2022 N° 41 | ECONOMIE INTERNATIONALE | INTERNATIONAL ECONOMICS

eCahiers
de l'Institut
Graduate Institute
ePapers


# The Heralds of Hydrogen

## The Economic Sectors that are Driving the Hydrogen Economy in Europe

Floris de Klerk Wolters

THE GRADUATE INSTITUTE GENEVA

INSTITUT DE HAUTES ÉTUDES INTERNATIONALES ET DU DÉVELOPPEMENT
GRADUATE INSTITUTE OF INTERNATIONAL AND DEVELOPMENT STUDIES

Graduate Institute Publications

# The Haralds of Hydrogen

## The Economic Sectors Driving the Hydrogen Economy in Europe

**Floris Jacobus Adrianus de Klerk Wolters**

DOI: 10.4000/books.iheid.8612
Publisher: Graduate Institute Publications
Place of publication: Geneva
Year of publication: 2022
Publication date: 7 janvier 2022
Series: eCahiers de l'Institut
Digital ISBN: 978-2-940600-36-6



## DIGITAL REFERENCE

de Klerk Wolters, Floris Jacobus Adrianus. *The Haralds of Hydrogen*. Graduate Institute Publications, 2022, https://doi.org/10.4000/books.iheid.8612.

Cover metadata
Credits
Sander van der Werf
This text was automatically generated on 5 mai 2025.

## ABSTRACT

This paper analyses membership data from 39 hydrogen associations to understand which economic sectors support the hydrogen transition in Europe, and why. It finds support from manufacturers of motor vehicles, chemicals, (electronic and electrical) machinery, electricity and gas companies, companies working in transport and storage (including ports), oil and gas companies, and many professional, scientific, and technical companies. Chemicals manufacturers and natural gas utilities stand out in their interest, as well as SMEs working in the value chain of hydrogen and fuel cell products. Registrations are clustered in the North Sea Region and the Iberian Peninsula, with many fewer registrations in Italy and Eastern Europe (including Russia). Motives for supporting the hydrogen transition include sales and market growth, rising $CO_2$ emissions costs, regulatory and public pressure to decarbonise, avoiding stranded assets, diversification, investor concerns about the long-term profitability of carbon-intensive sectors, and sector-specific concerns.

*We extend our heartfelt thanks to the Vahabzadeh Foundation for financially supporting the publication of best works by young researchers of the Graduate Institute, giving a priority to those who have been awarded academic prizes for their master's dissertations.*

## FLORIS JACOBUS ADRIANUS DE KLERK WOLTERS

Floris de Klerk Wolters graduated in 2020 with a master's degree in International Affairs from the Graduate Institute of International and Development Studies. He received his bachelor's degree in Liberal Arts & Sciences from University College Utrecht.Floris is currently a Junior Project Officer at DCAF - Geneva Centre for Security Sector Governance, where he works for the International Security Sector Advisory Team and the Asia-Pacific Unit.

# TABLE OF CONTENTS

# Acknowledgements

1 I would like to thank Professor Giacomo Luciani for his supervision, support and advice in the writing process. This publication would not have been possible without his help. I would also like to thank Noé van Hulst for his willingness to answer some of the questions I had about the hydrogen transition.

# List of Abbreviations

1 **ADEME** Agence de la transition écologique, previously Agence de l'environnement et de la maîtrise de l'énergie

2 **AE** Alkaline electrolyser

3 **AFHYPAC** Association française pour l'hydrogène et les piles à combustible

4 **BEV** Battery electric vehicle

5 **CCS** Carbon capture and storage

6 **CCU** Carbon capture and utilisation

7 **$CO_2$** Carbon dioxide

8 **DWV** Deutscher Wasserstoff- und Brennstoffzellen-Verband

9 **EU** European Union

10 **EU-ETS** European Union emissions trading system

11 **FCV** Fuel cell vehicle

12 **FCH** Fuel cell and hydrogen

13 **FCH JU** Fuel cell and Hydrogen Joint Undertaking

14 **GBP** British pound sterling

15 **GDP** Gross domestic product

16 **HRS(s)** Hydrogen refuelling station(s)

17 **HYPOS** Hydrogen Power Storage & Solutions East Germany

18 **IEA** International Energy Agency

19 **IRENA** International Renewable Energy Agency

20 **Mt** Million tonne(s)

21 **MW(h)** Megawatt(-hour)

22 **NACE** Nomenclature statistique des activités économiques dans la Communauté Européenne: Statistical Classification of Economic Activities in the European Community.

23 **n.e.c.** Not elsewhere classified

24 **NRW** North Rhine-Westphalia

25 **PEMs** Proton exchange membrane(s)

26 **PTE-HPC** Plataforma Tecnológica Española del Hidrógeno y de las Pilas de Combustible

27 **SEK** Swedish krona (crown)

28 **SMEs** Small and medium-sized enterprises

29 **SOECs** Solid oxide electrolysis cells

30 **TW(h)** Terawatt(-hour)

