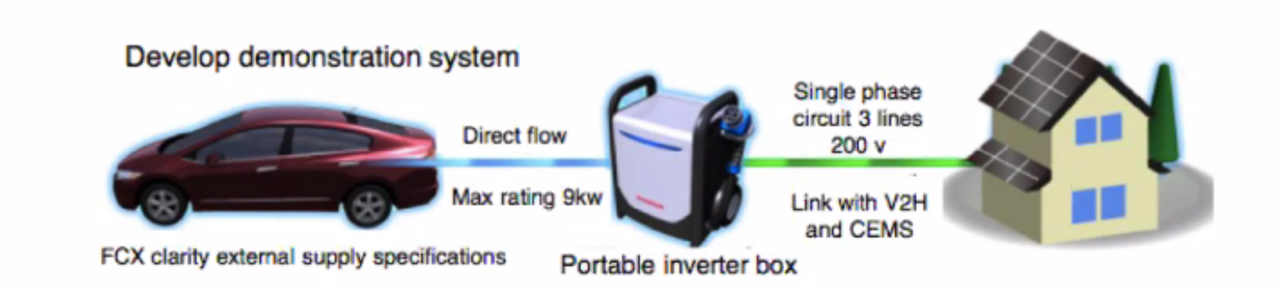

Figure 18. Powering a house with an FCEV in case of a shut-down. Source: Jammes.L. 2021.

Similar to Japan, France is host to strong localised hydrogen-storage projects. Most notable are within Normandy. A leading region for hydrogen production and mobility. Nearly one-third of national consumption is found here.[250] Thought-provokingly, within the region 22 committed and determined civil society organisations are involved in making Normandy a hydrogen leader.[251] Although at the beginning hydrogen in Normandy was decided on in a centralised top-down manner, the region is now operating in a much more civil society orientated, bottom-up, way. Even so, France definitely still have huge issues in terms of understanding public perception on hydrogen and fully engaging them. For instance, at the national level only industry players are consulted on hydrogen decisions, other stakeholders such as civil society are only involved afterwards and are treated as people to convince.[252] However, Normandy acts as a promising building block for change. In Normandy workshops were organised for members of society to debate the topic and people were even encouraged to propose hydrogen functions that could directly benefit their daily life.[253] Civil society were even encouraged to engage with hydrogen through the clever use of the local fire brigade. Portable fuel-cell hydrogen-storage components were fitted to fire trucks in Brunnthal.[254] This integration tactic demonstrated the safety of the fuel, and the socio-political framing encouraged social acceptance. A strategy of civil society engagement and participation was integral for success and accelerating the take-up of hydrogen for decarbonisation.

Due to the fact that technology does not spread alone, it is necessary to understand how a technical innovation fits into society. Both countries boast unique manners to tackle this and

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[250] BusinessFranceNordic. 2021. Normandy: a leading French for hydrogen production and mobility. Online: https://world.businessfrance.fr/nordic/2021/04/23/normandy-a-leading-french-region-for-hydrogen-production-and-mobility/
[251] Ibid.
[252] Jammes, L. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 31st March 2021.
[253] Ibid.
[254] FuelCellsWorks. 2020. Brunnthal Voluntary Fire Brigade.
Online: https://fuelcellsworks.com/news/brunnthal-voluntary-fire-brigade-relies-on-efoy-fuel-cell/

civil society holds varying degrees of power. The level of civil society involvement is noticeably ramped up in France. This process takes time and money yet ensures greater levels of social acceptance. The cultural setting warrants these extra efforts and although France are worthy of praise in this regard, Japan have an outright advantage in terms of civil society. As shown by MacKay in chapter 1 public consultation slows progress. Japan essential operates without rigorous civil society participation being necessary[255] and this accelerates the role of HBES for decarbonisation.

In summary, the varied civil society influence, societal normalities and external cultural pressures highlight the importance of civil societies and, depending on civil society's role their involvement may vary, but above all else they must always participate in the decision-making process.

[255] Anonymous Informant #4. 2021. *Interview on a potential hydrogen economy.* Zoom with Toby Walker. 14th June 2021.

Recommendations

From the analysis done thus far, some policy recommendations can be made to guide decision-makers. Here the thesis project will be split into two sub-categories, *Near-term Opportunities* and *Long-term Recommendations,* the suggestions provided will attempt to align the three main dimensions developed, policy, market and civil society, whilst accounting for the historical path dependency of the HBES industry. Stressing the need for cohesive discourse not just within each dimension but just as importantly between them. The recommendations mentioned will be orientated towards Japan and France and inspired by their opposing best practices. Due to the case study analysis, however, the points discussed can also act as valuable guidelines for any other country wishing to expand their industry.

