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THE DIFFERENT PATHWAYS OF HYDROGEN ADOPTION:
A SOCIAL-TECHNICAL ANALYSIS OF HYDROGEN APPROACHES IN GERMANY AND AUSTRALIA

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The Different Pathways of Hydrogen Adoption:
A social-technical analysis of hydrogen approaches in Germany and Australia
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Abstract

In recent years, there has been growing interest by governments and firms to use hydrogen and hydrogen technologies to help decarbonise the energy sector and help reach climate and emission targets. However, as a niche innovation still in its infancy, hydrogen is not without its issues causing friction for its widespread adoption. Currently, these issues are mainly economic and political in nature; governmental policies and international taxonomy around hydrogen and sustainable finance are still quite fuzzy, causing a lack of confidence and public investment into the industry.

This dissertation will outline and distinguish between two pathways of hydrogen adoption taken by governments around the world. Governments can take different pathways towards the same goal of using hydrogen to decarbonise and reach climate targets. The 'green hydrogen emphasis' and 'scale first-clean later' approaches proposed in this dissertation are interesting lenses to view how governments are supporting the use of hydrogen in their economies.

Specifically, this dissertation will analyse the two countries of Germany and Australia and their different approaches to hydrogen adoption. Both Germany and Australia have a long historical dependence and culture of coal and natural gas, however, the different governmental pathways will ultimately lead to very different uses of hydrogen in their energy landscape. Quite critically, Germany's government is a firm believer of taking the 'green hydrogen emphasis' approach as a way to decarbonise its economy, whilst the Australian government is taking the 'scale first-clean later' approach by growing its hydrogen export economy with 'grey' and 'blue' hydrogen and decarbonising at a later stage.

Using the multi-level perspective framework, this dissertation will analyse key actors, policies, and markets mechanisms and the result of these two different approaches towards hydrogen. This dissertation will also discuss the current investment landscape of hydrogen and why there is currently a 'stalemate' preventing early hydrogen investments, and finally, suggest some market design mechanisms that would improve investor confidence and spark more public investment to help grow the hydrogen economy.

Key words:

Hydrogen, Hydrogen Economy, Energy Transition, Multi-Level Perspective, Social-Technical Transitions, Market Design, European Union, Germany, Australia

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List of Acronyms

BESS	Battery energy storage solutions
CCS	Carbon capture and storage
EU	European Union
EVs	Electric vehicles
FCEV	Fuel cell electric vehicles
GHC	Green hydrogen certificates
GoO	Guarantees of origin
GW	Giga-watt
HPPAs	Hydrogen purchase power agreements
kWh	Kilo-watt hour
LCOE	Levelised cost of electricity
LT-LEDS	Long-term low-greenhouse-gas emission development strategies
MLP	Multi-Level Perspective
mWh	Mega-watt hour
NDCs	Nationally determined contributions
PHES	Pumped hydroelectric energy storage
PPAs	Purchasing power agreements
PPP	Public-private partnerships
REC	Renewable energy certificates
RES	Renewable energy systems
SMR	Steam methane reforming

Introduction

Since the industrial revolution and the human exploitation of fossil fuels to create a more energy reliant economy, there has been adverse negative impacts on the environment and the legacy we aim to leave behind. As a global society, the importance of creating a sustainable, zero-carbon future has been at the forefront of political and social agenda in recent years. In the advent of the Kyoto Protocol and subsequent Paris Agreement, there is now a concrete political and social target to limit global average temperature to well below 2 degrees Celsius above pre-industrial levels, and to limit the increase to 1.5 degrees Celsius(*The Paris Agreement | UNFCCC*, s. d.-a).

In light of these climate commitments and the need for an economic recovery after the Covid-19 pandemic, more and more governments around the world have been turning their attention to hydrogen as a means to reduce their carbon emissions and to fulfil their nationally determined contributions (NDCs) and long-term low greenhouse gas emission development strategies (LT-LEDS) (*The Paris Agreement | UNFCCC*, s. d.-b). As at June 2021, there are over 50 targets, mandates, roadmaps, and policy incentives around the world that directly support hydrogen (*The Future of Hydrogen – Analysis*, s. d.).

Hydrogen offers a complimentary solution along with renewable energy sources to decarbonate a wide variety of sectors including, the energy, transport, and industrial sectors (Mitrova et al., 2019). Hydrogen, especially 'green' hydrogen derived from the electrolysis of water from renewable energy are slowly being endorsed by governments to become a major player in the energy landscape within the coming decades, especially to decarbonise hard-to-abate sectors such as mobility and industry, to reach emission targets.

As with all new technology, hydrogen faces a slew of issues that must be addressed before its widespread adoption. Though the lens of the Multi-level Perspective (MLP) framework, this dissertation examines the current social norms and technical structures and how hydrogen as a niche technology has the opportunity to disrupt the current fossil fuel-based regime and social landscape (Geels, s. d.). This analysis will be done by comparing the main actors in the German and Australian hydrogen landscape to see how the presence of powerful actors supporting the niche innovation help mature hydrogen into the regime (McDowall, 2014). The countries of Germany and Australia are chosen due to their historical reliance on coal and faced similar challenges in decarbonising their energy sources. The two countries were also chosen because of their government's long-term outlook on hydrogen in their respective economies; Germany aims to be a net importer of hydrogen and Australia as a net exporter (Department of Industry, 2019a; *Germany's National Hydrogen Strategy*, 2020).

Introduction

Similarly, analysis of Germany and Australia are chosen due to their philosophical approach to growing the hydrogen economy. Germany's government under the European Union (EU) framework is a firm believer of promoting 'green' hydrogen as a way to decarbonise its economy, whilst the Australian government has supported the exporting of hydrogen by scaling first with 'grey' and unproven 'blue' hydrogen and to decarbonise at a later stage. This 'Green Hydrogen Emphasis' approach and 'Scale first - Clean later' approach is an interesting lens to view different pathways towards the same goal of using hydrogen to decarbonise and reach climate targets.

However, as a niche attempting to disrupt the current regime, hydrogen is not without its issues causing friction for its adoption as the dominant design. Currently, these issues are mainly economic and political in nature. Still in the early phase of niche adoption by the social technical regime, governmental policies and the international taxonomy around hydrogen are still quite fuzzy causing a lack of public investment into the industry. The lack of taxonomy and clarity around the different coloured hydrogen, makes the investment landscape very unstable and it is difficult for investors to assess the long-term viability of any investments into the industry. This dissertation will also discuss the current stalemate within hydrogen investing and the need for taxonomy around sustainable finance to create confidence for investors to pour capital into the growing industry. Finally, due to the niche nature of hydrogen and the emerging state of hydrogen markets, this dissertation will discuss some of the market mechanisms that could be implemented to help develop the hydrogen economy.

Chapter 1. Energy Systems: The Role of Hydrogen in a New Era

1.1. The Decarbonisation of Energy

Since the boom of the industrial revolution in the 1760's, humanities consumption of fossil fuels has been growing at a rapid pace as economic growth became tied with energy consumption. Coal, oil, and natural gas have become the cornerstones of economic development and GDP growth, which improved the prosperity of the countries and the standard of living for its citizens (Stern, 2018). Coal, oil, and natural gas have grown to become 25%, 31%, and 23% of the global power mix, respectively (*Bp Statistical Review of World Energy 2020*, 2020), and combined contribute to 95% of carbon emissions of all fuel types (Friedlingstein et al., 2020). In recent years, the casual link between carbon emissions and climate change (greenhouse effect) (Appiah et al., 2019; Dones et al., 2004) has become a huge factor in the social and political sphere as the global society aims to halt the global environmental changes that carbon emissions poses.

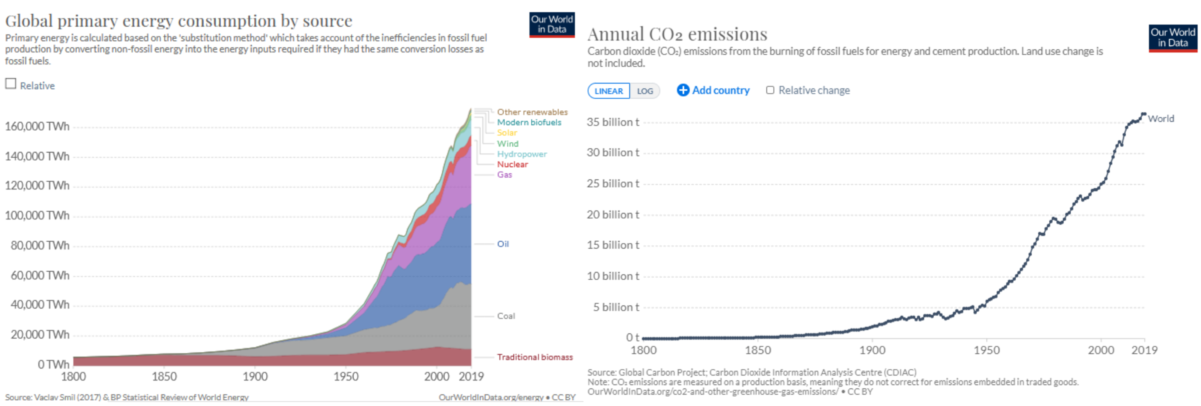


Figure 1 & Figure 2: There is a causal relationship between the rise of fossil fuel based energy consumption and carbon emissions which is leading to global environmental changes. Carbon emissions are now at the forefront of political and social agendas around the world. (CO2 emissions*, s. d.;* Energy Production and Consumption*, s. d.)*

As a global society, the importance of creating a sustainable, zero-carbon future has been at the forefront of political and social agenda in recent years. In the advent of the Kyoto Protocol and subsequent Paris Agreement, there is now a concrete political and social target to limit global average temperature to well below 2 degrees Celsius above pre-industrial levels, and to limit the increase to 1.5 degrees Celsius(*The Paris Agreement | UNFCCC*, s. d.-a). This global target has led to a re-examination of our historic fossil-based energy systems towards low-carbon, sustainable, and renewable types of energy in order to meet these climate targets.

1.1.1. Rise of Renewable Energy Systems (RES)

Renewable Energy Systems such as solar, wind, hydro, biofuels are primary energy sources that have been key for the transition towards a less carbon-intensive and more sustainable energy system. RES systems utilise resources that naturally replenished on a human timescale to generate very low carbon emission energy, the National Renewable Energy Laboratory showed that RES emitted 20 times less carbon emissions per kilowatt-hour (kWh) compared to coal over its lifetime. Renewable energy has been at the forefront of social and political adoption and used as one of the main resources in the energy transition and the decarbonisation of energy.

Since the Paris Agreement in 2016, 134 of the 190 signatories have ratified the agreement and submitted National Determined Contributions (NDCs) which set quantified renewable energy targets (*Renewable Energy and Climate Pledges*, s. d.). As a result, the RES have grown by 1,700 GW since 2016 (*IRENA_-RE_Capacity_Highlights_2021.pdf*, s. d.) and is expected to overtake coal and be the largest source of electricity generation by 2025 (*Renewables 2020 – Analysis*, s. d.). This political and social will of renewable energy adoption has also created a virtuous cycle where the adoption of RES has led to dramatic price decreases and thus even more widespread adoption.

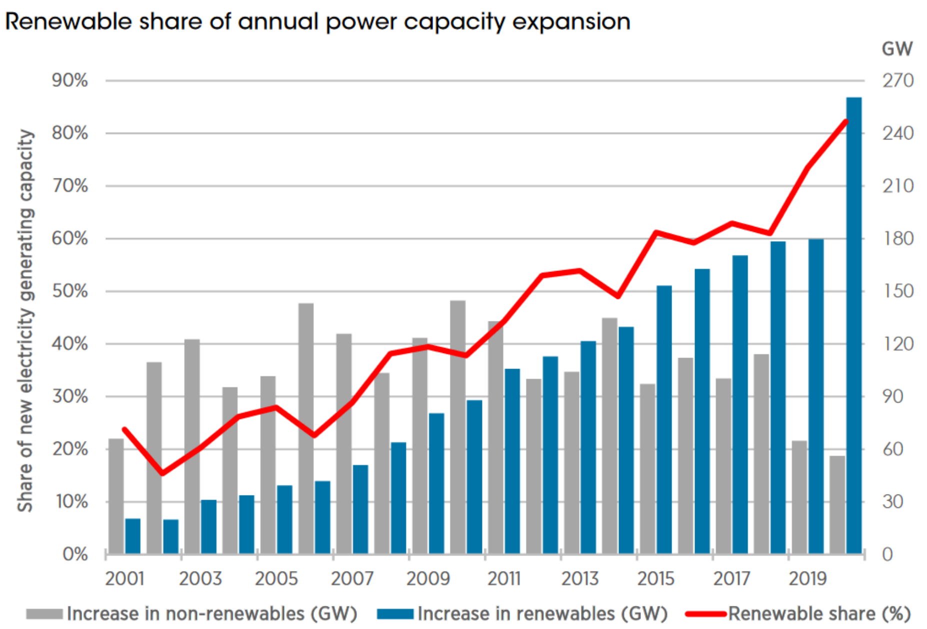


*Figure 3: Renewable energy capacity has dominated new power generation projects as reducing carbon emissions are being pushed through social and political agendas. (*IRENA_-RE_Capacity_Highlights_2021.pdf*, s. d.)*

1.1.2. Cost Competitiveness

Even with a strong political and social agenda to transition to renewable energy, one of the biggest drivers of technological adoption is its price competitiveness with the incumbent technology (Geels, 2019). It has taken many years of technological development and government intervention before RES became competitive with fossil fuels. The cost of producing electricity from wind and solar fell dramatically in the past decade[1], with the levelized cost of electricity (LCOE) from solar and wind declining by 89% and 70% respectively from 2009 to 2019.

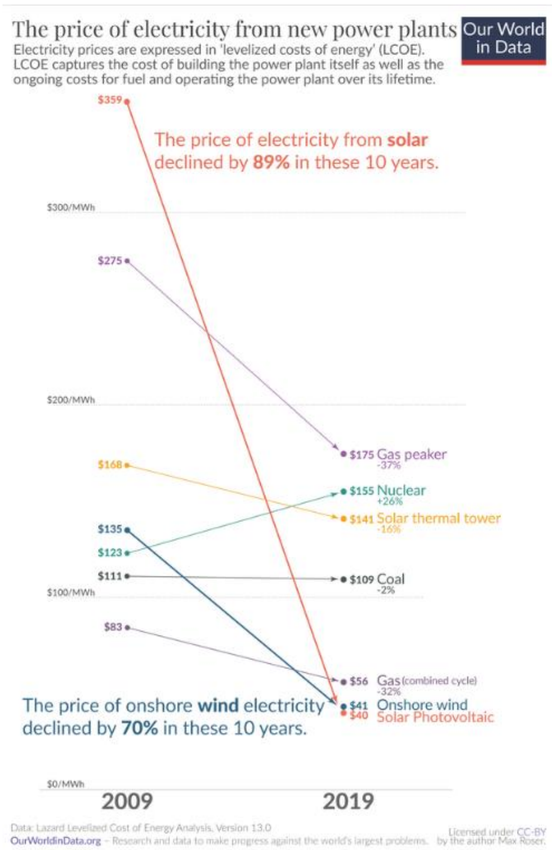


*Figure 4: The cost of renewable energy sources such has wind and solar has dropped dramatically as adoption began to grow. (*Why did renewables become so cheap so fast?*, s. d.)*

This dramatic drop in prices were due to many governmental policies and subsidies following the Kyoto Protocol and subsequent Paris Agreement that led to advances in technology that greatly improved the learning curve and economies of scale for these technologies. As governmental policies cause greater deployment of RES, the technology entered a virtuous cycle where it caused prices to fall, which created more demand, which in turn would cause prices to fall, leading to the dramatic drop in RES cost and increase in RES capacity expansion.

[1] This dissertation was written in 2021; the price of RES has dropped significantly in the decade from 2010 to 2020 and continues to drop.

Due to this virtuous cycle, the LCOE for these renewable technologies have dropped dramatically and are now more economically viable than coal or gas-powered electricity power plants. Although, the price competitiveness of RES is leading to a new age of decarbonised energy, where RES is expected to be the dominant electricity supply by as early as 2025 (*Renewables 2020 – Analysis*, s. d.), there still remains many issues that come with using renewable energy as a power source.