31 **R&D** Research and development

32 **UK** United Kingdom

33 **UN** United Nations

34 **US** United States

35 **USD** United States dollar

# Chapter 1: Introduction

1 The June 2019 International Energy Agency (IEA) report on the future of hydrogen highlighted the renewed interest in hydrogen as a potential pathway to a zero-carbon future. Since then, many new projects have started and many investment programmes reaching into the billions of euros have been announced, such as an earmarked fund of €9 billion for hydrogen as part of the German government's COVID-19 recovery effort (Steitz et al., 2020). The Dutch NorthH2 project, revealed in early 2020, is another example of this. It aims for tens of billions of euros to be invested in the world's largest offshore wind farm, in the North Sea, with a very large hydrogen facility capable of supplying a substantial part of Northwestern Europe (Van Dijk, 2020). Critical questions quickly followed about the financing and the general feasibility of the project (De Boer, 2020). This makes it a good example of the uncertain role for hydrogen in European visions of the energy transition. A growing number of projects are working on green hydrogen, and the project sizes, in terms of megawatt (MW), have increased a lot over the past four decades (IEA, 2019c, p. 45). Simultaneously, global government spending on research & development (R&D) has fallen considerably since the 2000s, including in Europe (IEA, 2019c, p. 20). This raises questions about the support base of the hydrogen economy in Europe. What prompts companies as diverse as for instance Airbus, BP, Enagás, Fincantieri, Linde, Siemens, Škoda, SNCF, and Thyssenkrupp to become members of hydrogen associations? Which economic sectors support the hydrogen economy? Do small and medium-sized enterprises (SMEs) also support it? And where are these companies from? This paper addresses these questions to give a clearer picture of the economic sectors that support the hydrogen economy, and why they do so. The central question is the following:

2 *Which economic sectors and companies are promoting the hydrogen economy in Europe, and what are their reasons for doing so?*

3 This is a very relevant question. The momentum for hydrogen comes at a time when policymakers at the subnational, national and supranational level are tasked with reviving their economies in response to the COVID-19 crisis. At the European level, the outlines of a Green Deal with explicit reference to hydrogen were announced in December 2019, just before the COVID-19 crisis began (European Commission, 2019a, 2019b). European Commission Vice-President Frans Timmermans, whose portfolio includes the European Green Deal, sees a pivotal role for hydrogen, and by March 2020

the EU had revealed plans to increase hydrogen investment and launch an EU-wide hydrogen partnership (Fleming & Hollinger, 2020; Keating, 2019; Khan, 2020). Many national policymakers are working on hydrogen too: while German policymakers are still preparing a national hydrogen strategy, France released one in 2018. At the same time, waves of enthusiasm for hydrogen have subsided in the past, and Timmermans also warns that hydrogen is no silver bullet. This leaves analysts and onlookers with the above questions about what can realistically be expected from hydrogen.

4 This paper compiles the membership data of 39 hydrogen associations across Europe and classifies 1670 membership entries according to their business activities. These are analysed to identify the economic sectors that are driving the hydrogen economy in Europe. It finds an approximately equally numerous (90-110 registrations) presence of motor vehicle manufacturers, metals manufacturers, chemicals manufacturers, and electricity utility companies, and a slightly less numerous (approx. 50-70) presence of natural gas utility companies and oil and gas companies. There is a larger presence of (electronic and electrical) machinery manufacturers, as well as companies conducting professional, scientific, and technical activities such as engineering, research and development, and testing. However, these companies also appear to be smaller on average. The number of companies interested in hydrogen can be crudely predicted by gross domestic product (GDP). Areas that are relatively well represented include the Iberian Peninsula, and especially a wider North Sea Region that includes the Benelux countries, the Nordics and Germany. Fewer registrations are by entities from Ireland, Italy, Greece, Finland, and Eastern Europe generally – Belarus, Ukraine and Russia combined are the origin of only three entities in total. Notable exceptions of relatively well-represented countries in Central and Eastern Europe include the Czech Republic, Hungary, Slovakia, and the Baltic states.

5 There are different motivations per sector. Straightforward business growth is the leading motivation for many sectors active in the value chain, but other sectors are also pushed to hydrogen by rising carbon costs in the EU Emissions Trading System (EU-ETS) and stricter regulations, such as the basic metals (i.e. steel) and chemicals sectors. Other motivations include doubts about the prospects of battery electric vehicles (BEVs), as well as ports and integrated oil and gas companies anticipating a changing role for them in the energy system.

6 The paper is structured to first clarify the methodological approach, and then provide some background information about hydrogen and its perceived benefits. This is followed by a brief literature overview on the political economy of hydrogen, and where support might be expected to come from. The core of the paper consists of an analytical part, where an analysis of the geographical background is followed by an analysis of each relevant economic section. These analyses are based on the data and secondary literature research on the motives of these sections' interest in hydrogen. Some sections are split into several main divisions (e.g. motor vehicles under manufacturing). The makeup of the section/division is discussed, as well as the leading motivations for supporting the hydrogen economy. This is followed by a conclusion.

# Chapter 2: Methodology

1 The core methodological approach of this paper is the use of qualitative methods, with limited use of quantitative methods. The methodological challenge is (1) to reliably and objectively identify which economic sectors (and which actors within them) are supportive of hydrogen and fuel cell technology in Europe, and (2) to analyse what their motives are for doing so. Europe is chosen as it is one of the regions that is globally most involved in hydrogen and fuel cell research (alongside China and Japan), and because there is substantial support from a supranational (i.e. EU) level. This creates an interlinkage with questions about the role of global governance in promoting technology shifts. The paper uses the UN Statistical Division (2020) M49 standard to define the geographic scope of Europe.[1]

2 The paper identifies support for the hydrogen transition by manually gathering membership directory data of all non-government and non-public entities[2] registered in international, national or sub-national hydrogen and fuel cell associations, and categorising these by primary business activity and country. These associations aim to promote hydrogen projects, cooperation between interested parties, and can function as lobby groups in support of the hydrogen transition.[3] They are used as proxy for supporting the hydrogen transition. In total, 1670 registrations are categorised, from 39 hydrogen associations. Business activity is registered based on the Statistical Classification of Economic Activities in the European Community, commonly known as NACE (Eurostat, 2008). These are standardised in the European Single Market, and consequently cover most registrations. Several NACE levels are registered, from the overarching section level, to division, to group or class.