	Near-term Opportunities	Long-term Recommendations
Japan	<u>Policy</u> • Despite the lack of green hydrogen implement a **GO scheme**, similar to the AFHYPAC one to increase transparency. • Continue to push for an **internationally** shared vision on hydrogen with a comprehensive regulatory framework <u>Market</u> • Ensure subsidy initiatives have a clear **timeframe** to avoid propping up hydrogen sectors similar to German wind turbines. • Frame future hydrogen usage as a means to provide green **jobs** and economic opportunities. • **Collaborate** with EU Energy Exchange and learn from their developed energy market. <u>Civil Society</u> • Increase **research** into the perception and acceptance of hydrogen across the three Wüstenhagen categories. • Improve understanding of the **socio-economic** impacts of a hydrogen economy.	<u>Policy</u> • Align international trade with **international** standards for hydrogen use, alongside a clear GO operating system. • Bring **together** hydrogen producers and consumers to ensure stable prices and harmonise a regulatory framework. • Enable more **public-private** partnerships. <u>Market</u> • Collect spot price information for hydrogen projects with the intention of creating a hydrogen **exchange**. • Encourage greater collaboration with **China** for knowledge transfer and investment in order to fulfil the role of the EU for France. <u>Civil Society</u> • Consider and research the acceptance issues with establishing an **export** hydrogen market. • As civil societies role grows in Japan due to traditional Confucian culture diminishing[256] learn from the French way of **engaging** civil society in Normandy.

[256] Hirata, K., 2002. *Civil society in Japan: The growing role of NGO's in Tokyo's aid and Development policy*. Springer. P.37

France	<u>Policy</u> • Extend AFHYPAC **GO scheme** to neighbouring hydrogen operating countries. • Engage in regional interconnectivity of hydrogen projects and ensure the **standardisation** of business models. • Further develop hydrogen **collaboration** efforts within the EU e.g. France-Germany. <u>Market</u> • Outline a clear and credible **subsidy roadmap** for FCEV infrastructure. To signal car companies to scale up production. Inspired by China and Japan model. • Collect spot price information for hydrogen projects to create a **hydrogen exchange**. • Introduce sector specific direct **subsidy** roadmaps. To allow initial growth of tech. <u>Civil Society</u> • Increase **research** into the perception and acceptance of hydrogen. Focussing on how best to transform conflicts, into practices, policies and regulations that give voice and reflect everyone involved equally. • Launch civil society consultation from the very **beginning** of a project.	<u>Policy</u> • Improve the political narrative surrounding hydrogen. Ensuring **consistency** above all else in order to clearly indicate to industry players to move on hydrogen as in Japan. • Increase **international** trade as a means to engage in international hydrogen discussion. • Align national leadership on regulations to facilitate more **multi-level** cooperation. <u>Market</u> • Showcase greater ambition in more **wide-ranging** hydrogen applications as Japan do. • **Pilot** a world leading hydrogen exchange, based off current EU expertise. • Improve subsidy knowledge and **evaluate** the market alongside any implementation. <u>Civil Society</u> • Continue to innovate on **framing** hydrogen-storage in a culturally desirable manner in order to increase acceptance levels. • View citizen **participation** as fundamental to the transition towards hydrogen. • Turn research into understandings. Using **Normandy** as a best-case example for similar hydrogen initiatives within the country.

Table 2. Recommendations for Hydrogen-based Storage development in Japan and France. Source: Author. 2021.

Conclusion

Hydrogen has gained global recognition as a necessity for complementing the required energy transition, acting as a source of long-term and large-to-short scaled energy storage. The energy carrier is therefore already in use across numerous sectors and countries. This new hydrogen wave is promising, with unique drivers converging on hydrogen-storage deployment; the maturity of the technology, recognition of its ability to make power systems flexible, national pledges towards net-zero and a more extensive base of stakeholders engaged. Despite the unprecedented attention hydrogen is receiving, several barriers are still impeding its full contribution to the energy transition.

In order to explore why this is the case, this paper first highlighted the core challenges positing the industry through expert interviews and paper research. It was discovered here that considerations must be given to a range of issues across three core analytical themes – policy, market and civil society – whilst also considering alternative pathways to decarbonisation, such as the EV and FCEV competition. Geels multi-level perspective simplified these challenges, by highlighting that factors within the socio-technical regime must align for a niche-innovation, such as hydrogen-storage, to emerge. This theoretical lens emphasised the importance of each separate challenge but equally as vital it stressed the interconnected nature of incumbent actors and how interlinked their challenges are. For instance, how ensuring a detailed regulatory framework leads to greater market transparency, informing subsidy roadmaps and investment decisions, or how the socio-political framing of hydrogen-storage can generate higher levels of social acceptance.