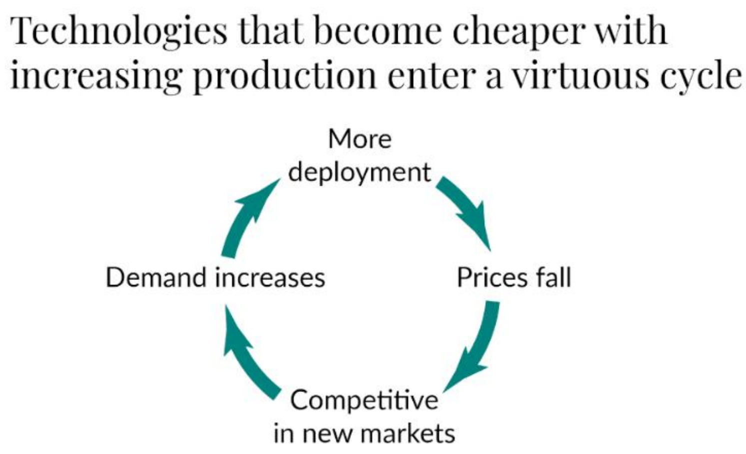


*Figure 5: Renewable energy systems have entered the virtuous cycle, where the adoption of RES causes prices to drop which leads to even more widespread adoption.(*Why did renewables become so cheap so fast?*, s. d.)*

1.2. Intermittency and the Need for Storage Solutions

One of the greatest issues of adopting wide-scale RES into the energy sector is that RES technologies like wind and solar draw power from natural resources such as the wind and sun, which are affected by environmental, seasonal, and daily cycles that means RES cannot consistently produce energy at all hours of the day. This intermittency of RES has been one of the limiting problems for the growth of renewable energy (baranes et al., s. d.), as the grid has very little storage capacity and the balance between electricity supply and demand must be kept in order to avoid blackouts and keeps the grid operating (Fares, s. d.).

To combat one of the biggest limiting factors of RES, there have been an ever-increasing need for energy storage solutions as RES is growing to become one of the most dominant energy sources. Energy storage solutions are vital to compliment RES as they store excess energy produced during peak cycles and discharges these reserves into the power grid when cycles dip, therefore, negating the intermittency of renewable energy. The ability to store energy is also critical to use renewable energy in the transport and mobility sector, where vehicles which are not connected to the grid require portable fuel solutions. Addressing storage solutions to enable renewable energy use for mobility and transport is vitally important in the decarbonisation of energy and the energy transition as transportation contributes to 24% of total carbon emissions (*Tracking Transport 2020 – Analysis*, s. d.).

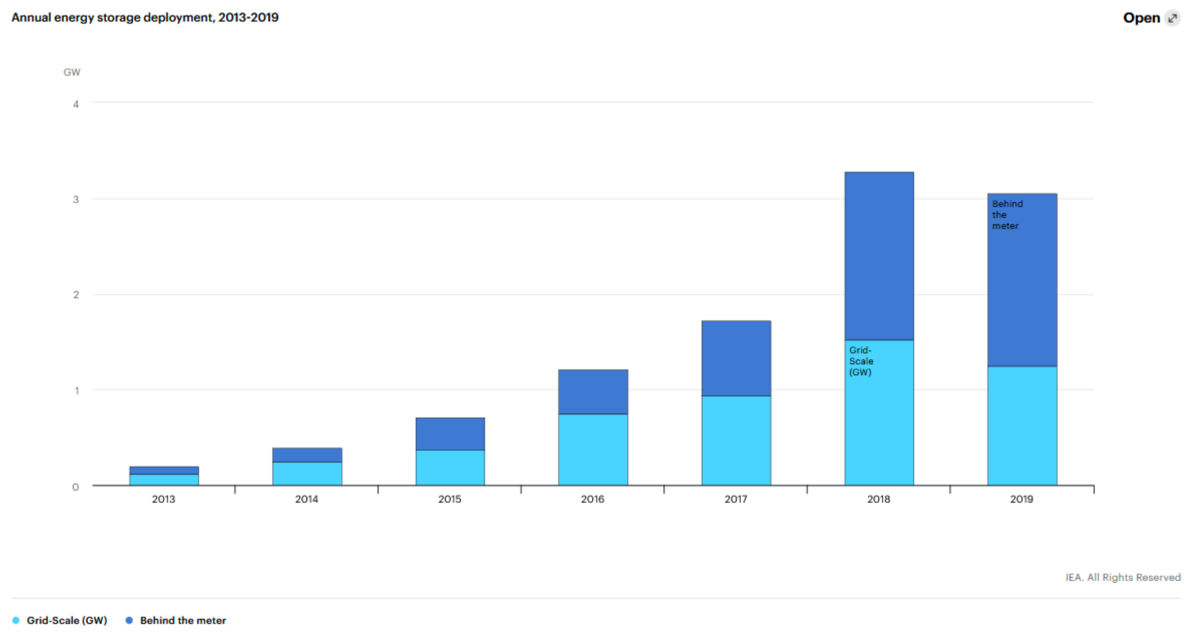


*Figure 6: The intermittency of RES means energy storage is increasingly crucial for a stable energy network. However, these energy storage systems are currently being dominated by behind the meter solutions and for renewables to address the energy landscape, grid-scale solutions need to be addressed as well. (*Energy Storage – Analysis*, s. d.)*

Strongly correlated with the development of RES, energy storage has significantly grown in the past ten years as renewable energy started entering the electricity grid and as electric vehicles (EVs) started to gain popularity (*Energy Storage – Analysis*, s. d.). Energy storage is currently deployed in two main ways, at a grid-scale level to help balance the load and at a behind the meter level, to help consumers with RES store electricity for personal consumption.

As of 2017, pumped hydroelectric energy storage (PHES) dominated the total installed energy storage capacity, with a total of 176 gigawatts (GW) installed making up 96% of all energy storage capacities (*2030 - Electricity storage and renewables Costs and mark.pdf*, s. d.) One of the greatest downsides of PHES is it requires very specific geographical restraints; PHES require either large reservoirs of water and/or significant height differences but relatively geographically near between the two reservoirs. Combined with the need for large capital investment to build PHES, not many countries have a feasible combination of renewable energy, geography, and capital investment to make PHES a widespread storage solution; over three-quarters of PHES is installed in only 10 countries with three countries, China, Japan, and the United States accounting for almost half (48%) of global PHES (*2030 - Electricity storage and renewables Costs and mark.pdf*, s. d.). Similarly, as the decarbonisation of energy and reaching carbon targets are becoming more and more important, the inability for PHES to be scaled down means it is unable to service many carbon-intense sectors such as mobility and transport.

Batteries energy storage solutions (BESS) currently only account for 4 gigawatts or 1.1% of total energy storage capacities worldwide (*Battery Storage Is (Almost) Ready to Play the Flexibility Game – Analysis*, s. d.), and adoption of batteries have grown greatly in past few years as prices have dropped dramatically as a result of technological improvements. Although battery storage systems are becoming more and more important as renewable energy capacities are growing, there are still currently some applications in which batteries fail to be able to address. The most common type of batteries , lithium-ion batteries are rarely able to deliver full power capacity for more than four hours at a grid-wide scale (*So, What Exactly Is Long-Duration Energy Storage?*, s. d.), making it a poor and uneconomical solution for long duration energy storage[2] (*Long-Duration and Long-Term Energy Storage for Renewable Integration | Frontiers Research Topic*, s. d.).

Similarly, the role of batteries as energy storage is limited in some sectors that require specifications which batteries are not well adapted for. These 'hard-to-abate' sectors include heavy industry such as cement, steel, aluminium, and chemical manufacturing, where

[2] Long duration energy storage is classified as 10-100 hours of charging and discharging duration. This is currently beyond the capacities or economics of conventional batteries. (*Long-Duration and Long-Term Energy Storage for Renewable Integration | Frontiers Research Topic*, s. d.)

batteries are unable to provide the energy intensity required. Batteries are also poorly applicable for the heavy-duty transport industries of shipping, trucking, and aviation due to the heavy weight and long charge times that batteries require, and for which weight and downtime are a premium in these industries. (*Tackling the Harder-to-Abate Sectors*, s. d.).

Many energy storage systems, namely batteries and hydrogen, are still in its early stages of technological development and are only present in few key markets that have strong policy support (*Energy Storage – Analysis*, s. d.; *Fact Sheet | Energy Storage (2019) | White Papers | EESI*, s. d.). Limitations to each of these energy storage solutions and their applications means that there is space for other energy storage solutions.

1.2.1. Hydrogen

In recent years, there has been lots of interest to use hydrogen and hydrogen technology as an energy storage system to help store energy from RES and help achieve decarbonisation targets. Hydrogen has been used for over 40 years as a chemical feedstock for industrial chemicals and as fuel for space exploration (*H2*, 2020). Of the 60 million tons of hydrogen produced each year, only 1% is used as an energy vector, used as a high energy density propellant in the space industry. There is growing support amongst industry, academia, and political leaders that hydrogen can be used to help to reach decarbonisation targets due to its versatility in use.

Hydrogen as an energy vector can be used as a compliment to RES and battery storage systems as an energy storage system in the power and electricity sector; it also has the ability to be adopted in the mobility, transport and industry sectors, specifically poised to tackle 'hard-to-abate' use cases; as hydrogen is energy dense, portable, and lightweight compared to other energy storage systems like batteries and pumped hydroelectric storage systems. Hydrogen can be transported and used as a gas in high-pressure containers, or as a cooled liquid in insulated containers, or as processed forms as methanol or ammonia. This lends hydrogen to be a potential energy carrier for a variety of different applications.

Hydrogen is already implemented in mobility solutions around the world; in 2019, there were over twenty-five thousand fuel cell electric vehicles (FCEV) and 470 hydrogen refuelling stations in operation worldwide as countries start to encourage hydrogen into the transport fuel mix (*Hydrogen – Analysis*, s. d.-a). Fleet vehicles are also becoming one of the biggest growth areas to decarbonate the trucking and warehousing industries, where the need for long ranges and short reset times means that hydrogen is much more viable than BESS vehicles for these use cases. Automakers such as the world's largest long-haul truck maker, Daimler Truck are investing heavily to create a 'hydrogen highway' and changing their business model to begin delivering hydrogen powered trucks by 2050 (*Daimler Truck, Shell sign agreement on hydrogen trucking in Europe*, 2021; Ewing, 2021). Fundamentally, the mentality of big corporation has been adopting hydrogen technology as they must transition away from developing fossil fuel-based vehicles.

Hydrogen non-road vehicles are gaining recognition also with successful trials of hydrogen-fuelled trains in Germany led to the announcement by the Germany government to implement a total of 16 trains by 2021 (*A hydrogen-powered train will make history as Europe looks to become world leader in green rail travel | Fortune*, s. d.). Hydrogen powered ships and plane concepts are also being tested as hydrogen becomes more and more popular and emission targets being increasingly important (*Hydrogen in Aviation*, s. d.; Timperley, s. d.). These 'hard-to-abate' sectors are looking to transition away from fossil fuel based fuels towards alternatives which BESS is not well suited to address.

Hydrogen as gas can also benefit from being using to use existing gas infrastructure and networks meaning it has a lower cost to entry as social and political policies encourage more low-carbon energy solutions(*When Will Hydrogen Be Cost Competitive?*, 2021). Pipeline transportation is by far the most economically viable method as via pipelines, very high energy transportation capacity can be achieved (*Repurposing Gas Pipelines for Hydrogen*, s. d.). The GRHYD project in France showed the technical feasibility of hydrogen in the gas network by blending 20% of the natural gas supply with 6% hydrogen (*The GRHYD demonstration project | Gas | ENGIE*, s. d.). Similar projects have been replicated as a growing number of countries are interested in hydrogen-blending into the gas grid to combat the intermittency of RES leading to periods of surplus and curtailment (*Hydrogen – Analysis*, s. d.-b). Events such as the 'Paris de l'hydrogène', which lit up the Eiffel Tower in France with green hydrogen demonstrates the ability for hydrogen to be used as an energy carrier and shows the intentions of many nations around the world (Largue, 2021).

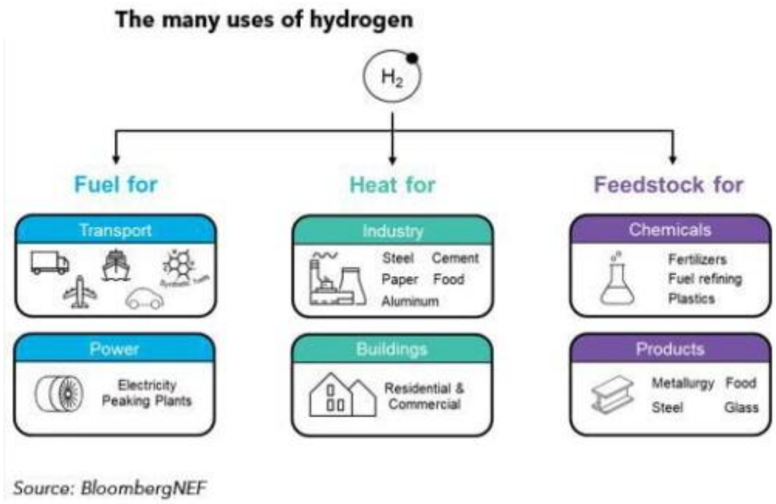


*Figure 7: Hydrogen as an energy vector is suited for a variety of use cases, including for use in 'hard to abate' sectors where electrification is not a suitable substitute of fossil fuels. It is the versatility of hydrogen that makes it a very exciting prospect to achieve decarbonisation and emission targets. (*Tracking the Hydrogen Economy*, s. d.)*

1.2.2. The Different Colours of Hydrogen

Although all hydrogen is fundamentally the same and can be used in identical ways, there are very different methods of producing hydrogen, each with very different carbon footprints. Up to 95% of hydrogen that is produced today is 'grey' hydrogen, produced through steam methane reforming (SMR) of natural gas (*Green and Blue Hydrogen*, s. d.; *hydrogen_report.pdf*, s. d.). This form of hydrogen production produces huge amounts of carbon dioxide and efficiency losses of up to 70% means that producing grey hydrogen is often more expensive than the natural gas used to produce it. Although grey hydrogen is not useful in helping achieve decarbonisation and climate targets, there is already a mature although niche industry that could scale up and grow the hydrogen infrastructure and economy in preparation for low and zero carbon hydrogen.

Low and zero carbon hydrogen production is also being developed in a way to utilise the benefits of hydrogen technology while also achieving emission targets. 'Blue' hydrogen is the production of hydrogen using SMR but with the addition of carbon capture and storage (CCS) technology, which aims to capture the carbon emissions from using natural gas in the production of hydrogen so it is not released into the atmosphere. These emissions are stored in underground geological formations such as in exhausted gas fields or salt caverns. Currently, CCS and blue hydrogen production only exist in demonstration plants and concept but does not exist at a commercial scale (*The Clean Hydrogen Future Has Already Begun – Analysis*, s. d.).

Another form of hydrogen is 'pink' or 'purple' hydrogen which is formed by the electrolysis of water from nuclear energy. 'Purple'[3] hydrogen is also considered low-carbon hydrogen as the nuclear energy used for the process is considered 'low-carbon' under EU taxonomy (Taylor, 2020). Although purple hydrogen may not be a feasible solution for countries all around the world who do not have nuclear assets or a political sphere to adopt nuclear, it may play a huge role for countries who already have huge amounts of nuclear capacity, such as France and China. Purple hydrogen may be a way for these countries to generate industrial amounts of low-carbon energy for either domestic consumption or trade.

The most anticipated type of hydrogen that is believed to help achieve decarbonisation and climate targets is 'green' hydrogen. 'Green' hydrogen is hydrogen derived from the electrolysis of water from renewable energy. Green hydrogen is considered zero carbon and are slowly being endorsed by governments to become a key player in decarbonising the energy landscape for the long-term. Governments, academics, and experts believe that green hydrogen has a big role to play in being an energy carrier and help alleviate the intermittencies

[3] This paper will use the term purple or pink hydrogen interchangeably.

of RES. However, there is still a lot of investment necessary before the infrastructure and technologies to create green hydrogen at scale and at a competitive price are feasible.

Ultimately, hydrogen of all 'colours' are all the same in terms of product and can be used in identical ways. Around the world there has already been some use cases in which hydrogen is being adopted as governments promote hydrogen to be a key energy source of the future.