3 Despite this standardisation, national systems for accessing business registers vary considerably, and many require payment per information request. Where NACE-registration information is freely accessible (e.g. Belgium, Czech Republic, Denmark, France, Italy, Slovakia, UK), official government business registrations were used. Where information on NACE-registrations is not freely accessible (e.g. Austria, Germany, Netherlands, Sweden) through the relevant government agency, information services based on this information were used.[4] The former is much preferred for reliability, and subsequent research should aim to be based on the official government channels for business information.

4 There are validity problems with this classification method. In most jurisdictions, companies choose their classification. This means that companies conducting relatively similar or overlapping activities can register as carrying out different activities. This has mostly been left untouched, except for the manual change of Nouryon[5] and the inclusion of transporters via pipeline (e.g. GRTgaz and Gasunie) under electricity and gas instead of under transport and storage. Furthermore, companies active in multiple activities (e.g. integrated oil and gas companies, utilities, or conglomerates) are classified as conducting only one business activity. Finally, large companies tend to register as a head office[6] (NACE M70) with subsidiaries conducting different business activities, sometimes differing by country. For consistency and clarity, two principles in categorisation are used: (1) same-name subsidiaries are registered in exactly the same way as the company is registered in the country where the headquarters are located, (2) large organisations registered under NACE M70 are changed to the code of a registered subsidiary at the discretion of the author.

5 The above points are acknowledged methodological flaws. However, it is difficult to avoid manual corrections using any type of sector classification based on official registrations, while at the same time maintaining the validity of the results. Air Liquide, Deutsche Bahn, Électricité de France, Hyundai and Shell are all registered as carrying out the same activity, which is not an accurate reflection of their behaviour and business interests as economic actors. The support of subsidiaries may vary across countries, a nuance which is lost by registering them as "clones" of the parent company. However, here too, analytical consistency is lost when subsidiaries from the same company carrying out the same activities but registered differently abroad are considered as being part of different industries. To some extent, these issues are all the result of artificially rigid statistical groupings. These flaws may be inevitable when analysing sectors, rather than doing a company-by-company analysis for all 1670 registrations. Subsequent research could and should try to improve on this.

6 The paper uses this business activity dataset to analyse support across sectors for the hydrogen transition, and to identify who the main actors are in these sectors. This lays the foundation for answering the second part of the research question on the motivation of these actors. This is done with literature research, such as by going through annual reports, financial reports, sustainability reports, press releases, news articles, and existing (academic) literature on the sector's or actor's connection to hydrogen. A serious methodological improvement would be to engage representatives from all identified sectors and all key actors, as well as independent experts from governments and research institutions. Acquiring representative samples to make objective conclusions about all sectors and actors – taking account of large differences even within sectors – requires considerable resources and falls outside the scope of this paper. A larger study could attempt doing this or first focus on specific actors and/or sectors.

# FOOTNOTES

**1.** The observant reader might note that some countries (notably the Russian Federation) are not represented in the list of companies and hydrogen associations. This can be because hydrogen associations do not exist, have no members, or have no public directories. Additionally, there might not be any companies registered with the associations analysed (as is the case for Russia).

**2.** Universities and university research institutes are considered as public, and hence excluded.

**3.** For more information, see the chapter Activities and Influence of Hydrogen Associations.

**4.** For instance the website www.firmenwissen.com for Austria, Germany and Switzerland, or www.bedrijvenmonitor.info for the Netherlands.

**5.** Nouryon was registered under NACE Section G: Wholesale and retail trade and repair of motor vehicles and motorcycles (as a wholesale chemicals trader) and was moved to NACE Division C.20: Manufacture of chemicals and chemical products. This was already the case for some of its subsidiaries in other jurisdictions.

**6.** Registered under NACE M70: Activities of head offices; management consultancy activities.

# Chapter 3: Background

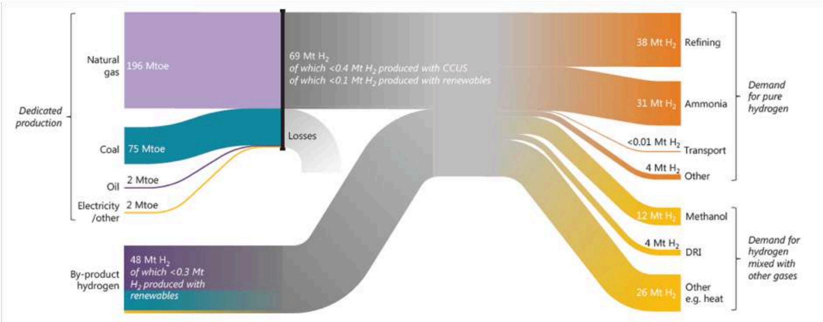
1 Before addressing this paper's central questions, it is useful to understand why hydrogen has received so much attention lately. The first thing to note is that hydrogen is not an energy source, but an energy carrier. Hydrogen is in this sense more like electricity, rather than oil or natural gas. There are no naturally occurring hydrogen reserves, as hydrogen is very reactive and easily forms other chemical compounds. In these compound forms, hydrogen is one of the most common elements on the earth's surface, for example in the form of water or hydrocarbons (e.g. oil). In the universe at large, hydrogen is by far the most abundant element.