The most important message here was that as hydrogen transitions from niche to mainstream, the policies that drive the transition must not only cover the deployment of hydrogen, ensuring adequate regulations and market conditions, but also its integration into society as a whole. It is economy-wide policies that affect the sustainability and pace of the transition.[257]

Building on the first chapter and to then comprehend more real-world examples of HBES a country comparison of Japan and France was carried out in the second chapter. Unfortunately for France and the rest of the world, some key characteristic that set Japan above the rest are

[257] IRENA .2020. Green Hydrogen: A guide to policy making. p.31.

historically unique and have taken a long-time to establish: a clear long-standing political narrative, the Fukushima incident and its concomitant greater appreciation of energy, and a more subservient civil society stemming from traditional Confucian values. These are strengths to the hydrogen regime that cannot be easily replicated in other countries. Although they are not sole determinants of hydrogen achievements, with plenty of other issues influencing progress, they are evidently natural building blocks for success.

It is these other issues, revealed within this paper, that require attention in order to progress towards decarbonisation quicker. Although the comparison in this paper is based on only two political systems – France and Japan – many of the findings are of a more universal nature.

For the political environment, greater cooperation on the international stage would destabilise the key challenges that currently act as bottlenecks to the industry. A reliable and transparent regulatory framework is a prerequisite for governments, industry players and civil society alike. For this reason, it is of central importance to work towards a level playing field in terms of policy across the globe, and international cooperation is fundamental. Enhanced international cooperation is needed across the board, but especially on standards, GOs and the sharing of good practices. A clear regulatory framework across nations will increase the ease of trade and interoperability, and individual countries best-case examples must be utilised. For instance, the French GO scheme should be expanded, and Japan's international trade practices imitated. Hydrogen is the missing link for an international energy system and therefore international cooperation is fundamental.[258]

When it comes to the conditions that would best support a hydrogen market, the importance of a hydrogen exchange is stressed in this paper. Transparency is integral, for knowing who to trust facilitating social acceptance, to guide public spending on hydrogen and to allow for competitive market conditions. An exchange ensures this setting. An exchange has been revolutionary in the electricity market for Japan and France and there is no reason why it cannot set the same precedence for a future hydrogen market.

The final universal finding to mention comes from the civil society theme. The civil society issue is a unique one. As shown by this paper it represents a country specific problem, with country specific solutions. To progress in this domain, increased research into the acceptance

[258] IRENA. 2018. Hydrogen from renewable power: Technology outlook for the energy transition.

and perception of HBES is crucial. This will help understand the desires of civil society and edify the best means with which the technology should be framed in order to increase social acceptance levels within that country. Additionally, the social aspects of the hydrogen economy must be considered. For example, how shifting demographics and social issues, such as the aging, shrinking population of Japan, impact people's preferences and perceptions toward using hydrogen as part of their daily lives.

The holistic and wide-ranging nature of hydrogen means that this paper inherently comes with limitations. The research carried out took a broad approach to hydrogen and its end-uses. A singular end-use was not focussed on but many and these then compared across sectors and countries. Moreover, comparisons were made across the various production sources of hydrogen; when each one comes with unique variables that impact its adoption. For the scope of this thesis, this was necessary. Hydrogen-storage is not yet a well-established enough technology and so a more streamlined analysis was not possible. Looking at what currently inhibits or accelerates its more general take-up is more important at this stage. Albeit a more detailed, end-use, production source, and country specific, analysis is needed moving forward.

Acknowledging that an abundance of hydrogen end-uses exist is important. To avoid diluting efforts, national policy makers must identify the applications that provide the highest value and prioritise action towards them. This is a key suggestion for future research. As by doing so, governments can ensure their policy efforts provide more immediate benefits, both towards the goal of decarbonisation whilst simultaneously in terms of generating a higher demand for hydrogen in the near-term.

Within this paper the question *what are the different factors that accelerate and/or inhibit the role of hydrogen-based energy storage in contributing to national decarbonisation targets?* was addressed. The research has demonstrated that HBES has a critical role to play in global decarbonisation and will be a major player. Inhibiters and enablers of the technology towards decarbonisation were then mapped throughout the paper. These coincided with three core themes that hold the greatest influence: the political, market and civil society spheres. Each sphere is proven to hold the ability to both accelerate and/or inhibit hydrogen-storage development.

Under this precedence, the research hypothesis that three core areas, policy, market and civil society are able to accelerate and/or inhibit hydrogen-based energy storages' role in attaining decarbonisation targets, can be confirmed with confidence. Although the role of history is also important as seen with the path dependency issue and the Japanese conditions for success, its consequences are still mapped across the three hypothesised themes. Under these conditions considering each theme is an absolute necessity for ensuring hydrogen-storage has the optimal impact it can for decarbonisation.

If policy-makers are not to lose sight of the long-term goal of a globally decarbonised economy, the development of hydrogen-storage is a key priority. The energy system of the future will be more diverse and complicated than the one we have been accustomed to. At a time when the climate emergency has never been so urgent, hydrogen is market ready, civil society are engaged, and policymakers must ensure that hydrogen has as big an impact as possible.

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