Box 1. Hydrogen at a glance		
Colors are often used to refer to different types of hydrogen according to how it was produced, in the following way.		
Green	Produced from water by electrolysis, using renewable electricity (e.g., solar, wind). Nuclear electricity can also be used in this manner to produce hydrogen, and this is referred to as 'yellow hydrogen'.	Mostly pilot projects.
Blue	Produced by steam methane reforming **with** carbon capture, utilization and storage (CCUS), using natural gas or biomass (thus with very low or no CO_2 emissions).	Numerous demonstration size plants exist and are in development. The technology is proven but needs to be scaled to industrial size.
Gray	Produced by steam methane reforming **without** CCUS, using natural gas. Gray hydrogen produces a lot of CO_2.	Most of the current production.
This report discusses the economic opportunities in developing low-carbon hydrogen production and application. We therefore focus mostly on blue and green hydrogen production. Of course, from the point of view of applications, hydrogen of all "colors" are the same and can be used in identical ways.		

*Table 1: The 'colour' of hydrogen referes to the method in which hydrogen is produced. This is very important as the aim of hydrogen is to reduce carbon emissionsm and different colours of hydrogen emit different amounts. Due to process inefficiencies, some colours of hydrogen produced from fossil fuels are more carbon intensive than using the fossil fuel itself. (*Tracking the Hydrogen Economy*, s. d.)*

1.3. The Two Approaches to Hydrogen Adoption

Hydrogen is becoming more and more popular tool as a way for countries to transition away from fossil fuels towards a more sustainable energy landscape and to reach climate targets. Over 13 countries have a dedicated hydrogen strategy, and over 40 other countries are either preparing strategies, engaging in initial policy discussions, or have invested in pilot or demonstration projects (*Tracking the Hydrogen Economy*, s. d.). This engagement from governments have created a landscape to grow the hydrogen economy and spark investments into hydrogen production of all 'colours'.

Green hydrogen produced from 100% renewable energy sources is agreed upon by the European Commission and most international energy organisations to be the only type of zero-carbon hydrogen that is sustainable for the long term (European Commission. Directorate General for Energy. et al., 2020). However, with the growing push for decarbonisation and reaching zero-carbon emissions, governments have very different approaches on how they intend to adopt and grow the hydrogen economy. Although the hydrogen landscape and hydrogen policies are still in its infancy, this dissertation will outline two core approaches to hydrogen adoption and analyse them to see how they may reach decarbonisation targets.

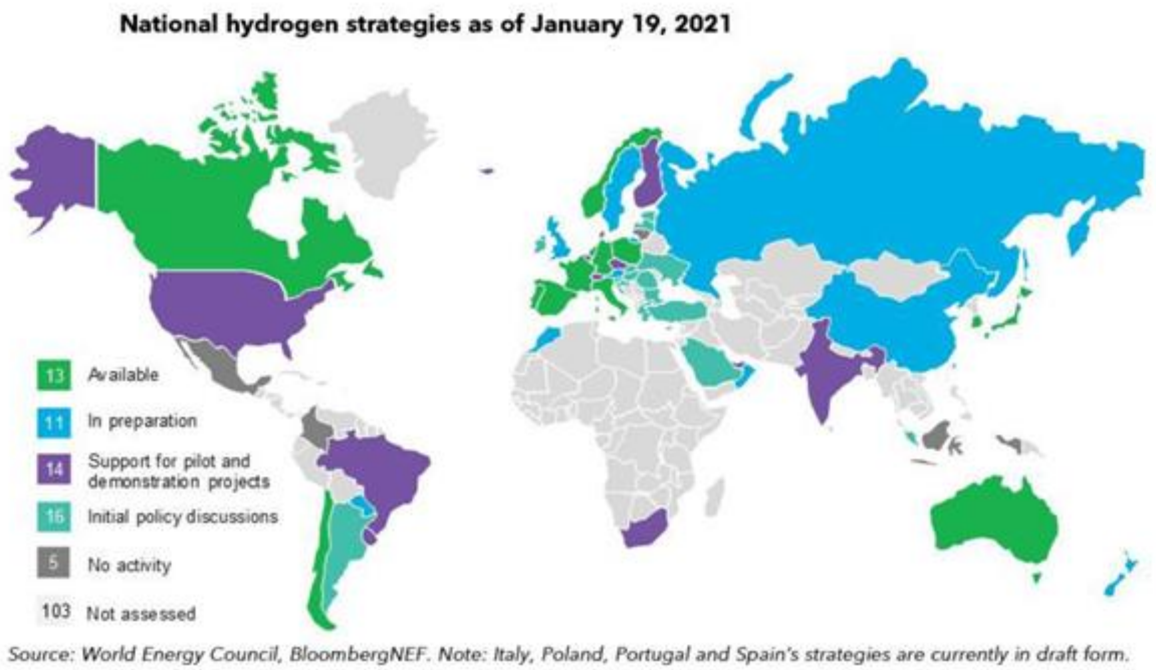


*Figure 8: Hydrogen is becoming a popular tool for countries and governments around the world to help achieve climate targets and grow their economies. So far there are over 50 countries engaged in some sort of policy development for hydrogen. However whilst hydrogen is still a very niche innovation, all these countries have different views and pathways in their adoption of hydrogen. (*Tracking the Hydrogen Economy*, s. d.)*

1.3.1. 'Scale First-Clean Later' Approach

One of the approaches that countries and governments are taking are the 'scale first – clean later' approach to hydrogen. This approach is centred around the growth of the hydrogen economy through investments and policies that support hydrogen regardless of the 'colour'. These governments plan to build and develop hydrogen infrastructure and a fluid hydrogen economy with the intention of 'cleaning' these hydrogen assets in the long-term. The 'cleaning' of hydrogen refers to utilising CCS technology to enable the use of fossil fuels to produce hydrogen while meeting emission targets or the retrofitting of hydrogen production facilities to use renewable energy. It is important to note that CCS technology is still very much in its infancy and only exists in small-scale pilot and demonstration projects and is largely economically unproven for widescale use (*Carbon Capture, Utilisation and Storage - Fuels & Technologies*, s. d.). This 'scale first – clean later' strategy is often adopted by countries who aim to develop enough capacity to be net exporters of hydrogen to other countries and in the hopes that CCS technology will advance enough to enable 'blue' hydrogen to be a viable production method in the future.

Some of the main characteristics of governments that are taking this approach are countries that have historically been dependent on fossil fuel resources in their energy mix. These include historical exporters of energy that have huge potential for RES growth, such as Australia and Saudi Arabia, who have huge amounts of natural gas and oil reserves respectively, and both have huge potential for RES (Department of Industry, 2019a; *Saudi Arabia takes steps to lead the $700B global hydrogen market*, s. d.). This environment lends itself to a 'scale first-clean later' approach as these countries see the importance of leveraging their current fossil fuel resources to help them build infrastructure that will benefit them in the long-term as net exporters in a low-carbon emissions energy landscape.

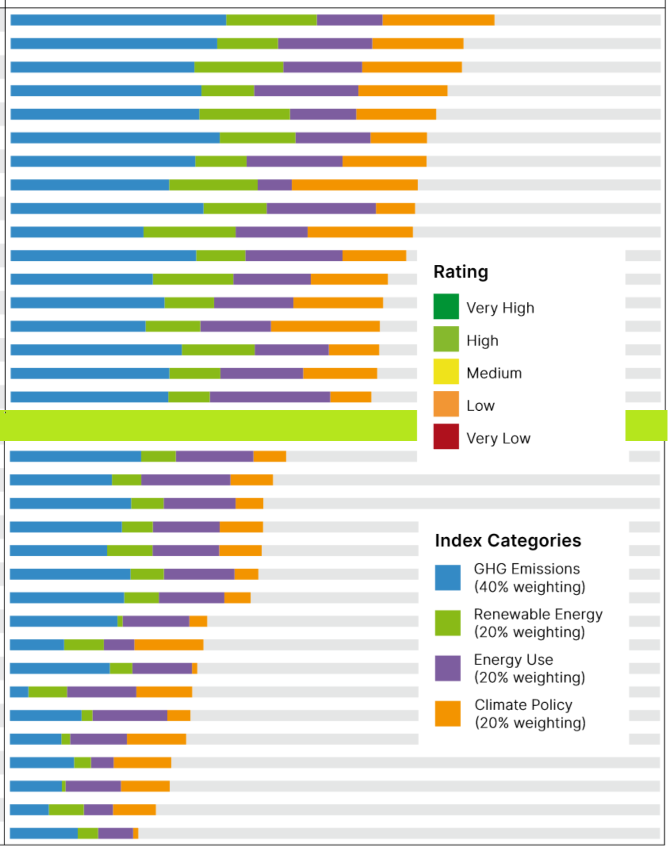
Countries taking this approach also tend to be to be independent nations where there is less emphasis of sustainability and decarbonisation targets set at a national federal level. This is often because developing the 'grey' hydrogen economy is contradictory to most short-term climate goals. Countries such as Korea, Australia, Japan, Canada, and Saudi Arabia all have hydrogen strategies that appear to be adopting the 'scale first-clean later' approach, these countries are also rated 'very low' on the Climate Change Performance Index as seen in Figure 9, which ranks countries' progress towards preventing climate change (*Climate Change Performance Index 2021 | Climate Change Performance Index*, s. d.). We see that Japan, Korea, Australia, Canada, and Saudi Arabia rank 45th,53rd, 54th, 58th, and 60th out of 61 countries ranked on this list and are some of the worst performers in attempting to reach sustainability and decarbonisation targets. By adopting this strategy, it is possible that the countries low on the index can make progress towards achieving long-term climate targets by sacrificing short-term targets to grow and develop the hydrogen capacities and infrastructure that would propel them in being economic and climate front-runners in the long-term.

However, this approach is not without its downfalls. An emphasis on grey and blue hydrogen investments to grow the hydrogen economy forms hesitance in the investment landscape as investors face greater risk as green hydrogen is still often the long-term stated goal. These concerns of long-term uncertainty combined with external factors such as, ever-changing global climate policies, developing sustainable taxonomies, and a hydrogen economy still very much in its infancy, places a huge dilemma for investors under the 'scale first-clean later approach'. Without strong government policies and incentives to de-risk investment into early-stage hydrogen projects, there will be an investment dilemma that may paradoxically stunt the growth of hydrogen in countries that are aiming for high initial growth. This concept of the investment dilemma will be discussed in Chapter 3. The Investment Landscape of Hydrogen and the need for Hydrogen Markets

Climate Change Performance Index – Rating table

Rank		Country	Score**
1.*	–	–	–
2.	–	–	–
3.	–	–	–
4.	–	Sweden	74.42
5.	▲	United Kingdom	69.66
6.	▼	Denmark	69.42
7.	▼	Morocco	67.59
8.	▲	Norway	65.45
9.	▲	Chile	64.05
10.	▼	India	63.98
11.	▼	Finland	62.63
12.	▲	Malta	62.21
13.	▲	Latvia	61.88
14.	▲	Switzerland	60.85
15.	▼	Lithuania	58.03
16.	▲	European Union (28)	57.29
17.	▲	Portugal	56.80
18.	▲	Croatia	56.69
19.	▲	Germany	56.39
20.	▼	Ukraine	55.48
45.	▲	Japan	42.49
46.	▼	Argentina	40.48
47.	▼	Czech Republic	38.98
48.	▲	Poland	38.94
49.	▼	Cyprus	38.73
50.	▼	Hungary	38.22
51.	▼	Slovenia	37.02
52.	–	Russian Federation	30.34
53.	▲	Korea	29.76
54.	▲	Australia	28.82
55.	▼	Kazakhstan	28.04
56.	▼	Malaysia	27.76
57.	▲	Chinese Taipei	27.11
58.	▼	Canada	24.82
59.	▼	Islamic Republic of Iran	24.58
60.	–	Saudi Arabia	22.46
61.	–	United States	19.75

Categories



* None of the countries achieved positions one to three. No country is doing enough to prevent dangerous climate change.
** rounded

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*Figure 9: Countries adopting the 'scale first – clean later' approach for hydrogen are often ranked very low on achieving climate targets. This approach to hydrogen adoption can be a way in which these countries leverage fossil fuel resources to achieve long-term climate goals (*Climate Change Performance Index 2021 | Climate Change Performance Index*, s. d.)*

1.3.2. 'Green Hydrogen Emphasis' Approach

The other approach that countries are adopting is the 'green hydrogen emphasis' approach, where a combination of legal frameworks, policies, climate targets create a landscape where investment into 'green' hydrogen projects are given much more support than 'grey' or 'blue' hydrogen. Countries that adopt this approach prioritise green hydrogen projects and often incorporate green hydrogen targets as part of their strategy to achieve climate goals. This includes developing in hydrogen infrastructure and networks while investing in technologies and innovations that are aimed to grow the renewable, green hydrogen market. Ultimately, these countries see green hydrogen as being a big part of their medium to long term energy mix and decarbonisation mission and are encouraging the growth of green hydrogen as quickly as possible. Often this approach is adopted by countries that already have made strong commitments to decarbonisation and climate targets and see green hydrogen as a way to further their commitments.

Some of the main characteristics of nations that are adopting this approach are those countries that have ambitious decarbonisation agendas. These include many of the developed countries in the European region including core member states of the European Union (EU), countries such as Germany, France, Sweden; and the United Kingdom can be considered to be adopting a 'green hydrogen emphasis' approach. The sustainability and climate agenda has been very high in the European Union as reflected through its numerous policies in the European Green Deal, Fit For 55 package, Renewable Energy Directives, etc; as a result, many of their member states and core trading partners[4] have similarly adopted a strong landscape for reaching climate targets. These targets have permeated from the EU level down to the federal level, where the states are finding green hydrogen as viable way to hit climate targets and as a way to stimulate economic growth and job creation by promoting the green hydrogen industry.

Another main characteristic of the countries adopting the 'green hydrogen emphasis' approach is that they often have high amounts of renewable or low-carbon energy in their energy mix. Countries such as Germany, the UK, Sweden, and France[5] that are taking the 'green hydrogen emphasis' approach are countries that also have the highest share of renewable energy use in their energy landscape (Nhede, 2020). A high share of renewable energy capacity lends itself for better development of the green hydrogen economy; as green hydrogen technology develops and matures, countries with already high amounts of RES will be able to capitalise on these benefits.

[4] Key trading partners such as the United Kingdom and China, although are not part of the EU have enormous political and economic pressure to be aligned in adopting and achieving climate goals.

[5] France has a huge amount of low-carbon nuclear energy in its energy mix. Nuclear accounts for 70% of its electricity generation or 41% of its total energy supply (*France - Countries & Regions*, s. d.).

Countries following the ‘green hydrogen emphasis’ approach however, face a greater economic and social barrier in deciding how to fund green hydrogen projects. By placing emphasis on technology that has not achieved cost parity governments must incentivise investment or development into the green hydrogen industry. This may mean that the governments are required to create incentives such as subsidies, tax write offs, or invest public funds to spark growth into the industry. However, these incentives that boost the green hydrogen will be costs born onto taxpayers and the public which may not be favourable policies to enact. The costs of a heavily government subsidies program can be seen in the German Renewable Energy Act (EEG) surcharge which funds the heavily funded feed-in tariffs that led Germany to be a forefront of renewable energy. However, this has meant that electricity prices in Germany are the highest in the world and on average 20% of electricity prices paid by consumers goes towards funding the renewable energy subsidies (*Electricity Prices by Country 2020*, s. d.; *What German Households Pay for Power*, 2015). Although funding mechanisms have shown to grow energy related industries in the short term, (Frondel et al., 2010) suggests that these policies ‘show little long-term promise for stimulating the economy, protecting the environment, or increasing energy security.’

The ‘green hydrogen emphasis’ approach has huge potential for governments to keep their social and political commitments to reaching climate targets and decarbonisation and also to stimulate the economy and create jobs; however, it is important that this approach makes economic sense for the government and will not place financial burden on consumers through heavy taxpayer funded subsidies.

Chapter 2. Multi-Level Perspective Analysis on Hydrogen Adoption in Germany and Australia

This dissertation will attempt to analyse two countries that are adopting different approaches to hydrogen adoption to identify some of the key strengths, weaknesses, and characteristics of the two approaches. The countries of Australia and Germany are chosen due to their historical dependency on coal and natural gas and how even with similar starting points, this path dependency is broken through their very different approaches and pathways towards the adoption of hydrogen.