2 Hydrogen has several qualities that make it interesting in the energy transition (Jain, 2009). Its usage does not produce any carbon pollution; only heat and water. It is a very light fuel and is rich in energy per unit mass. It can be produced from water using electrolysis, and can be converted into thermal, mechanical, and electrical energy. It can be stored in various states, ranging from liquid to (compressed) gaseous and hybrids. Currently, hydrogen is mainly used to refine oil and produce ammonia. For an annual global production of around 70 million tonnes (Mt) of hydrogen, 830 Mt of $CO_2$ is emitted (IEA, 2019b); approximately the combined 2018 $CO_2$ emissions of France, Spain and the United Kingdom (IEA, 2018a). An additional 45 Mt of hydrogen that is mixed with other gases for methanol and steel production is also produced (IEA, 2019c, p. 31). The annual hydrogen production in the EU is roughly 8 Mt (Navigant, 2019, p. 28).

## 3.1 Types of Hydrogen

3 There are three 'types' of hydrogen, based on the production method: grey, blue and green hydrogen. Grey hydrogen is produced from fossil fuels without carbon capture and storage (CCS). This is currently the almost exclusively used form of hydrogen production. Sometimes grey hydrogen is broken down into black, grey and brown hydrogen. This refers to using coal, natural gas and lignite respectively, without CCS. Grey hydrogen cannot be a component of a zero-carbon energy future without additional offsetting measures, and it is not this type of hydrogen that this paper focuses on.

Figure 1: Sankey graph showing current hydrogen value chains and role grey hydrogen

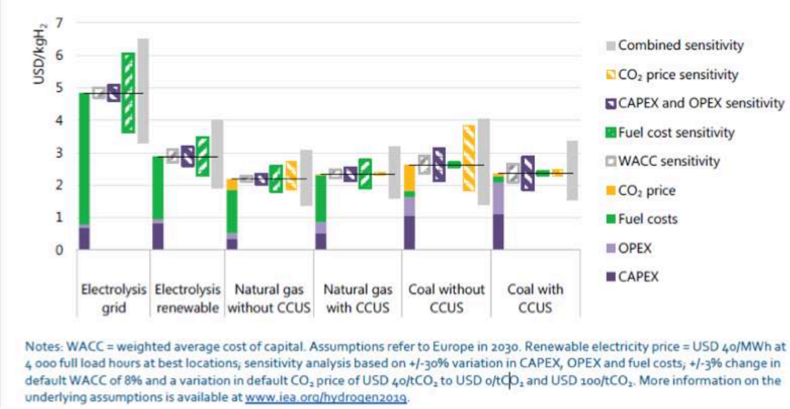



Source: IEA, 2019c, p. 32.

4 Blue hydrogen is grey hydrogen with CCS. This makes it a low-carbon option, that can play a (major) role in the energy transition. Blue hydrogen is a realistic option in Europe, as there is enough $CO_2$ storage space, and 5.8 Mt of hydrogen production could be equipped with CCS in the very short term (Navigant, 2019, p. 25). There are two main types of blue hydrogen: blue hydrogen with distributed decarbonisation, which leaves CCS to the user, and blue hydrogen with centralised decarbonisation, which makes producers responsible for CCS. Centralised decarbonisation has the advantage of small industries not needing to install expensive CCS systems, and the benefit that it can be centrally monitored, but it requires very large infrastructure investments (Navigant, 2019). Additionally, 300 Mt of captured $CO_2$ can be used as input in the manufacturing (70 Mt) and chemical (230 Mt) industry. The advantage of blue hydrogen is its (financial) feasibility in the short term, and the kickstart it could give to the development of a (green) hydrogen network. The role of blue hydrogen is an important point for debate in shaping the future of hydrogen.

5 Green hydrogen is the basis of most visions of the hydrogen economy. It is produced through electrolysis, with electricity as input.[1] Currently, electrolysis accounts for just 2% of hydrogen production. There are three main technologies through which green hydrogen can be produced (IEA, 2019c; Navigant, 2019): Alkaline Electrolysers (AEs), Proton Exchange Membranes (PEMs), and Solid Oxide Electrolysis Cells (SOECs). AEs are technologically the most developed and cheapest but not very flexible. As renewables tend to be intermittent, flexibility is desired. PEMs are flexible but need significant cost reductions to become competitive. This is also the case for SOECs, which are technologically the most promising technology but are much less developed. The main obstacles for green hydrogen are the development of a hydrogen market and economies of scale. This requires large investments in both infrastructure and technology. For the time being, the price competitiveness of green hydrogen is still far from reaching parity with blue, let alone grey, hydrogen. This is expected to converge around 2030 (IEA, 2019c).

Figure 2: Estimated costs of producing hydrogen through various methods in Europe in 2030




Source: IEA, 2019c, p. 52.

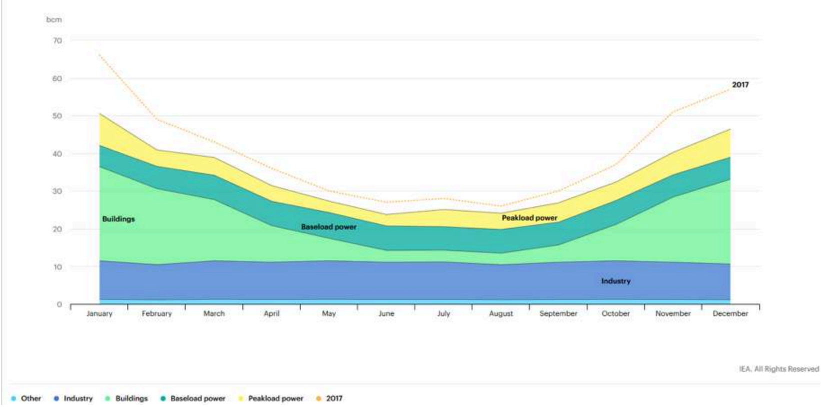
## 3.2 Perceived Benefits

6 Hydrogen has several big perceived benefits: it can complement the flow-based nature of electricity, diversify energy input, is compatible with existing infrastructure, and can help decarbonise hard-to-abate sectors in industry and transport. Although this paragraph focuses on the benefits, it is important to keep in mind that there are also many downsides to hydrogen. Examples of these include efficiency losses when it is converted, but also safety issues due to its highly inflammable nature, and (for blue hydrogen) the debates surrounding the desirability and viability of CCS. These are given more attention in the literature overview.

7 The first benefit of hydrogen is that it can complement the flow-based nature of electricity: electricity production and consumption must be matched across time. There are ways to decrease the necessity for perfect matching (e.g. batteries), but these are only a partial solution. Gas storage capacity in Europe today is over 50,000 times the current global battery storage capacity (IEA, 2019b, p. 580). Matching is a problem for solar and wind energy, which have high variability. This challenges energy grid stability in grids with a high percentage of wind and solar energy production (see e.g. Castillo & Gayme, 2014; Kroposki et al., 2017). Other renewables such as hydropower and geothermal energy are more stable, but many regions in Europe do not have the potential for these. Although there are serious energy losses from conversion, hydrogen is a potential solution, as it can be transported and stored to fulfil changing demand over time and space. Excess renewable energy could even be used directly to produce hydrogen through electrolysis. This is important: European energy transport still primarily (80%) relies on molecules rather than electrons (20%), and unfolding energy grid limitations can hold back the deployment of solar and wind energy production (Chatzimarkakis, 2020). This is also relevant for the big seasonal demand swings for building heating (Zeniewski, 2019).

8 Solar energy production in Europe runs countercyclical to heating demand: most solar energy is produced during long summer days when demand for heating is low. Although there is more wind in winter, the difference is not enough to compensate for the seasonality of heating demand. Hydrogen could be a better zero-carbon solution to replace natural gas demand in winter than electric heating.

Figure 3: Graph on seasonal gas demand in the EU in the IEA's New Policies Scenario in 2040




Source : Zeniewski (2019).

9 Diversification is a second benefit. The increasing role of electricity in consumer homes (e.g. heat pumps, cooking) and personal mobility also increases the severity of electricity disruptions. Hydrogen has the potential to offer a more diversified energy supply, as well as serving communities with a lesser developed electricity infrastructure (e.g. remote communities or older neighbourhoods).

10 A third benefit is the compatibility with existing natural gas infrastructure. This is especially interesting for the countries with big natural gas networks, high heating demand in winter, and older buildings. EU countries where natural gas plays a big (>40%) role in the total building heating demand include, in decreasing order of nonseasonal share of demand, the Netherlands, Italy, the UK,[2] Hungary, Slovakia, Belgium, the Czech Republic, France, Germany, Croatia and Romania (FCH JU, 2019a, p. 36). Borderline cases are Spain, Ireland, Austria and Poland. The grid-level advantages are clear: capital investments in natural gas networks are not lost, as they would be in a purely electricity-based scenario. This is a major advantage: 38% of European buildings are heated via gas networks, and this will likely remain so until 2030 (CătuŢi et al., 2019). Given the continued investments in natural gas, there are incentives to maintain existing networks. This is more attractive when they have utility beyond the horizon of natural gas. Hydrogen allows the diversification of these natural gas distribution networks, rather than increasing electricity dependency.

11 Hydrogen can already be blended into existing gas flows, with no need for changes. This delivers direct carbon emissions reductions. Safe current blending estimates range between 5-20% (CătuŢi et al., 2019, p. 22; FCH JU, 2019a; IEA, 2019b, p. 590; Melaina et al., 2013). Concerns exist for older engines and industrial users with lower hydrogen tolerance turbines and compressors (IEA, 2019b, p. 592). Nevertheless, replacing older machines is cheaper than building capacity up from zero. Fuel stations can also be converted to hydrogen refuelling stations (HRSs) rather than the much higher cost for electric mobility infrastructure.

12 The fourth benefit is the ability to decarbonise chemical feedstocks in hard-to-abate industries and transport. These include aviation, shipping, rail and road transport, as well as the chemical, iron, steel, and cement industry. Main electrification problems in heavy industry are difficulties with switching fuel, the difficulty of designing high-temperature electric furnaces, changing industrial processes, and the long lifetime of

industrial capital stock (IEA, 2018b, p. 403). The International Renewable Energy Agency (2018) notes that hydrogen as competitive feedstock can avoid carbon leakage of heavy industries moving elsewhere.

13 There are similar hopes for various forms of transport, such as rail (FCH JU et al., 2019), shipping (Pratt & Klebanoff, 2018; Tronstad et al., 2017), road (FCH JU, 2019a; IEA, 2019c, p. 133; IEA Energy Technology Network, 2019), and even aviation (Contreras et al., 1997; IEA, 2019c; Pohl & Malychev, 1997; van Zon, 2018). However, the IEA (2019c) is pessimistic about the ability of hydrogen to become competitive in shipping without policy intervention, hydrogen in aviation is still largely an infant technology, and consumers still pay a 100% premium for fuel cell cars vis-à-vis fossil fuel cars (Oladini, 2018). Most focus for now is thus on heavy road transport (IEA, 2019c), and rail.

## FOOTNOTES

1. For it to be truly green, this electricity needs to come from renewable (or nuclear) sources.
2. The UK has since left the EU.