Australia has the third biggest proven coal reserves in the world and is a major cornerstone for its global exports and internal energy consumption. Coal exports from Australia is valued at $67 Billion and accounts for 4% of its GDP (*Australia Coal Reserves and Consumption Statistics - Worldometer*, s. d.). Coal remains the major energy source for electricity production in the country, and coal power generation accounted for about 56% of the total electricity produced in the country in 2019 (*Australia Coal Reserves and Consumption Statistics - Worldometer*, s. d.; *Australian Energy Update 2019, Australian Energy Statistics*, 2019). Australia also has a huge dependency on natural gas into the future as a low-carbon energy source. Australia is currently the world's largest exporter of liquified natural gas (LNG), exporting around 80 million tonnes per year and accounts for 21% of Australia's energy mix and is expected to grow as 65% of coal powered plants are planned to be closed by 2040 (*Australia Is Now the World's Largest Gas Exporter*, 2020; *Integrated System Plan (ISP)*, s. d.)

As the world places more emphasis on reducing GHG emissions and achieving climate targets set out in the Paris Agreement, fossil fuel demand around the world is expected to drop, and Australia appears to be adopting the 'scale first-clean later' approach to leverage its current coal and natural gas resources to develop its hydrogen economy to focus on 'economic growth' and 'job creation'.

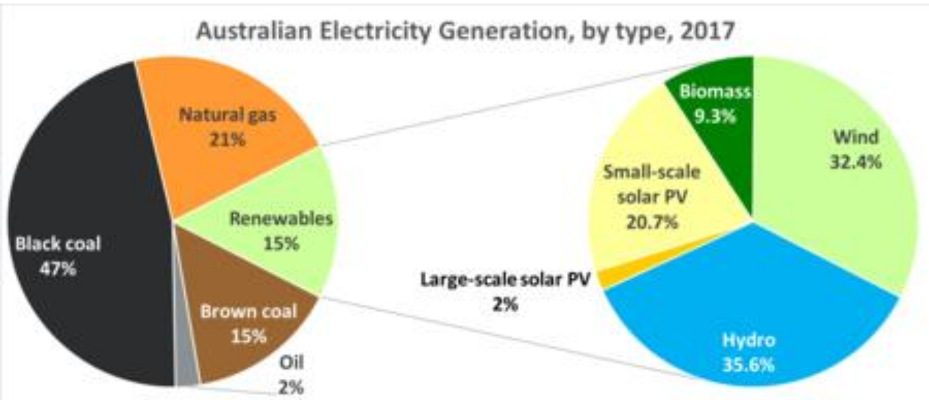


*Figure 10: Australia still has a heavily dependence on fossil fuels such as coal and natural gas for its electricity generation. Taking the 'scale first – clean later' allows Australia to leverage its fossil fuels to develop its hydrogen economy. (*Australian Energy Update 2019, Australian Energy Statistics*, 2019)*

Like Australia, Germany has also had a heavy historical dependence on coal and natural gas. Coal is the second-largest source of electricity generation in Germany, after renewable energy. As of 2020, around 24% of the electricity in the country is generated from coal; at its peak, coal made up of 45% of Germany's electricity mix in 2013 (Holm, s. d.). Natural gas is the second most important primary energy source for Germany, with its share of primary energy consumption at 16% in 2020. However, Germany is heavily dependent on gas imports for its natural gas supply (Energy, s. d.-a). As such, significant social and political factors[6] of 'energy security' and 'climate neutrality' has led Germany to heavily decrease its reliance on fossil fuels and increase its adoption of RES and in adopting a 'green hydrogen emphasis' approach for hydrogen adoption to help further their goals surrounding the German energy transition, also known as the Energiewende[7].

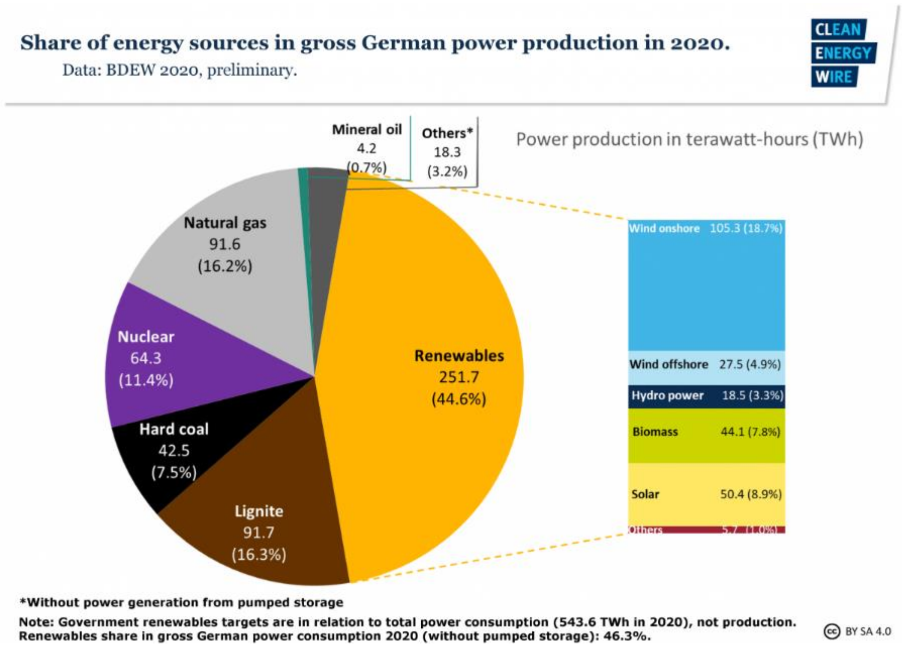


*Figure 11: Much like Australia, Germany still has a lot of coal and natural gas use in its energy landscape. However, strong climate policies and heavy investment into renewable energy means Germany will be adopting the pathway of a 'green hydrogen emphasis' approach to hydrogen adoption. (*Germany's Energy Consumption and Power Mix in Charts*, 2015)*

By comparing these two countries through the lens of multi-level perspective, this dissertation aims to analyse how different factors in the regime and landscape level shape the social-technical adoption of hydrogen by two countries taking very different approaches yet have very similar starting points[8].

[6] These factors will be explored further in this dissertation, but the most important landscape factors for Germany are achieving 'climate neutrality' and 'energy security'.

[7]The Energiewende is the deliberate German energy transition away from fossil fuels towards an 'environmentally sound, reliable and affordable energy supply'. (« The Federal Government's Energy Concept of 2010 and the Transformation of the Energy System of 2011 », 2010)

[8] Starting points from an energy landscape point of view. Both these countries have strong historical dependencies on coal and natural gas.

The Multi-Level Perspective (MLP) analytical frameworks allows us to analyse the complexity of social-technical transitions, such as energy transitions, through understanding the interaction between different actors, environments, and innovations (Geels, 2002b, 2019). The adoption of hydrogen in Australia and Germany can be viewed through the lens of MLP theory as it encompasses a holistic view to identify the different elements and the connection between process from different levels (Gui & MacGill, 2018). From contextual environmental and social-cultural concerns to technological innovation, market development, and social and economic adoption; the MLP framework can track the development of hydrogen adoption down to three different levels: the landscape developments, the social-technical regime, and technological niches.

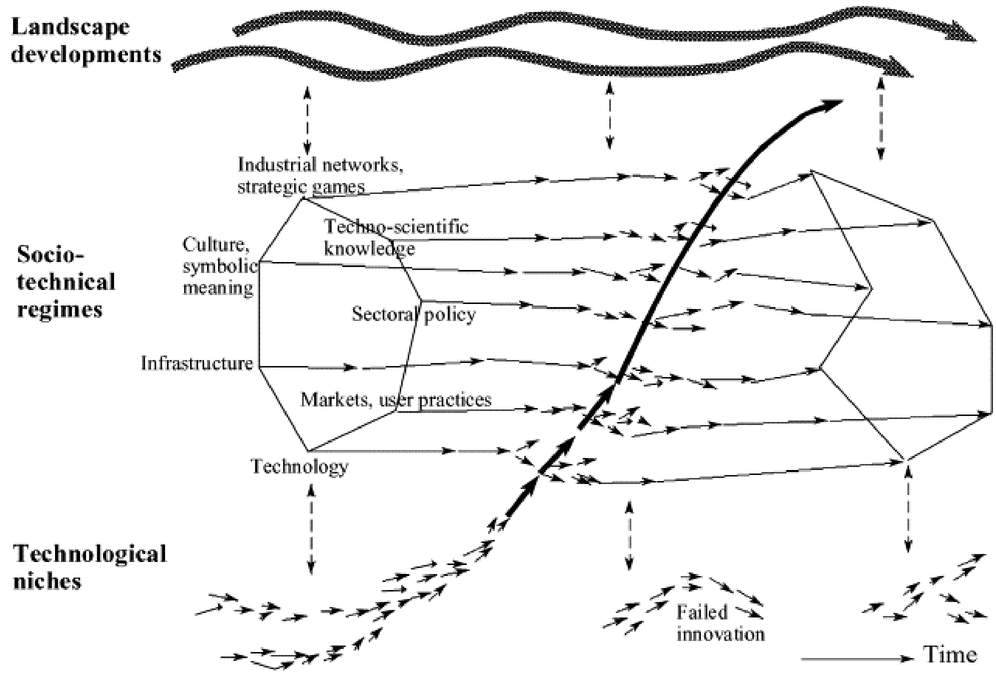


Figure 12: Social-technical transitions can be described through three levels; landscape developments, social-technical regimes, and technological niches all influence each other into either failure or adoption of innovative technologies such as hydrogen. (Geels, 2002b)

2.1. Landscape Level

The landscape level is defined as the 'external structure or context for interactions of actors' and is the wider context and environment that will influence changes in the social-technical regime and the niche levels (Elzen et al., 2004; Geels, 2002a). Here, factors such as environmental stewardship and sustainable energy ideology, economic growth, energy security, peak fossil fuel can be attributed to put pressure on the regime and niche levels for the development and adoption of hydrogen. Here factors such addressing 'climate and environmental action'[9] and on 'energy security'[10] play bigger role in Germany's 'green hydrogen emphasis approach' while factors such as 'economic growth' and 'job creation'[11] have a greater influence on Australia's 'scale first-clean later' approach of hydrogen adoption. These contextual factors which are slowest to change, have a strong effect on the development of hydrogen in the regime and nice levels.

2.2. Social-Technical Regime Level

Here, the regime[12] is the collection of 'rules and incentives' which are supported by stakeholders (Elzen et al., 2004). Stakeholders are defined as actors who possess the power of action (Geels, 2002b) and this can range from governments who enact policies, to energy producers and utilities, to the consumers and society that defines user practices. All these stake holders have very delicate interplays, from consumers dictating policies, to energy producers influencing infrastructure developments, etc. These 'rules and incentives' are shared beliefs, capabilities, institutional arrangements and regulations which relate to the energy transition and the development and adoption of hydrogen (Geels, 2002a).

For example, the policies enacted by the European Union, and by the Australian and German governments reflect the factors outlined in the landscape level. Policies such as the 'EU Green Deal', 'Fit for 55' package, and the corresponding national hydrogen strategies all reflect the context for 'economic growth', 'energy security', and 'climate neutrality' that has been permeating at the landscape level. Similarly, the interplay of actors in the regime due to contextual factors lead to social-technical change. For example, Australian consumers demand for greater low-carbon electricity has driven the development of new business models for Australia's largest energy utility company, AGL.(*AGL announces intention to create two leading energy businesses | AGL*, s. d.) This interplay has had knock-on effects of affecting infrastructure projects, such as AGL investing in hydrogen infrastructure as the company shifts its focus away from coal (*AGL to Leverage Floating Solar at Loy Yang for Hydrogen Project*,

[9] Language used by the European Commission in the European Green Deal (*EUR-Lex - 52019DC0640 - EN - EUR-Lex*, s. d.). Similar language is used in the German Renewable Energy Sources Act (Energy, s. d.-b)

[10] Language used by the European Commission in the Energy Union Strategy (*EUR-Lex - 52015DC0080 - EN - EUR-Lex*, s. d.)

[11] Economic growth and job creation are key factors identified by the Australian Government in the Australian National Hydrogen Strategy (Council of Australian Governments & Energy Council, 2019).

[12] In this dissertation, the author will use regime to mean social-technical regime.

s. d.). Changes that occur in the regime level will inevitably interplay again with the landscape and the regime levels.

The 'rules and incentives' that are created by stakeholders are what shape and form social-technical transitions and will shape how the adoption of hydrogen occurs in the two approaches. Although there are many shared landscape factors that spur the adoption of hydrogen, it is the differences that will shape the hydrogen economy in both the 'scale first-clean later' and 'green hydrogen emphasis' approach.

2.3. Niche Level

The niche level for social-technical transitions is where innovation and development happens. It 'acts as incubation rooms' from normal market forces; this is often driven by governmental policies, technological advances, or changing consumer preferences that occur in the regime level (*DOWNLOAD-Multi-Level-Perspectives.pdf*, s. d.). In the case of hydrogen, its role as a niche in the energy industry is still evolving and slowing moving towards dominant design. Niche innovations include the use of hydrogen for a wide variety of applications that seek to replace incumbent technology. Although hydrogen has been used heavily as industrial feedstock it is still developing its role as an energy carrier, it is still very much in the niche innovation level for applications such as mobility and transport, energy storage and production, residential and commercial heating, and heating for industrial applications. Hydrogen is still a niche that currently must be supported by governmental policies that are being developed at the landscape level.

2.4. The Four Criteria of Hydrogen Development as a Niche Innovation

In a paper by (Geels & Schot, 2007), titled 'Typology of socialtechnical transition pathways', the authors developed four criteria that would determine whether a niche has developed sufficiently enough to become an alternative to the incumbent regime. These are: (i) the emergence of a dominant design, (ii) the enlargement of the network of actors, (iii) improvements in the price/performance ratio, and (iv) a cumulative market share of more than 5% for the new technology. Finally, a transition ends when a new socio-technical regime has emerged, meaning that the social and technical aspects of innovations and their use become embedded in the institutional, the production and the user subsystems of the sociotechnical system. Through these criteria, hydrogen is still very much in the niche landscape level and yet to be able to be an alternative to the incumbent regime.

The emergence of dominant hydrogen design is still not determined, with the different 'colours' of hydrogen still in contention to become the dominant process within the hydrogen industry. The hydrogen industry itself is also competing against BESS storage and natural gas in many domains to assert itself as the dominant design in the electricity, mobility, heating, and industrial sectors. As governmental and institutional actors in the regime level begin to develop more regulations, policies, and business decisions that promote specific ‘colours’ of hydrogen[13], there will inevitable be an emergence of dominant design.

The potential of hydrogen and hydrogen technologies has created an enlargement of the network of actors. There has been a growth of support from governmental actors and currently, there are over 50 targets, mandates, roadmaps, and policy incentives around the world that directly support (*The Future of Hydrogen – Analysis*, s. d.). The Hydrogen Council that was formed in 2017, now has grown to have 92 members of ‘leading energy, transport, industry and investment companies with a united and long-term vision to develop the hydrogen economy.’ (*Hydrogen Council*, s. d.) As the network of actors grow within the social-technical regime, it allows further development of hydrogen at all levels of the social-technical transition, until it satisfies the four criteria and becomes a viable alternative to the incumbent regime.