# Chapter 4: Literature Overview

1 There has been relatively little (academic) work on the political economy of hydrogen, nor even on the specific economic actors that can be expected to back it. The political economy of hydrogen is closely connected to the literature on the political economy of the energy transition in general, and, for blue hydrogen, on that of CCS. This chapter first discusses the general political economy of hydrogen before looking into specific actors and sectors, as well as its economic geography.

## 4.1 Political Economy of Hydrogen

2 Market conditions for economic actors in energy transitions are predominantly shaped by governments (Hisschemöller et al., 2006; McDowall & Eames, 2006; Meadowcroft, 2005; Meadowcroft & Langhelle, 2009). There are, however, doubts on the desirability of government pushes for specific technologies, amplified by the many competing alternatives in some sectors, such as the small vehicle market where fuel cell vehicles (FCVs) compete with BEVs, hybrids and biofuel cars (Torvanger & Meadowcroft, 2011). Moreover, there is a lot of issue overlap, which makes specific government policy support more difficult: think of legal and regulatory obstacles, economic interests, and public acceptability (Flamme et al., 2019; Kern et al., 2016; Meadowcroft & Langhelle, 2009). Such policies for encouraging specific technologies are decades long processes, where some (e.g. Victor et al., 2003) have rightfully pointed at the risk of path dependencies.

3 The role of blue hydrogen is an important issue here. CCS balances several economic interests as a possible 'bridge' technology between grey and green hydrogen. The roll-out of CCS suffers from an image problem as being a temporary fix rather than a long-term solution in the energy transition. It is not truly green and cannot mobilise support that way. Subsidies for CCS are vulnerable to accusations of violating the argument that polluters should pay, as it has the public image of subsidies for the fossil fuel industry (Meadowcroft & Langhelle, 2009). This is not unfounded, as industry and government have different motivations for backing CCS (Kern et al., 2016; Markusson et al., 2011; Meadowcroft & Langhelle, 2009). Whereas governments back CCS to reduce carbon emissions and bridge the gap to cleaner technologies, industries also do so because it

allows the continued use of fossil fuel (infrastructure). This raises problems, as the public image can be an important factor in guiding economic actors, for instance by steering investment and shaping investor views on long-term profitability. It is a key factor in the hydrogen transition (Flamme et al., 2019; Kern et al., 2016; Meadowcroft & Langhelle, 2009; Torvanger & Meadowcroft, 2011). James Meadowcroft and Oluf Langhelle (2009) stress, in the context of CCS, the importance of widespread endorsement of transition technologies by many different sectors to gain public acceptance.

4 William McDowall and Malcolm Eames (2006) also note public acceptability as a key barrier in the hydrogen transition, along with the absence of infrastructure, industry standards, surplus renewable electricity, and global cooperation. Other factors include high costs, technological immaturity, safety, the ability to adapt to hydrogen competition, the limited skills base, the limited availability of industrial components, the difficulty of technological development, lack of demand for hydrogen, social opposition and uncertainty about the technology's future. Underlying problems for these interests are climate change, energy security, air quality, and competitiveness. Important positive drivers are social/environmental values, political will, technology and of course price competitiveness and economic interests.

5 One thing to note on top of the above is the organisation of political interests itself, in what Carl-Jochen Winter (2005) calls "energy technology politics". Existing interests organise much more readily than newcomers (Victor et al., 2003). Concretely, this means that future beneficiaries of the hydrogen system are much less influential than companies benefitting from the current system. In the energy transition at large this has been exemplified by the suppression of cautionary climate change reports by ExxonMobil and Shell in the 1980s (Franta, 2018). However, the changing stance of some fossil fuel companies toward hydrogen makes this more complicated: some energy incumbents have begun to co-opt changes rather than resist change.

## 4.2 Literature Economic Sectors

6 The IEA (IEA, 2019c, p. 19) sums up "renewable electricity suppliers, industrial gas producers, electricity and gas utilities, automakers, oil and gas companies, major engineering firms and the governments of the world's largest economies" as actors in support of the hydrogen transition. Much of the existing literature on the hydrogen transition, however, focuses specifically on the role of the fossil fuel (most notably oil and gas) and automotive industry, more so than other industries.

7 This is understandable. Integrating blue hydrogen has various direct benefits for oil and gas companies, pipeline owners, and even the coal industry (Kern et al., 2016; Markusson et al., 2011; Meadowcroft & Langhelle, 2009). They get access to cheap or free $CO_2$ in pipelines from CCS which they can use for enhanced oil recovery (EOR). Secondly, CCS allows the continued use of natural gas, which means that producers can continue to sell it to a big energy market. Thirdly, they can sell the now-redundant $CO_2$ emission rights to other parties and earn extra money that way. Fourthly, blue hydrogen guarantees the continued use of pipelines for CCS purposes, which for pipeline owners is preferable compared to them falling into disuse. Much attention has been paid to BP and Shell as long-time backers in particular (Balat & Balat, 2009; Meadowcroft & Langhelle, 2009; Royal Dutch Shell & Wuppertal Institut, 2017). Oil and

gas companies in Norway, such as Equinor, are known to have pushed for blue hydrogen from the perspective of remaining able to use natural gas and the infrastructure (Meadowcroft & Langhelle, 2009). A similar argument is made for those supportive of 'clean coal' technologies, and the possibility of making hydrogen with CCS from coal has led to speculation on the eventual willingness of the coal industry to become part of a pro-hydrogen coalition. (Victor et al., 2003; Winter, 2005).

8 The existence of both blue and green hydrogen creates the possibility for actors to pursue relatively narrow interests (Moliner et al., 2016). Concretely, this means that hydrogen is perceived by some environmentalist groups through a green lens and is promoted as such. In other respects, hydrogen is seen as capable of replacing oil and gas, but also coal, specifically. This perspective tends to focus more on the potential of blue hydrogen. This creates the potential for strange coalitions between oil and gas majors, as well as between environmentalists and renewable energy companies.