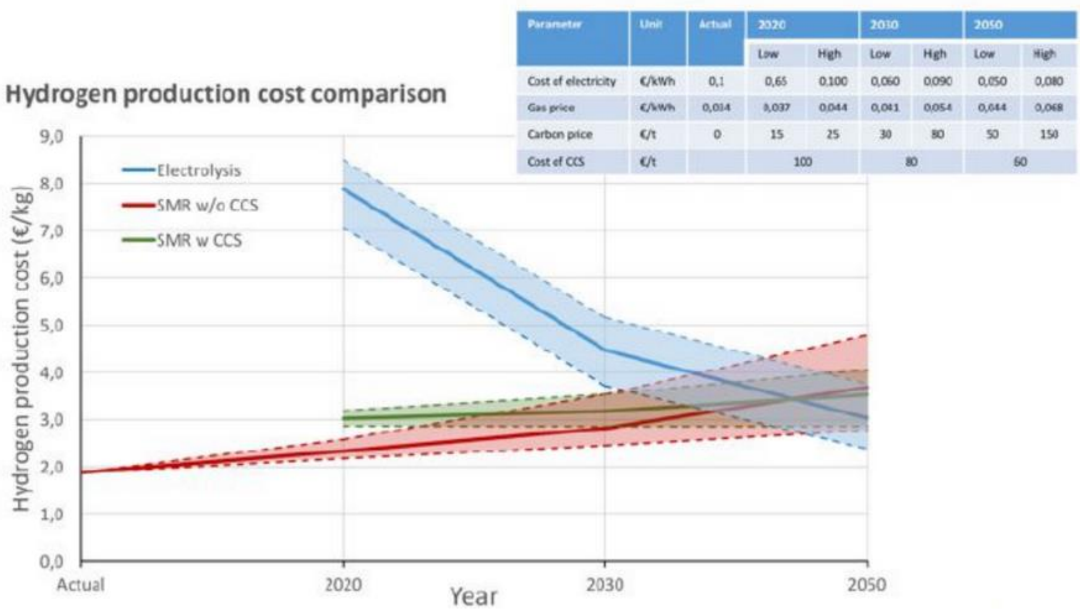
*Figure 13: The hydrogen council group is a collection of high profile companies that are dedicated to the growing of the hydrogen economy and are part of the enlargement of the network actors for the social-technical adoption of hydrogen. (*Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf*, s. d.)*

Another key criteria developed by (Geels & Schot, 2007) in determining the progress of niche development is the improvements in price to performance ratio. This criterion is a measure of technological development and of economies of scale that suggest enough development of innovations to become an alternative to the incumbent technologies. For the social-technical technology in the energy landscape, price-competitiveness is one of the driving

[13] e.g. the European Union and Germany developing regulations that promote green hydrogen as a way to reach decarbonisation and economic growth goals, through the EU Green Deal, Hydrogen Strategy, etc.

factors that leads to widespread adoption, of which hydrogen is no exception (Doner, s. d.; Neij, 1997).

Currently, the cost of hydrogen production is directly correlated to the cost of natural gas and renewable energy prices which are the feedstock into hydrogen production. Hydrogen's niche applications mean it is still yet to reach economies of scale and the cost of producing hydrogen remains very high; costing $USD 3-8/ kg to produce green hydrogen, and $USD 0.9-3 for grey hydrogen (*Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5C Climate Goal*, s. d.). As hydrogen technology is still developing, the cost-parity of hydrogen production to its current alternatives of natural gas or battery storage systems has not yet been achieved. However, as the technology develops and the cost of electrolysers and hydrogen production begins to fall, there will be improvements in the price to performance ratio and it is predicted that green hydrogen can reach cost parity by 2030 in Germany and Australia (*20200423 - Hydrogen Economy - Cost - Risk and safety aspects(1).pdf*, s. d.; *Green Hydrogen to Reach Cost Parity by 2030*, s. d.).



Parameter	Unit	Actual	2020		2030		2050	
			Low	High	Low	High	Low	High
Cost of electricity	€/kWh	0,1	0,65	0,100	0,060	0,090	0,050	0,080
Gas price	€/kWh	0,014	0,037	0,044	0,041	0,054	0,044	0,068
Carbon price	€/t	0	15	25	30	80	50	150
Cost of CCS	€/t		100		80		60	

*Figure 14: Still early in its development, hydrogen of all colours are still yet to experience improvements in the price to performance ratio that would allow it to be a competitor to the current incumbent design. (*20200423 - Hydrogen Economy - Cost - Risk and safety aspects(1).pdf*, s. d.)*

Finally, because of the mature use of hydrogen within industrial production, hydrogen is already close to the 5% market share required to be considered an alternative to dominant design. According to the International Energy Agency, around 120 million tonnes of hydrogen are produced each year, equalling 14.4 exajoules (EJs) of energy and about 4% of global final energy and non-energy use (*IRENA_Hydrogen_2019.pdf*, s. d.). However the vast majority of hydrogen today is produced and used on-site in industry for the production of ammonia and oil refining, and hydrogen utilisation is well below 5% market share in other sectorial applications such as transport, mobility, heating, or electricity generation (*Hydrogen – Analysis*, s. d.-b; *IRENA_Hydrogen_2019.pdf*, s. d.).

Through these criteria, hydrogen is still very much in the niche landscape level and yet to be able to be an alternative to the incumbent regimes of fossil fuels and alternative storage systems. However, through developments by actors in the regime level; we see hydrogen make significant progress towards moving away from being strictly a niche innovation through its enlargement of network of actors and towards acquiring 5% of energy market share.

2.5. Government as Key Social-Technical Regime Level Actors: Policies and Mechanisms in Australia and Germany

Governments are considered one of the key actors at the regime level in a social-technical transition. Like all actors in the regime, governments take on pressure from exogenous factors in the landscape level that aim to change the status-quo from an intangible level (The governance of sustainable socio-technical transitions). The rise of popularity of hydrogen is a subset of the social-technical transition towards sustainability and low-carbon values that have permeated at the social, political, and world view level (Geels et al., 2017; Lawhon & Murphy, 2012).

However, even in the social-technical transition towards energy decarbonisation and environmental sustainability, different governments enact different pathways that either resist or facilitate the transition. This could be seen in countries such as Germany that pioneered RES through their Energiewende, and in countries such as Australia, who are adopting a much more reserved approach in the transition. These different approaches are again broken down within the different levels of government; from supranational and federal levels, down to state and local levels, where the landscape pressures often take on different forms in policy and project adoption.

2.5.1. Supranational and Federal Government Actors

Federal and Supra-governmental actors are possibly some of the most powerful actors in the regime network that can take in landscape factors and enact policies and mechanisms that affect the network of actors[14] and the nice innovation. These decisions will affect national policies that trickle down to state and local levels, further cementing decisions made by the Federal and Supra-national actors. For the social-technical transition to hydrogen, this is mightily important in determining countries approaches to the hydrogen adoption.

In the case of Germany, the European Union plays huge role in interpreting landscape factors into policies and directives that affects the economy and political structure of the EU and its member states. Not only, is Germany a member state of the EU, it is also a founding member, its most populous member state, the largest economy and contributor to the EU; it also has the most representatives in the European Parliament[15], and the President of the European commission, Ursula von der Leyen, is a German politician representative(*Germany's role in the EU: ten facts and figures*, s. d.). This relationship between Germany and the EU has created a self-reinforcing interplay of ideological and financial support for RES (Strunz et al., 2016) giving rise to a 'green hydrogen emphasis' approach by the German government.

[14] Policies and mechanisms will affect businesses, consumers, infrastructure decisions, investment decisions, etc.

[15] Germany sends 96 MPs to the European Parliament, which has a total of 705 representatives.

The current political landscape at the EU and German national level has focused on reflecting the exogenous landscape factors of ‘climate and environmental action’ and on ‘energy security’ which has driven the ‘green hydrogen emphasis’ approach taken by Germany. Policies such as the EU Green Deal, ‘Renewable Energy Directive, Fit for 55 package, and the EU hydrogen strategy all promote the adoption of green hydrogen to its member states. This is reflected through the German policies within the ‘Energiewende’ and ‘The National Hydrogen Strategy’.

‘The National Hydrogen Strategy’ published on the 10th of June 2020, outlined the aims and ambitions of the German government, which emphasised that "only hydrogen produced on the basis of renewable energies ('green' hydrogen) is sustainable in the long term" (*Germany’s National Hydrogen Strategy*, 2020). The strategy includes an economic stimulus package of investing €7 billion for the ramp up of hydrogen technology within Germany, with a further €2 billion euros for international partnerships. Investments such as these are aimed to enlarge the networks of actors involved in the development of hydrogen and push forward the dominant design of ‘green’ hydrogen. The German government specifically targets other key sectors aimed to involve other key landscape actors to further the goal of ‘green hydrogen emphasis’ approach. The strategy references the transport, heating, and industrial end use sectors and supports the distribution infrastructure and the research and innovation of hydrogen technologies.

By adopting the ‘green hydrogen emphasis’ approach at a federal level the German government is able to signal clear intentions to other key actors that is appropriate considering the landscape factors of ‘climate and environmental action’ and ‘energy security’. By ensuring a long-term vision towards green hydrogen, Germanys Federal government can draw in actors such as energy utilities, transport and mobility manufacturers, other levels of government, etc. This leverages Germany’s position as a key economic power within the EU, with Germany’s federal decisions effecting trade and economic ties with other countries and also spreading the adoption of green hydrogen within the EU and abroad. Trade ties are powerful tool for the promotion of green hydrogen, as Germany’s stated position is to be a net importer of green hydrogen (*Germany’s National Hydrogen Strategy*, 2020) and this places pressure on its trading partners that wish to enter the German market.

This ‘green hydrogen emphasis’ approach adopted by the German federal government also has the added benefit of giving confidence to investors and businesses in developing green hydrogen projects. The German government expects its investment of €9+ billion to attract over €20 billion from private investors, totalling €33 billion worth of investments to be triggered through its economic stimulus package. (*Germany investing €8B+ in 62 large-scale hydrogen projects; “We are making Germany a hydrogen country”*, s. d.).
Here, not only does the investment from the Federal government help achieve their main landscape goals of ‘climate and environmental action’ and ‘energy security’, but also helps

achieve many of the main landscape factors surrounding the transition to hydrogen including 'economic growth' and 'job creation'. Garrett-Peltier, 2017 shows that investments into clean energy yields over twice the amount of job creation than investments into fossil fuel industries.[16] By taking the 'green hydrogen emphasis' approach the German Federal government is able to lead by example and give confidence to many other network actors to grow the green hydrogen economy and in the same vein, achieve the landscape goals.

Australia on the other hand, has a federal policy stance that prioritises landscape factors of 'economic growth'[17] and 'job creation'[18] over environmental or sustainability concerns. As discussed above, this 'scale first-clean later' approach adopted by the Australian Federal Government is in part to leverage its heavy coal and natural gas resources to develop the hydrogen economy. And although Australia is part of a supra-national organisation, the Asia-Pacific Economic Cooperation (APEC) does not prioritise climate goals as much as other supra-national organisations such as the EU. In fact, APEC is comprised of countries such as China, Canada, the United States, Korea, Malaysia, etc., all countries which are lowly rated on the Climate Change Performance Index (*Climate Change Performance Index 2021 | Climate Change Performance Index*, s. d.). And as APEC partners make up more than 70 percent of Australia's total trade in goods and services there is very little pressure for the Federal government of Australia to invest or promote green hydrogen (*Asia-Pacific Economic Cooperation (APEC)*, s. d.). This mixture of self-interest and lack of pressure from supra-national actors or trade partners have created an environment that promotes the 'scale first-clean later' approach in Australia.

[16] The paper found that on average, 2.65 full-time-equivalent (FTE) jobs are created from $1 million spending in fossil fuels, while that same amount of spending would create 7.72 FTE jobs in the clean energy sector.

[17] Language used by the Australian Government in Australia's National Hydrogen Strategy (Department of Industry, 2019a)

[18] Language used by the Australian Government in Australia's National Hydrogen Strategy and the Low Emissions Technology Roadmap (Department of Industry, 2019a, 2021)

Figure 15: Measures of success from the Australian Hydrogen Strategy shows the focus on 'economic growth' and 'job creation' with no mention of environmental or sustainability criteria (Council of Australian Governments & Energy Council, 2019).

The Australian Hydrogen Strategy and the Low Emissions Technology Roadmap outlines the strategic intent of the Australian Federal government to grow the hydrogen industry in Australia (Council of Australian Governments & Energy Council, 2019; *TECHNOLOGY INVESTMENT ROADMAP; First Low Emissions Technology Statement – 2020*, s. d.). It is important to note that within these documents, that the Australian government promotes the term 'clean' hydrogen as part of their hydrogen strategy and not 'green' hydrogen (Longden, s. d.). This refers to the production of hydrogen from renewable energy and both the production of hydrogen from coal and natural gas with the use of CCS. Much of Australia's ability to produce clean hydrogen depends on the progress of CCS technology, and significant amount of its goals depend on not only developing the hydrogen economy but also in advancing CCS technology.

Australian governments has committed over $500 million dollars into the hydrogen industry since 2015 (Department of Industry, 2019b) in the hopes of becoming one of the world's biggest producers and exporters. Although the government predicts that public investment will catalyse $3-$5 worth of private investment through public-private partnerships (PPP) (*TECHNOLOGY INVESTMENT ROADMAP; First Low Emissions Technology Statement – 2020*, s. d.), it is still significantly less than other federal packages, such as the €9 billion package from the German government. Australia's hesitation in committing more public investments may signal low certainty to its approach and may affect investor confidence to Australian hydrogen projects.

As a hydrogen export focused strategy, Australia has engaged in building international partnerships to help develop its export potential. Currently, it has partnered with multiple countries such as Korea, Japan, Singapore, and Germany to develop joint intents on developing hydrogen projects and trade relations. These are crucial in enlarging Australia's network of actors and developing its hydrogen industry. It is important to not again, that with the exception of Germany[19], these relationship are forged with other APEC countries and are for the development of 'clean' hydrogen (Department of Industry, 2020a). Australia is heavily leveraging its trade relationship with other APEC nations to grow its hydrogen industry under the 'scale first-clean later' approach.

As with both Australia and Germany, the federal government and supra-national actors play key roles in developing the niche innovation hydrogen in the social-technical transition. Federal governments are arguably the most influential actors in the regime as the policies and mechanisms they implement effect a large network of actors that are engaged in the transition. Federal and supranational governments are often also the main interpreters of key landscape factors that also determine whether countries adopt a 'green hydrogen emphasis' or 'scale first-green later' approach. However, federal governments are not the only governmental actors that have a key role to play in the social-technical adoption of hydrogen, state governments are often key implementers of change.

[19] The joint feasibility study between Germany and Australia is to investigate the supply chain of renewable 'green' hydrogen between the two countries (Department of Industry, 2020b).

2.5.2. State Government Actors

State governments are huge actors in the energy transition and in the adoption of the hydrogen economy. States are often the ones that implement federal strategies and allocate capital, whilst managing the technical details of energy transitions. This is vitally important as energy industries, businesses, and utilities are historically located around coal and natural gas reserves within state borders. As countries shift away from fossil fuels or attempt to decarbonise their fossil fuel infrastructure, state actors must drive transitional measures to ensure there is adequate jobs, economic prosperity, and ensure security of energy supply in fossil fuel driven regions.

Germany is comprised of sixteen federated states (also known as Länders) who are offered constitutional rights and state autonomy to implement their own energy strategies. This is important as the goals of Federal policies may not be respected by the states, it is therefore that these two actors align their hydrogen strategies and that the federal policies benefits its constituent states (*State Autonomy in Germany and the United States on JSTOR*, s. d.). Here, at the level of state government actors, landscape factors still factor into the pressures along with federal government for the hydrogen transition.

Using the example of Germany's North-Rhine Westphalia (NRW) which was historically one of the three main areas in Germany for producing coal, and currently produces 53% of German lignite (*NIV-Energie-engl-Energies-in-North-Rhine-Westphalia.pdf*, s. d.), the social-technical transition is taking form using distinct goals even within the 'green hydrogen emphasis' approach. North Rhine-Westphalia is Europe's most important energy region. The state is home to international power utilities, energy-intensive manufacturing companies, power plant producers, as well as a large number of developers, providers and users of energy technology and services. Two of the world's largest utility companies are headquartered in NRW; E.ON and RWE (*Energy | NRW.GLOBAL Business*, s. d.). Formerly known as the 'Land von Kohle und Stahl' (land of coal and steel), NRW has seen dramatic changes to its economy as a result of the Energiewende.

The Hydrogen Roadmap released by the NRW outlines the motivations and areas of implementation that states have in the social-technical transition of hydrogen adoption. Unlike at the federal level, the NRW hydrogen roadmap focuses more on landscape factors of 'economic growth' and 'job creation'. The Energy minister of NRW, Andreas Pinkwart, stated that the "NRW also expects an economic boost and the creation of up to 130,000 new jobs through the adoption of hydrogen technology and infrastructure"(*North Rhine-Westphalia Presents Hydrogen Roadmap, Eyes Creation of 130,000 New Jobs*, 2020). The roadmap set targets to for hydrogen pipeline installations, hydrogen powered mobility rollouts, and industrial adoption of hydrogen in order to increase economic growth and job creation.

And although goals of climate-neutrality are explicitly mentioned in the plan, state government actors are pressured by their constituents to provide jobs and economic growth. For coal heavy region, NRW is calling for a technology-neutral approach, citing “Grey, blue and turquoise hydrogen are necessary transitional solutions for a fast and cost-efficient market ramp-up” (*mwide_br_wasserstoff-roadmap-nrw_eng_web.pdf*, s. d.) in order to build the hydrogen economy. Here, NRW is exerting pressure back upon the federal government and the ‘green hydrogen emphasis’ approach. However, with 4 billion euros marked for investment into the NRW hydrogen industry, with 3.4 billion euros of that fund provided by the federal government, the direction growth of the hydrogen economy seems to be strongly dictated by federal actors, while the implementation is left to the autonomy of the states. Strict ‘green hydrogen emphasis’ approach sees pushback from state governments as tough green constraints may not align with the hydrogen strategy goals set by state governments.