## 4.3 Literature Economic Geography

9 Which sectors support the hydrogen transition is strongly related to where these actors are located. At a global level the IEA (2019c, p. 20) makes clear that while investment in the US and China has changed significantly, most still comes from Europe and Japan. Research by A.N. Madsen and P.D. Andersen (2010) on hydrogen clusters in Europe marks a geographically relatively spread-out set of clusters, although heavily skewed towards Western Europe. Notable regional clusters they mention are southern Scandinavia, North Rhine-Westphalia in Germany, Aragon in northeast Spain, and several projects in northern Italy. They see little evidence of clustering in areas with existing hydrogen facilities and pipelines, and more in innovative regions with strong representation of chemical, energy, manufacturing, oil and gas, automotive, and aerospace industries (2010, p. 25). This is slightly at odds with the IEA's (2019c, p. 177) view. The IEA expects more from (coastal) industrial clusters, and areas with existing natural gas infrastructure, rather than from innovation clusters. The focus on clusters in the hydrogen transition fits into wider discussions on the role of clusters in energy policy, exemplified by an article from Pieter Mans, Floortje Alkemade, Tessa van der Valk, and Marko P. Hekkert (2008) on Dutch hydrogen clusters.

10 Policies from national governments should be part of this discussion. France (Ministère de la Transition Écologique et Solidaire, 2018), the Netherlands (Government of the Netherlands, 2020), and Norway (Tina Bru, 2020) for instance have official national hydrogen strategies. Norway and the Netherlands are particularly explicit in this respect. Norway emphasises CCS and maritime use, and the Netherlands puts the emphasis on decarbonising its relatively energy-intensive industries and retaining its international energy hub function. Although the Dutch strategy calls for clean hydrogen and often refers to green hydrogen, its policy output treats blue hydrogen as an important transition medium, notably for its now almost idle gas networks near Groningen. The French strategy also focuses on green hydrogen, but mostly ignores blue hydrogen and takes no clear position on it. Italy and Spain have no concrete national hydrogen strategies, although Spain has opened a public consultation.

11 Although the UK has no national hydrogen strategy, it funds projects and has a plan to convert the Northern English gas network to using hydrogen. Germany is expected to

publish a national hydrogen strategy by mid-2020, and in the wake of the COVID-19 crisis it has earmarked $10 billion for hydrogen investment. The German policy discussion is marked by a focus on green hydrogen. However, recent studies (e.g. Dickel, 2020) show that it is difficult to meet the German climate commitments (including phasing lignite out) without using blue hydrogen as a bridge technology. This is similar to discussions in the European Commission, which is reviewing its energy policy in the context of the European Green Deal and the new 2021-2027 budget. Here too blue hydrogen is not popular, and is sometimes excluded from discussions or studies. The European approach seems to favour phasing out blue hydrogen by 2030, when green hydrogen is not yet expected to be competitive. This raises questions about the viability of its energy transition scenarios, and the effectiveness of new regulations developed with such scenarios in mind (Barnes, 2020).

# Chapter 5: Activities and Influence Hydrogen Associations

1 Given the central role of hydrogen associations in this paper, it is useful to briefly consider their activities and the influence they have. For this, it helps to look at the six largest associations. These are Netzwerk Brennstoffzelle und Wasserstoff, Elektromobilität of the EnergieAgentur North Rhine-Westphalia (NRW; N=392, 23.47%), Hydrogen Europe (N=160, 9.58%), the Association française pour l'hydrogène et les piles à combustible – AFHYPAC (N=103, 6.17%), the Deutscher Wasserstoff- und Brennstoffzellen-Verband – DWV (N=85, 5.09%), Hydrogen Power Storage & Solutions East Germany – HYPOS (N=82, 4.91%) and the Plataforma Tecnológica Española del Hidrógeno y de las Pilas de Combustible – PTE-HPC (N=81, 4.85%). Together, they cover over 50% of the registrations.

2 Hydrogen Europe (2020) describes its two goals as those of a classical trade association and a supporter of innovation. In the former capacity, it is a channel for industry representation, lobbying and advocacy vis-à-vis policymakers. It also disseminates regulatory updates to members and shares best practices. Hydrogen Europe is represented both through its industry and its research arm as two of three members in the public-private partnership of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU), with the European Commission as the third partner. FCH JU has a total budget of €1.33 billion over the period 2014-2022 (FCH JU, n.d.). The funding from the European Commission from its Horizon 2020 budget (topped up with a significantly smaller input from industry and research) translates into approximately €90-100 million invested annually directly into hydrogen projects (FCH JU, 2019d). This makes it an influential player in the European hydrogen environment, with frequently cited research output and well-attended annual stakeholder forums. FCH JU is also in turn one of the main drivers behind the idea of "hydrogen valleys", or pioneering clusters of hydrogen in several regions, through its new project development assistance programme.

3 Hydrogen Europe also cooperates with funding from FCH JU on the maintenance of a legal database called Hydrogen Law (HyLaw, 2020), which keeps a tab on legislation and regulation relevant to the commercialisation of hydrogen and fuel cell technology for 18 European countries. This database contains national policy recommendations and overviews of relevant policy processes. Hydrogen Europe thus cooperates quite closely

with the European Commission to advocate and lobby decision-makers at various governance levels, and it also gives workshops oriented at different levels. The aim of these workshops is explicitly to convince public authorities to remove barriers.