On the other hand, very loose federal constraints taken by the Australian Federal government’s ‘scale first – clean later’ approach sees state adoption of even more stringent hydrogen adoption plans in order to meet the social landscape ideas of ‘climate neutrality’. In the hydrogen strategies and plans published by all of Australia’s states and its two main territories, they all outline the use and development of renewable ‘green’ hydrogen and neglect the government’s language of ‘clean’ hydrogen. Here, the landscape factors of the hydrogen transition exert different pressures into the state actors that differ from the plans of federal government. Again, the autonomy of state to push back the implementations of a ‘scale first – clean later’ approach taken by the federal government.

In reference to the hydrogen strategy for Victoria, historically one of Australia’s strongest coal states[20], the Hon. Lily D’Ambrosio writes[21], ‘Working across Victoria, we can accelerate decarbonisation, promote economic recovery, and establish a thriving renewable energy industry. […] We have a vision for renewable hydrogen to be a part of our economy and the transition to a net zero emission future.” (*Victorian-Renewable-Hydrogen-Industry-Development-Plan.pdf*, s. d.). These sentiments are echoed through all the other state and territory hydrogen strategies and show the divergence of goals between federal and state actors and their implementations of hydrogen adoption. The push for ‘green’ hydrogen by states can be rooted in the dedication by citizens and states to achieve climate ambitions despite the direction of the Australian Federal government’s refusal to stop supporting the fossil fuel industry (*The World Is Moving Away from Fossil Fuels, While in Australia, It’s All Systems Go for Coal and Gas | Bill Hare*, 2021).

[20] The La Trobe Valley in Victoria produces about 98.5% of Australia’s brown coal. (Statistics, 2003)

[21] The Hon. Lily D’Ambrosio is a member of the Victorian Legislative Assembly and also the Minister for Energy, Environment and Climate Change, and the Minister for Solar Homes.

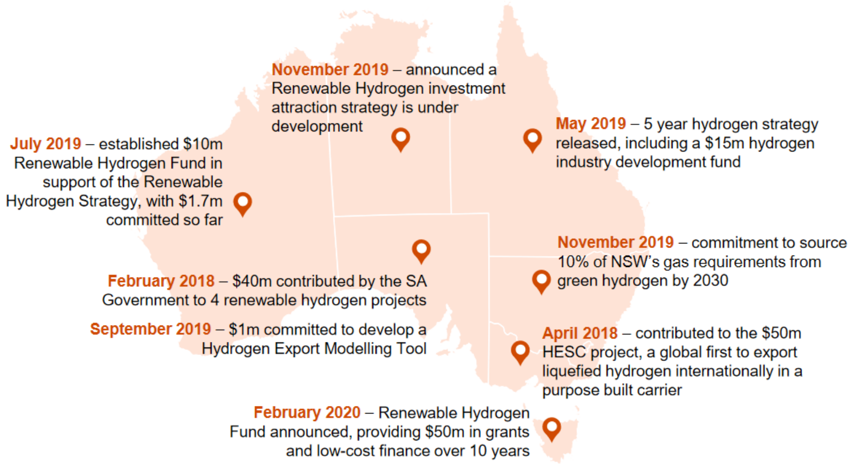


*Figure 16: States and Territories of Australia all reference green, renewable energy in their strategies which is a departure from the language of clean hydrogen used by the Federal government. (*Embracing Clean Hydrogen for Australia*, 2020)*

State governments upholding long-term commitments through their energy and hydrogen programs also benefit in creating long-term economic growth and job creation. States like Victoria see green renewable as a big source of export potential as large energy importers look towards green hydrogen to displace importation of fossil fuels to meet environmental, economic and geopolitical needs and aims (*Victorian-Renewable-Hydrogen-Industry-Development-Plan.pdf*, s. d.) and their strategies aim to develop infrastructure networks to be capitalise on this potential. Significant activities include continually developing renewable energy capacity to fund green hydrogen production, establishing hydrogen hubs in the costal to strengthen supply chains and export potential, exploring the potential of using 31,000 kms of existing gas infrastructure to adopt hydrogen into the network. The autonomy given to states see that the 'scale first – clean later' approach can be shifted through implementation.

Not only are states clear drivers of the implementation of hydrogen strategies, their goals and approached may not align with those of the Federal government. States like Victoria and NRW must serve their constitutients and in that way they may be pressured to focus on different landscape factors. Using the MLP perspective, we see that the federal governments that are adopting the more stringent 'green hydrogen emphasis' approach may face pushback from state governments, and those adopting the 'scale first – clean later approach' may fear state implementation strategies vary drastically from the national strategies for hydrogen implementation. Regardless, the importance of the role state governments has on the social-technical transition to hydrogen cannot be understated especially as they have strong influence on industry, businesses, and utilities who may operate on both the state and federal level.

2.5.3. Industry, Businesses, and Utility Actors

The social-technical transition towards the hydrogen economy can only be feasible with adoption by industry, businesses and utilities which are all key actors in the production, adoption, and use of hydrogen. The adoption of hydrogen is an environmental innovation that aims to fulfil societal objectives of environmental sustainability and economic growth post Covid-19. Since it is society rather than individual users that benefit more from environmental performance, incumbent firms[22] operating in the regime are not as pressured from consumers to adopt hydrogen the hydrogen economy. Consumers as individuals often pressure firms through their individual need rather than societal ones; factors such as cost, convenience, and reliability are more important to consumers than environmental issues (Sushandoyo & Magnusson, 2014). For firms it is tough to translate social value into economic value and create business models that optimise the trade-off between optimal product performance for the consumers with environmental performance for the broader society (Boons & Lüdeke-Freund, 2013; Loorbach & Wijsman, 2013). Several studies have pointed at policy as a key driver for environmental innovation, showing how federal and state policies, mechanisms, and regulations are required to motivate firms to invest in the development of cleaner new technologies (Lee et al., 2010; Norberg-Bohm, 2000; Visser et al., 2008).

As discussed above, the policies, mechanisms, and regulations imposed by the federal and state government in Germany and Australia are huge drivers in promoting the adoption of hydrogen by firms in these two countries. The different 'green hydrogen emphasis' and 'scale first – clean later' approaches that governments take are key drivers in the business models that these firms take. One of the strongest tools governments have at their disposal to promote the adoption of hydrogen by firms are public-private partnerships (PPPs), where governments partly fund hydrogen projects with private firms, inciting more private investment, development, and adaption. The German ministries had selected various PPP projects to invest €8 Billion euros worth of funds that is expected to be matched with €33 billion worth of private funds (*Germany investing €8B+ in 62 large-scale hydrogen projects; "We are making Germany a hydrogen country"*, s. d.).

Major firm actors see PPPs as strong incentives to test out new business models and develop some hydrogen capacities in line with new policies and regulations. Major firms in both Germany and Australia such as RWE, Vattenfall, Air liquid, AGL Energy, Origin Energy and even incumbent oil and gas firms such as Shell and Total are engaging in government backed projects to try to capture developments in the hydrogen economy. The funding mechanisms that governments implement often mean that firms must co-operate to de-risk investment into growing the hydrogen economy[23].

[22] Firms are used to describe industrial, business, and utility actors that are separate from individual consumers or government actors.

[23] By strategically partnering with other firms, firms can grow the network of actors required to promote niche innovations into the regime (Geels et al., 2017; Geels & Schot, 2007)

Although green hydrogen projects are more capital intensive and expensive, the firms in both the ‘green hydrogen emphasis’ and ‘scale first – clean later’ approaches often de-risks and incentivises many firms to test out green hydrogen business models. These projects often engage firms in different sectors and grow the network of firm actors, for example, the AquaDuctus project gathers over 45 companies, research institutions, and organizations to install, produce, and transport green hydrogen from the German North Sea [24]. Similarly, A project from Engie Renewables Australia will receive AU$42.5 million and be paired with a solar park to produce renewable hydrogen in a partnership with Yara Fertilisers at an ammonia facility in Western Australia (« Three Green Hydrogen Projects in Australia Secure Funding », 2021). It is interesting to note that despite the ‘scale first – clean later’ approach taken by the Australian Federal Government, firms in Australia are entering PPPs into green hydrogen projects as they see the opportunity for more secure, long-term business models (“Hydrogen energy,” n.d.)[25]. CCS technology and ‘blue’ hydrogen is currently uneconomically viable at a commercial scale and firms fear that investments into CCS may ultimately be less profitable than investment into green hydrogen.

Although government policies, regulations, and funding mechanisms play a huge role in incentivising firms to investigate new business models and develop the innovative niche of hydrogen, there is still a huge barrier in the overall investment landscape into hydrogen. Still in the infancy of the social-technical adoption, there is still need for more concrete regulations and policies before hydrogen is de-risked for wide investment adoption.

[24] The companies involved in the AquaDuctus project include many incumbent actors adopting hydrogen such as RWE, Shell, Gasunie, GASCADE, Ørsted, Siemens Gamesa, Vestas, Parkwind, Vattenfall, EnBW, and Northland Power.

[25] Of the 33 hydrogen projects currently engaged with a PPP with the Federal government, all of them are either green hydrogen or network expansion projects (*Projects - Australian Renewable Energy Agency (ARENA)*, s. d.).

Chapter 3. The Investment Landscape of Hydrogen and the need for Hydrogen Markets

Although green hydrogen produced from 100% renewable energy sources is agreed upon by the European Commission and most international energy organisations to be the only type of sustainable hydrogen for the long run (European Commission. Directorate General for Energy. et al., 2020), there exists many challenges in the short to medium term investment landscape to reach this vision of widespread sustainable green hydrogen.

The differences in policies and approaches to the adoption of hydrogen play a key role in the investment opportunities especially in the early stages of niche penetration. Governments who are taking the 'green hydrogen dominant' approach; such as the German government and under most frameworks of the European Union, through their policies, strategies, roadmaps, and incentives give investors greater reason and security to invest in sustainable hydrogen projects even though in the short-term they may not be as profitable compared to other alternative investments. However, this approach of emphasizing green, sustainable hydrogen may lead to a slow build-up of the hydrogen economy as it deters investors from investing in more economic hydrogen investments (grey and blue hydrogen projects). It is indeed in governments such as these, that the need for clear taxonomy on sustainable investment is needed.

On the other hand, countries that are taking a 'scale first-clean later' approach to hydrogen, such as Australia, are prone to creating an uncertain investment landscape that may be detrimental to reaching the underlying goals of the hydrogen economy: to decarbonise and achieve climate mitigation goals. Countries under this approach are promoting investment into hydrogen projects with little regard for the sustainability or 'colour' of the projects. This bears the risk of quickly establishing a new incumbent hydrogen economy that will become difficult to decarbonise and 'green' in the future, and thus exacerbate the climate problem. It is clear that in governments such as these that a clear and logical framework needs to be established so that the goal of green sustainable hydrogen can be reached.

3.1. The Current Economic Viability of Hydrogen

In both hydrogen approaches, the challenges for investment into hydrogen remains largely the same; there is great uncertainty about the economic viability for current hydrogen projects[26]. Due to the infancy of hydrogen technology to decarbonise and meet climate targets, there is currently no economies of scale for hydrogen to be able to compete with other forms of energy carriers and thus investors are not willing to invest in hydrogen projects that would ultimately drive the price down.

A major consideration for investors is the relative price of hydrogen compared to different energy vectors. Currently, due to the infancy of the hydrogen economy and its current lack of application in uses other than as a chemical feedstock for industrial use, the true cost of hydrogen as an energy vector is hard to calculate. This is due to the infrastructure behind hydrogen use is still also in development and lack economies of scale. Infrastructure such as hydrogen pipelines and networks, storage facilities, hydrogen-powered generation facilities are all still developing, and thus true efficiencies and costs are hard to determine. This uncertainty in hydrogen economics is one of the key factors in why there is a severe lack of investment into the hydrogen economy. The following analysis will aggregate costs of different types of hydrogen using currently available data and compare them with fossil fuel alternatives such as coal and gas[27].

The production of green hydrogen is heavily dependent on renewable energy costs, which contributes up to 60% of production costs (*How Much Will Hydrogen-Based Power Cost?*, s. d.) and are highly variable, and is currently, produced at between $USD 3-8 per kilogram. Similarly, the production of 'blue' and 'grey' hydrogen is dependent on the price of natural gas and is produced at $USD 1.5-2 and $USD 0.7-1.6 per kilogram respectively as seen in Figure 17. If this hydrogen was then to be used to generate electricity, electricity from 'green', 'blue', and 'grey' hydrogen will cost at current prices, $USD 140-373, $USD 70-93, and $USD 32-75 per mWh, respectively as seen in Table 2. Although this calculation does not factor in the cost of hydrogen turbines, cost of storage, and cost of storage transportation, it gives an indication of the current economics of hydrogen.

[26] Current, for when this paper was written in 2021.

[27] The price of hydrogen will not be compared to renewable energy as the goal of hydrogen use is to reach decarbonisation goals and phase out fossil fuels.

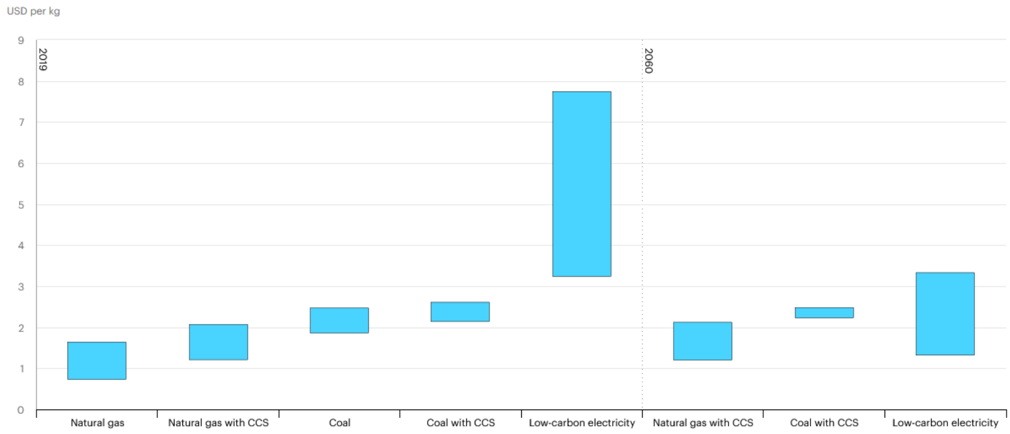


*Figure 17: The current price of hydrogen production is heavily dependent on input costs. Currently, the price renewable energy is highly variable and expensive and thus green hydrogen is currently uncompetitive. However, the price of renewable energy is expected to drop dramatically in the future. (*Global Average Levelised Cost of Hydrogen Production by Energy Source and Technology, 2019 and 2050 – Charts – Data & Statistics*, s. d.)*

The current cost of generating one mega-watt hour of electricity using hydrogen.

	Lower-Bound ($USD/mWh)	Upper-Bound ($USD/mWh)
'Green' hydrogen	140	373
'Blue' hydrogen	70	93
'Grey' hydrogen	32	75

Table 2: This table shows the cost to generate one mWh of electricity using hydrogen at current prices[28].

Comparing with the levelised cost of electricity (LCOE) from incumbent fossil fuels as seen in Figure 18:, sources such as gas peaking plants which produce at $USD 150-199 per mega-watt hour (mWh), coal powered electricity plants at $USD 66-152 per mWh, and gas combined cycle plants at $USD 44-68 per mWh, often only 'grey' or unproven 'blue' hydrogen is even remotely economically competitive at this current time. At current prices, 'green' hydrogen is only an alternative to gas peaking plants and is twice and triple the price of coal and gas combined cycle electricity. Although the prices of 'green' hydrogen production are expected

[28] This calculation was done with the assumption that hydrogen turbines convert every kg of hydrogen into 0.023 mWh of electricity (*How Much Will Hydrogen-Based Power Cost?*, s. d.; *idealhy.eu - Liquid Hydrogen Outline*, s. d.), and the price of hydrogen production was calculated using IEA data (*Global Average Levelised Cost of Hydrogen Production by Energy Source and Technology, 2019 and 2050 – Charts – Data & Statistics*, s. d.).

to drop dramatically as electrolyser technology increases and the cost of renewable energy is expected to decrease, there is still a 'chicken-and-egg' dilemma for investors who wish to invest in 'green' hydrogen projects but the costs remain prohibitively high, and the lack of investment slows the technological advance (Brozynski & Leibowicz, 2020).

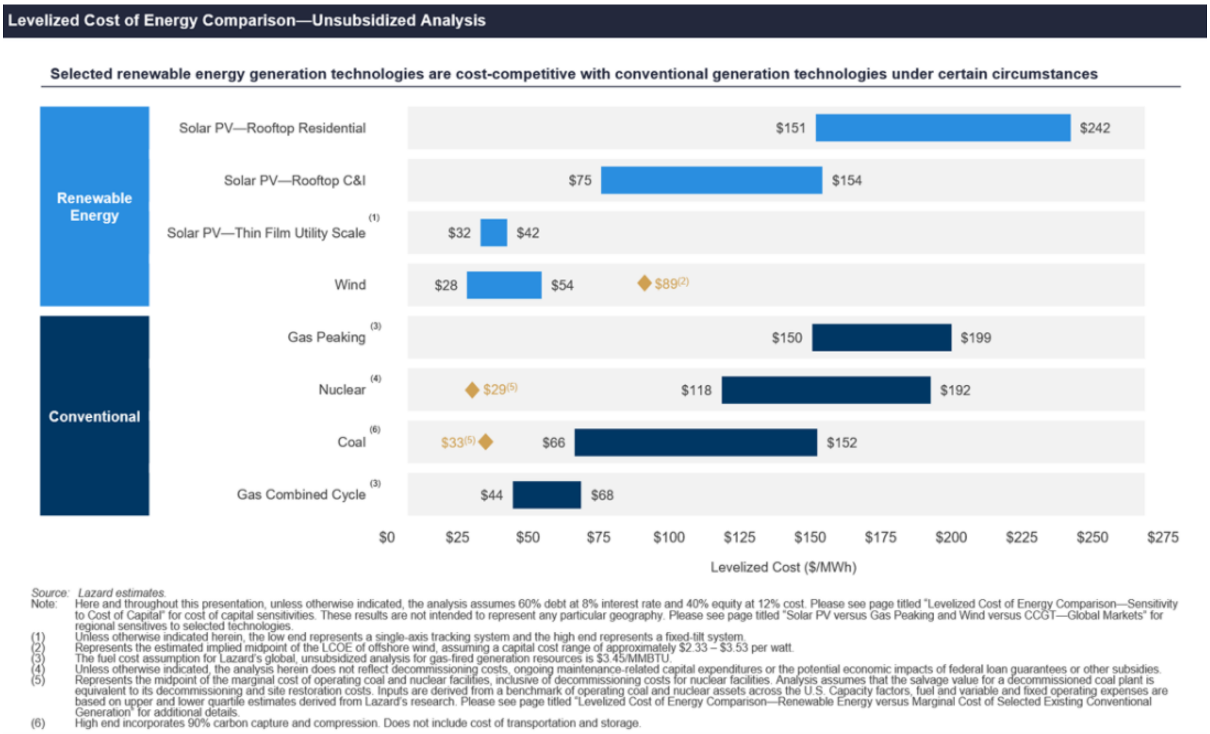


*Figure 18: For hydrogen to be economically viable, its costs need to be compared to its alternatives. Currently, hydrogen is still much more expensive than fossil fuels for both energy and electricity production. (*Levelized Cost of Energy and Levelized Cost of Storage 2019*, s. d.)*

3.2. The Current Stalemate in Hydrogen Investing: First-movers Disadvantage and Fast Seconds.

In both hydrogen approaches, the 'chicken-and-egg' dilemma exists for investors who wish to invest in 'green' hydrogen projects[29] for the long-term, firms are unwilling to be the first to invest in the hydrogen economy as they expect technological advances and price decreases. This 'stalemate' current investment landscape leads to a stagnation in growing the hydrogen economy and the social-technical adoption of hydrogen.

Especially in the 'green hydrogen emphasis' approach, investors struggle with the short and medium-term viability of green hydrogen projects as the cost of producing green hydrogen is extremely costly at current production costs of ~$6USD/ kg[30](European Commission. Directorate General for Energy. et al., 2020); it is economically unviable as an alternative to fossil fuels. This is the realisation of the 'first movers disadvantage', where pioneers suffer from persistent high costs and followers, also known as 'fast seconds', can adopt new and more efficient processes and technologies to gain a long-term competitive advantage (Boulding & Christen, 2001; Norman et al., s. d.). This can be seen in the early stages of the 'green hydrogen emphasis' approach, as investors continue to wait as the price of green hydrogen is expected to drop dramatically in the future, coinciding with expected price drops due to technological advances of electrolysers and as prices of renewable electricity is expected to drop due to greater availability. This expectation of dramatic price decrease causes the 'chicken and egg' dilemma and thus slows investment into the niche.

	First Mover	**Fast Second**
Focus of activity	Exploration and Creation of product on Niche Market	Creation of Mass Market
Firm characterization	Young, small	Established, big
Major role	Colonization (creation of product)	Consolidation (of market)
Innovation drivers	Technology push	Market pull
Object of competition	Rival innovation designs	Rival variants of dominant design
Dominant innovation design	Variation, Exploration	Selection
Market structure	Large firm population	Concentration, Shakeout

Source: Own overview according to Markides/Geroski (2005).

Table 3: Benefits of being the 'first mover' and 'fast second' as detailed by (Cleff & Rennings, 2011). However, many academics show that often 'fast seconds' benefit more than 'first movers' (Boulding & Christen, 2001; Norman et al., s. d.)

[29] As discussed in Chapter 2.5.2.-2.5.3, firms, and state governments are more attracted to 'green' hydrogen projects for their long-term potential.

[30] Levelized cost of producing hydrogen.

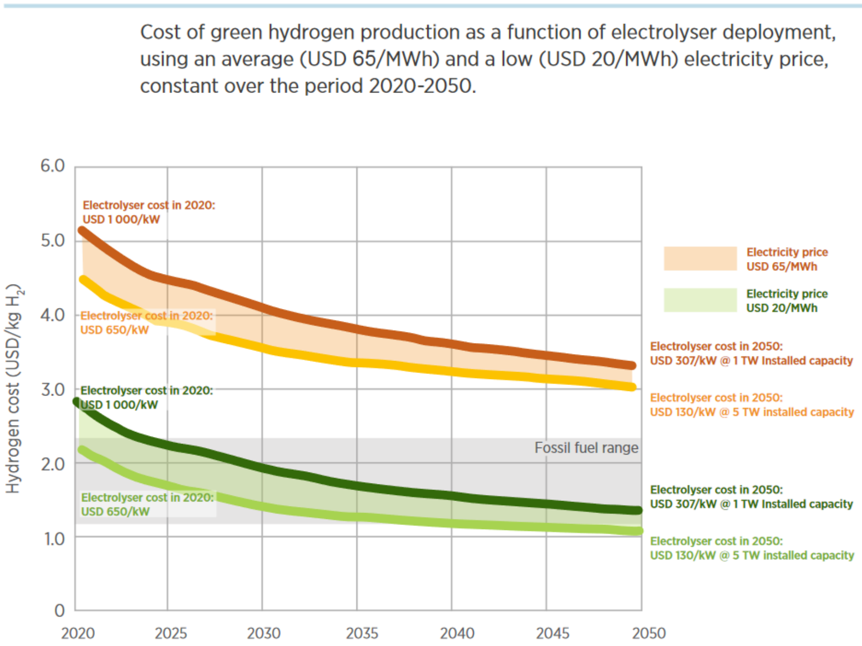


*Figure 19: The prices of electrolysers and electricity are expected to drop dramatically in the coming years as more renewables energy systems are implemented and investment is made into electrolyser technologies. This expected drop in price means that there is significant hesitation by investors to be first movers. (*Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5C Climate Goal*, s. d.)*

Investment into green hydrogen at these current beginnings of niche penetration is resorted to specific circumstances that involves subsidies or PPPs where costs and risks are help borne by governments and other collaborating firms, as discussed in Chapter 2; or companies with a long enough time-horizon to incorporate initial costs in order to capitalise on long-term 'first-movers advantages', which include moving through the experience curve faster than competitors and gaining technological leadership or patents, earning stronger brand recognition as the first movers, and gaining market share and early customers that will face high switching costs (Kerin et al., 1992). Currently, these advantages are not great enough to offset the lack of returns in investing into green hydrogen projects and companies often view current investment into 'green' hydrogen as a cost and hedge to gain potential future market share.

To overcome, this 'stalemate' of investing, firms require incentives or mechanisms that de-risk the disadvantages that of being the 'first mover'. Th Hydrogen Council has outlined the importance of key measures that would accelerate the competitiveness, cost-reductions, and investment into the hydrogen economy. These include the requirement of national strategies, co-ordination between firms and government, regulation and standardisation, the need for infrastructure, incentives, and a hydrogen market. Many of these policies and financial incentive suggestions have been discussed in Chapter 2, and the following chapters will discuss the how taxonomy, standardisation, infrastructure, and market design is required to promote investment into the hydrogen economy and help overcome the current stalemate of investing.

Need for policy alignment: level playing field to accelerate scale-up

Enabling regulations from governments will accelerate industry investments that will ultimately lead to scale. We see six ways in which governments can level the playing field:

- **National strategies.** Governments have a role to play a role in setting national targets, as they have done already through 18 hydrogen roadmaps developed across the globe.
- **Coordination.** Governments are well positioned as neutral conveners of industry stakeholders to mediate potential local investment opportunities.
- **Regulation.** Governments can help remove barriers that may exist to invest in the hydrogen economy today, e.g. by facilitating the process to obtain permits for new refuelling stations and developing internationally consistent regulation to limit market specifities.
- **Standardisation.** Governments can also support industry to coordinate national and international standards, e.g. around pressure levels and safety.
- **Infrastructure.** Governments can choose to invest in the deployment of new infrastructure and re-use, where relevant, of existing networks (e.g. natural gas networks).
- **Incentives.** Finally, governments could decide to apply incentives, e.g. tax breaks or subsidies to encourage the initial acceleration of hydrogen.

*Figure 20: In the early stages of the social-technical transition towards hydrogen adoption, key policies alignments need to be created and implemented to overcome the investment stalemate of fist movers disadvantage and fast seconds (*Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf*, s. d.)*

3.2.1. Taxonomy for Sustainable Investment and Standards

One of the main obstacles preventing early investment into new technological niches such as hydrogen is the lack of taxonomy or standards that are yet to be developed for an emerging technology. Especially regarding hydrogen, where the use of hydrogen is predicated on sustainability and environmental efforts such as achieving emission targets, there is a strong need for taxonomy that defines what constitutes as 'green', 'clean', 'sustainable', 'low-carbon' hydrogen. This is important for investors looking to invest in export projects, countries like Australia, who under the 'scale first -clean later' approach wishes to export 'clean' hydrogen. The discrepancy between what is considered 'sustainable' or 'green' is a major risk for investors under both hydrogen approaches; investors under the 'green hydrogen emphasis' approach will wish to protect their investment into hydrogen products that produce less emissions. Governments, firms, and investors under these approaches also wish to protect against carbon leakage through the import of inferior hydrogen products that may not meet higher emission standards. Unclear taxonomy also poses a risk for investors under the 'scale first – clean later' approach who face the risk of their hydrogen investments not meeting higher criteria.

The clear definition of taxonomy is also currently a hinderance for investors getting access to loans and other financial options. Especially under mechanisms such as the EU Green Deal, Fit for 55 package, etc., funds and financial options from institutions such as the International Monetary Bank, European Investment Bank, Green Development Banks, etc., are predicated on environmental and sustainable criteria(*Overview of Sustainable Finance*, s. d.). These sustainable financing are a huge instigator for capital access, investment, and growth, and strong, clear taxonomy and standards are required to help overcome the investing stalemate in hydrogen.

This has need for taxonomy and standards in the hydrogen industry is echoed by working groups and coalitions, especially those operating in the EU under the 'green hydrogen emphasis' approach. On March 31st of 2021, the coalitions of SolarPower Europe, the Renewable Hydrogen Coalition, and twenty one signatories signed an open letter to the European Commission calling for stricter and clearer rules regarding hydrogen in the proposed Sustainable finance package under the EU Taxonomy Climate Delegate Act that will heavily influence the future of the hydrogen economy in EU and abroad (*23 Organisations Urge the Commission to Promote the Highest Sustainable Clean Hydrogen Standards in EU Taxonomy - CEENERGYNEWS*, s. d.; « Open Letter Calls for the Highest Sustainable Clean Hydrogen Standard in EU Taxonomy », 2021; *Sustainable Finance Package*, s. d.).

3.2.2. The Need for Infrastructure Investment

The use of hydrogen as an energy carrier requires significant advances in infrastructure develop to support a function hydrogen economy. Hydrogen as a flexible energy vector that can be used for a wide variety of applications, from energy generation to hydrogen-based mobility and transport, hydrogen as energy storage, and hydrogen for heating. Use for these applications all require significant infrastructure that is still developing. The hydrogen economy will require hydrogen re-fuelling stations, compressors and generators, shipping terminals, etc.., and most importantly, pipelines that will enable the transfer of hydrogen at scale across large distances. While most of the hydrogen infrastructure is expected to develop in tandem with hydrogen technology, hydrogen pipelines are a crucial low-risk, early-stage development that can be a way to attract investors into deploying capital into the hydrogen economy. The importance of early grid infrastructure is vitally important to growing the hydrogen economy, as the transportation of hydrogen is independent of its production method (colour neutral) and allows for development in the hydrogen economy without the need of addressing the 'colour' of hydrogen.

One of the benefits of investment into hydrogen pipeline infrastructure, is the ability to re-use and adapt existing natural gas infrastructure for hydrogen use. Christoph von dem Bussche, the CEO of Gascade[31], stated that "the existing gas infrastructure is of very high value for the EU Hydrogen Strategy"(*Repurposing Gas Pipelines for Hydrogen*, s. d.). In Germany, gas pipeline operators are implementing a plan named 'H2 Startnetz' to create a twelve-thousand kilometre grid by 2030 to transport hydrogen around the country. This €660 million project will convert eleven-thousand kilometres from former gas pipelines, whilst only one hundred kilometres will need to be built anew (Radowitz (58b67e5794f55), 2020). Currently,

[31] Gascade is one of the largest natural gas pipeline companies in Germany.

'H2 Startnetz' is the largest hydrogen pipeline plan in the world and demonstrates the confidence of German pipeline firms in the future of the hydrogen economy in Germany and the 'green hydrogen emphasis' approach[32].

The lack of investor confidence and lack of trust in the Australian 'scale first-clean later' approach can be seen through the lack of development into hydrogen infrastructure in Australia. Australia's leading energy infrastructure business, APA Group, has announced a $AUD 3 million dollar project that aims to convert forty-three kilometres of pipeline in Western Australia to be hydrogen ready (*APA Set to Unlock Australia's First Hydrogen-Ready Transmission Pipeline - APA Group*, s. d.). Meanwhile, the APA group is simultaneously investing $AUD 460 million into building a five hundred and eight kilometre pipeline connecting gas fields in Western Australia(*APA Group to Spend Half Its Capex on WA Pipeline*, 2020). A lack of confidence in the Australian 'scale first – clean later' strategy by firms and investors is leading to a severe lack of investment into developing the hydrogen economy. If Australia truly wishes to be a world leader in hydrogen generation and exports, it must create a landscape where hydrogen pipeline infrastructure should be an attractive investment in the eyes of firms.

3.3. Market Design of a Hydrogen Economy

As hydrogen becomes bigger part of the decarbonisation equation, countries and economies need a fluid market that allows for widespread use of hydrogen. Not only must hydrogen find and develop use cases for there to be a hydrogen economy, but the hydrogen economy must also require an underlying fluid financial system that facilitates the production, trading, and use of hydrogen. The following will suggest some market design mechanisms that would allow a hydrogen market to develop under a 'green hydrogen emphasis' approach and also should be implemented for a 'scale first - clean later' approach as well.

3.3.1. Hydrogen Exchanges

As the development of the hydrogen economy and network is underway and producers are being readily connected to new consumers, there is an increasing growing need of hydrogen exchanges. Currently, there is no open market or exchange for hydrogen or hydrogen products. Hydrogen cannot be bought and sold like other commodities such as oil, gas, or electricity. Hydrogen is currently sold and moved through business-to-business (B2B) transactions, where industrial users such as fertilizer and steel companies, or oil refineries will purchase hydrogen from producers who produce and transport the gas.

The role of hydrogen exchanges will help facilitate the growth of hydrogen by providing an open marketplace what will make the price of hydrogen more transparent and allow

[32] Currently, Germany's gas grid has a total length of 511,000 km, and 'H2 Startnetz' will convert 1/5th of this into hydrogen pipelines.

producers and consumers to connect. An open hydrogen exchange will benefit the hydrogen economy by driving down prices and increasing hydrogen volume through a few different means. A hydrogen exchange will firstly, increase the demand of hydrogen through customer discovery; new consumers will be able to purchase and consume hydrogen if it was more accessible. An open and transparent exchange will also aid in price discovery and price competition; as the prices of different producers are made public, the price of hydrogen will become more standardised and reach an equilibrium market price through market economics (strategies et al., s. d.). If hydrogen was traded on an open exchange like other commodities, it will also become more attractive to more consumers as exchanges allow for price hedging (Boroumand et al., 2015); this allows consumers to lock in prices of hydrogen for later consumption which is important especially as green hydrogen is highly sensitive to fluctuations in renewable electricity prices. Thus, the role of hydrogen exchanges are vital in increasing the demand of hydrogen, driving down prices, and growing the hydrogen economy.

3.3.2. Guarantees of Origin Scheme

One of the biggest hurdles to designing a hydrogen market under the European and German policy context and 'green hydrogen emphasis' approach is the focus on green sustainable hydrogen in order to achieve decarbonisation and climate targets. Currently with almost all hydrogen produced being grey hydrogen, and the cost of green hydrogen as a product significantly higher, it is important to designate and protect green hydrogen producers. A guarantee of origin (GoO) scheme will audit producers of green hydrogen to ensure they are producing zero or low carbon hydrogen and this certification will provide consumer confidence as it will guarantee that the product will help hold up to the consumers carbon considerations. Not only is a GoO scheme vital for developing legitimacy within the hydrogen market, but it is also vital for developing market pull for green hydrogen.

Currently, there is already a pilot program of a guarantee of origin scheme in Europe called the CertifHy project that is beginning to audit and certify hydrogen producers (*CertifHy - Designing the first EU-wide Green Hydrogen Guarantee of Origin for a new hydrogen market | www.fch.europa.eu*, s. d.). It is programs such as these GoO that give confidence to investors and de-risk investments as 'green' hydrogen products become protected. The lack of GoO scheme in Australia can be one of the main reasons that the investment into 'green' hydrogen projects are so low. And as the hydrogen economy grows, and the roles of imports and exports become more important, a robust GoO scheme in countries around the world becomes important if the aim of hydrogen is to reach decarbonisation and emission targets.

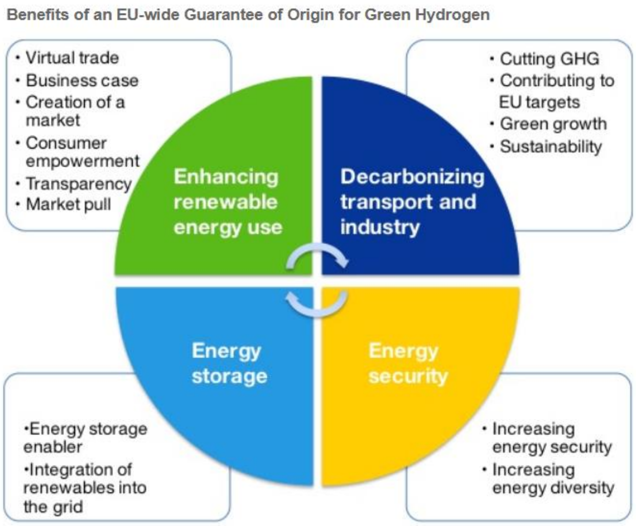


*Figure 21: An EU GO scheme will bring consumer confidence by protecting green hydrogen products and grow the hydrogen market.(*Why a Guarantee of Origin for Green Hydrogen?*, s. d.)*

3.3.3. Green Hydrogen Certificates

Being able to certify and guarantee the quality of hydrogen is a key step in developing the hydrogen market as certification allows for other market mechanisms to be developed that will help in growing a 'liquid low carbon hydrogen market' as per the European Commission's goals (HJ, 2021) but is also vital for all developing hydrogen economies around the world. Once the production of hydrogen can be safely guaranteed and certified, it allows for the market to implement Green Hydrogen Certificates. Green Hydrogen Certificates (GHC) function much like Renewable Energy Certificates (REC), it is an easily tradable commodity that proves that the hydrogen produced meets emission standards. GHCs can only be effectively granted after a solid guarantees of origin scheme are in place, and certificates are given out according to green production.

GHC certificates are important when large hydrogen infrastructures are developed, and it becomes almost impossible to distinguish the different types of hydrogen in an interconnected network. GHC's will separate hydrogen gas as a commodity and a guarantee of green or low carbon production as another commodity; these certificates can be traded separately from the hydrogen produced. Purchasing of GHC's by consumers will be equal to purchasing a claim of consuming a portion of the green hydrogen produced. GHC are a vital component of creating a hydrogen economy and market that promotes both hydrogen as a general commodity and green hydrogen as a method to achieve climate targets.

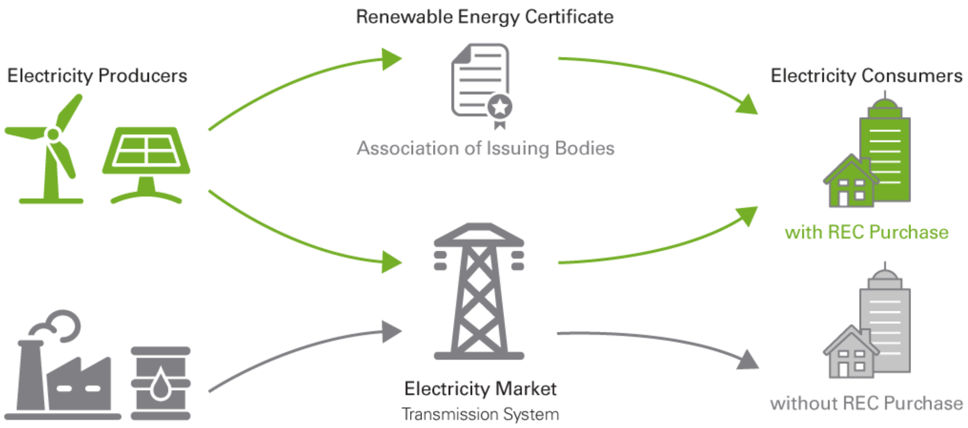


*Figure 22: GHCs will operate similarly to the REC system and separates hydrogen gas from its production method. (*Lazard Asset Management*, s. d.)*

3.3.4. Purchase Power Agreements and Hydrogen Purchase Power Agreements

Another powerful mechanism that the niche hydrogen market can use to develop are Purchase Power Agreements (PPAs) and Hydrogen Purchase Power Agreements (HPPAs). PPAs allow producers of 'green' hydrogen to engage in contracts with renewable energy producers that ensure that hydrogen production will incur constant and forecastable costs compared with wildly variable renewable energy costs from the electricity market. This security of a predicable electricity cost is important for the financial viability of 'green' hydrogen as electricity costs account for up to 60% of production costs (*How Much Will Hydrogen-Based Power Cost?*, s. d.). PPAs are a symbiotic relationship that promotes both the growth of renewables and 'green' hydrogen that will drive down prices, increase volume, and grow the hydrogen production industry.

Hydrogen Power Purchase Agreements allow consumers of hydrogen will enter contracts with producers of hydrogen to guarantee the purchase of a specific amount of hydrogen over a specific length of time. HPPAs are powerful as it gives producers confidence in developing hydrogen projects and being able to guarantee future sales and cash flows is key in project finance and determining the viability of hydrogen projects. It also allows consumers to hedge on the future price of hydrogen as a HPPA will guarantee prices and volume for a specific length of time. Although HPPA's are a powerful instrument to grow the hydrogen economy, it will also require subsidies and support from government as the price of hydrogen is expected to fall dramatically as the technology and economies of scale develop (*Hydrogen Production Costs by Production Source, 2018 – Charts – Data & Statistics*, s. d.). Under a European context it is also important for the government to promote and subsidise specifically target 'green' hydrogen purchase power agreements in order to not only promote the hydrogen economy as a whole but to specifically target growth through incentives of the 'green' hydrogen sector.

3.3.5. Euro-Denominated Hydrogen

Possibly one of the mechanisms that will help promote investment into hydrogen economy is the denomination of hydrogen to the Euro. Since 1974, OPEC countries have been selling oil exclusively in US dollars and not long after, all fossil fuel commodities such as coal, oil, and gas have been denomination by the US dollar. This rise of the 'petrodollar' created a strong economic backing for the trade and exchange of fossil fuels in the world system (*The Fraying of the US Global Currency Reserve System*, s. d.). However, as fossil fuels being phased-out through the energy transition, the European Union have a unique opportunity as champions of the hydrogen economy to push for the denomination of hydrogen in Euros. The EU are also pioneers in establishing markets for decarbonisation, such as establishing the Emissions Trading Scheme, and are well poised to remain front-runners in establishing the hydrogen and green economy (Brandes, s. d.).

The denomination of hydrogen products in Euro's signal to investors and actors within the hydrogen economy the support of the EU behind the hydrogen economy. Price benchmarks based on Euros are the precondition of establishing the EU as the global hub for hydrogen trading. As the EU aims to be one of the biggest economies of the clean energy transition and one of the biggest consumers within the hydrogen economy (*EUR-Lex - 52020DC0301 - EN - EUR-Lex*, s. d.), the denomination of Euros will support the production and consumption of hydrogen will mitigating foreign exchange risks. As the champions of the hydrogen economy in the world, the European Union should set the Euro as the underlying denomination for hydrogen in order to grow both the economy of the EU and also the hydrogen economy.

Conclusion

Hydrogen and hydrogen technologies are becoming an ever more popular tool in helping decarbonise the energy sector and help countries and firms reach decarbonisation and emission targets. The rise of renewable energy systems has shown the need for energy storage systems and hydrogen is poised as a major tool to help fill that role. Countries and governments around the world are quicky adopting two different pathways of hydrogen adoption. Countries are either taking a 'green hydrogen emphasis' or 'scale first – clean later' approach to the social-technical transition for hydrogen.

It seems that countries that have that have strong climate commitments and currently utilise a lot of renewable energy mix are more prone to adopt the 'green hydrogen emphasis' approach. These countries see 'green' hydrogen as being a big part of their medium to long term energy mix and decarbonisation mission and are encouraging the growth of green hydrogen as quickly as possible. Countries adopting the 'scale first – clean later' approach look to grow the hydrogen economy through investments and policies that support hydrogen regardless of the 'colour'. This approach is often adopted by countries who aim to develop enough capacity to be net exporters of hydrogen to other countries and in the hopes that CCS technology will advance enough to enable 'blue' hydrogen to be a viable production method in the future. However, countries taking these different approaches also face very different issues in the promotion and adoption of their hydrogen agendas. The countries of Germany and Australia who are adopting the 'green hydrogen emphasis' approach and 'scale first – clean later' approaches, respectively, face push back from key actors who may have differing goals to the federal government.

In Germany, the federal policies and mechanisms are more heavily influenced by landscape factors of 'climate and environmental action' and 'energy security'. Despite pushback from state governments who wish to prioritise landscape factors of 'job creation' and 'economic growth', strong and ambitious policies and mechanisms set by the federal government means that both state and firm actors have strong confidence in the future of hydrogen development in Germany. All actors at federal, state, and firm level are incentivised to invest in green, renewable hydrogen. However, the 'green hydrogen emphasis' approach creates an investment dilemma for those looking to invest and develop green hydrogen projects. The emphasis on 'green' hydrogen means that there is a lack of investment into early green hydrogen projects as firms and investors are expecting dramatic price decreases as technology improves. As all investors attempt to benefit from being a 'fast second' there is a 'stalemate' in the investing landscape.

Australia on the other hand, has federal policies that prioritises landscape factors of 'economic growth' and 'job creation, while state actors focus on 'job creation' and 'economic growth' from the hydrogen economy. This mis-alignment of federal and state actors create a highly uncertain landscape for firms and investors. In its policies and documentation, the Australian government promotes the term ‘clean’ hydrogen as part of their hydrogen strategy and not ‘green’ hydrogen. This refers to the production of hydrogen from renewable energy and both the production of hydrogen from coal and natural gas with the use of CCS. Much of Australia’s ‘scale first – clean later’ approach depends heavily on the progress of CCS technology, and significant amount of its goals depend on not only developing the hydrogen economy but also in advancing CCS technology. This lack of policy alignment combined with Australia’s hesitation in committing more public investments signals low certainty to its approach and has had a negative effect on investor confidence in Australian hydrogen projects.

In both approaches to hydrogen adoption, there is significant hesitation from investors to fund hydrogen projects. In order to boost investor and firm confidence and re-risk investment into the hydrogen economy, governments need to implement key policies and market design mechanisms. These include creating clear taxonomy and standards that define the definitions of ‘green’, ‘sustainable’, ‘clean’, and ‘low-carbon’ hydrogen and to outline the criteria that would open hydrogen projects to sustainable financing. Similarly, the government needs to ensure early-stage infrastructure investments are attractive to investors. The transportation of hydrogen is independent from its production method, and thus hydrogen pipelines projects need to be promoted as low-risk to attract investors into deploying capital into the hydrogen economy.

Finally, in the early stages of niche development, implementing a strong market design is crucial in the social-technical adoption of hydrogen. As hydrogen becomes bigger part of the decarbonisation equation, countries and economies need a fluid market that allows for widespread use of hydrogen. Not only must hydrogen find and develop use cases for there to be a hydrogen economy, but the hydrogen economy must also require an underlying fluid financial market that facilitates the production, trading, and use of hydrogen.

The role of hydrogen exchanges will help facilitate the growth of hydrogen by providing an open marketplace what will make the price of hydrogen more transparent and allow producers and consumers to connect. An open hydrogen exchange will benefit the hydrogen economy by driving down prices and increasing hydrogen volume through a few different means. A hydrogen exchange will firstly, increase the demand of hydrogen through customer discovery; new consumers will be able to purchase and consume hydrogen if it was more accessible. An open and transparent exchange will also aid in price discovery and price competition; as the prices of different producers are made public, the price of hydrogen will become more standardised and reach an equilibrium market price through market economics.

Conclusion

As the demarcation between 'green' hydrogen and other colours of hydrogen become more crucial, it is important to designate and protect green hydrogen producers. A guarantee of origin scheme will audit producers of green hydrogen to ensure they are producing zero or low carbon hydrogen and this certification will provide consumer confidence as it will guarantee that the product will help hold up to the consumers carbon considerations. Not only is a GoO scheme vital for developing legitimacy within the hydrogen market, but it is also vital for developing market pull for green hydrogen.

Once the production of hydrogen can be safely guaranteed and certified, it allows for the market to implement Green Hydrogen Certificates. GHC certificates are important when large hydrogen infrastructures are developed, and it becomes almost impossible to distinguish the different types of hydrogen in an interconnected network. GHC's will separate hydrogen gas as a commodity and a guarantee of green or low carbon production as another commodity; these certificates can be traded separately from the hydrogen produced. GHC are a vital component of creating a hydrogen economy and market that promotes both hydrogen as a general commodity and green hydrogen as a method to achieve climate targets.

Another powerful mechanism that the niche hydrogen market can use to develop are Purchase Power Agreements and Hydrogen Purchase Power Agreements. PPAs allow producers of 'green' hydrogen to engage in contracts with renewable energy producers that ensure that hydrogen production will incur constant and forecastable costs compared with wildly variable renewable energy costs from the electricity market. HPPAs are powerful as it gives producers confidence in developing hydrogen projects and being able to guarantee future sales and cash flows is key in project finance and determining the viability of hydrogen projects.

Finally, possibly one of the strongest mechanisms that will help promote investment into hydrogen economy is the denomination of hydrogen to the Euro. As champions of the hydrogen economy, the European Union have a unique opportunity to push for the denomination of hydrogen in Euros. This would signal to investors and actors within the hydrogen economy that one of the major economies in the world are putting their support behind the hydrogen economy.

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