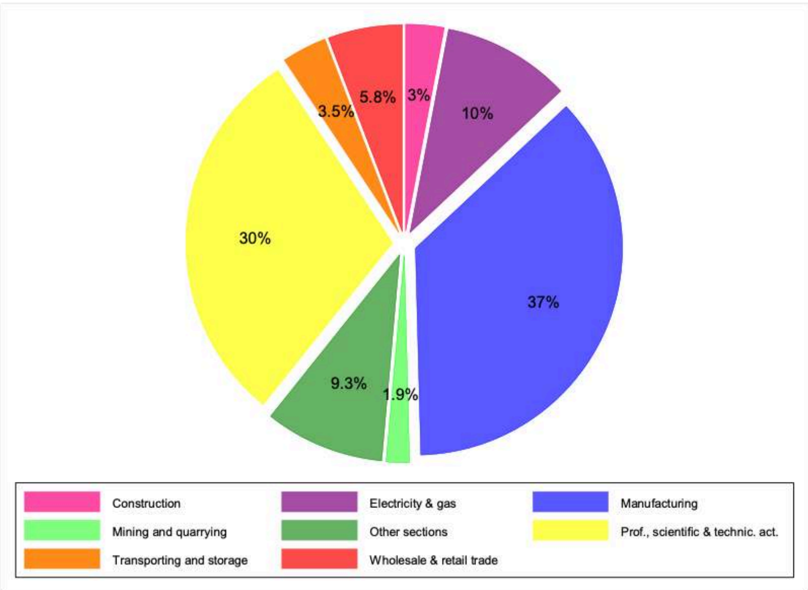
4 The hydrogen & fuel cell network of EnergieAgentur NRW (2020), AFHYPAC (n.d.), HYPOS (n.d.), PTE (n.d.), and DWV (n.d.) all follow much the same model, although, apart from EnergieAgentur NRW, without the direct investment capacities that Hydrogen Europe has. All groups are involved in lobbying activities, coordinate among members to disseminate information on regulations and technology, and are involved in the organisation of regular conferences and the facilitation of shared projects. Like Hydrogen Europe, many have permanent staff members specifically involved in media and political advocacy. DWV is the most explicit in this, calling itself a leading lobby group, aiming to make its voice heard in politics, "securing the business environment needed by our industry", and pursuing targeted lobbying activities in regular contact with political decisionmakers. Many of the other associations have less openly political goals, but in effect pursue similar goals.

5 This does not mean that these organisations are necessarily private. Most hydrogen associations are forms of public-private partnerships and have close ties to governments. EnergieAgentur NRW, despite being nominally independent, is closely tied to the state government of North Rhine-Westphalia, and HYPOS gets funding from the German federal government's Zwanzig20 project. AFHYPAC receives money from the French government's Agence de la transition écologique (ADEME) and has close ties to the Ministry of the Ecological and Inclusive Transition. PTE-HPC is supported by the Spanish Ministry of Science and Innovation. Moreover, many hydrogen associations cooperate with municipalities, regional authorities, universities, local development agencies, and other public institutions. A significant number of public organisations are full members. AFHYPAC is a good example, as it has a separate members list for these institutions. It ranges from federations of municipalities, departments, and metropolitan areas (e.g. Aix-Marseille, Grenoble, Montpellier, Nantes, Nice, Rouen), to all of the French regions except Corsica. This active participation of regional governments is further analysed in the analysis.

# Chapter 6: Analysis

1 In the following chapters (chapters 6-13), the paper will provide a sector-by-sector analysis. It lists sectors based on their prevalence in the data and analyses their motives for participation in the hydrogen economy based on secondary literature. It begins with an analysis of the geographic background, followed by the largest three sectors (i.e. manufacturing, professional, scientific and technical activities, and electricity and gas respectively). This is followed by the much smaller sectors of mining and quarrying, and transporting and storage. These are much smaller in quantitative terms but stand out for the size of the registered companies in the list.

Figure 4: Pie chart general overview (some sector names abbreviated).




Source: author.

Table 1: Overview of selected divisions (combinations).

| Selected (combined) divisions | Frequency | Percentage |
|---|---|---|
| Architectural and engineering activities | 260 | 15.57 |
| Manufacture of machinery and electronic or electrical equipment | 255 | 15.27 |
| Research and development | 113 | 6.77 |
| Electricity utilities | 106 | 6.35 |
| Manufacture of metals and non-metallic mineral products | 99 | 5.93 |
| Manufacture of chemicals | 97 | 5.81 |
| Manufacture of motor vehicles | 92 | 5.51 |
| Natural gas utilities | 70 | 4.19 |
| Oil and gas industry | 53 | 3.17 |
| Land transport | 24 | 1.44 |
| Ports & warehousing | 13 | 0.78 |

Source: author.

Table 2: Section overview.

| Section | Frequency | Percentage |
|---|---|---|
| Manufacturing | 611 | 36.59 |
| Professional, scientific & technical activities | 499 | 29.88 |
| Electricity and gas | 167 | 10.00 |
| Transporting and storage | 59 | 3.53 |
| Mining and quarrying | 31 | 1.86 |
| Other sections | 232 | 18.16 |
| *(Wholesale & retail trade; repair of vehicles)* | *97* | *5.81* |
| *(Construction)* | *50* | *2.99* |
| *(Other services activities)* | *44* | *2.63* |
| *(Administrative and support services)* | *28* | *1.68* |
| *(Water supply; sewerage; waste management)* | *21* | *1.26* |
| *(Information and communication)* | *18* | *1.08* |
| *(Financial and insurance activities)* | *16* | *0.96* |
| *(Public administration & defence)* | *14* | *0.84* |
| *(Education)* | *9* | *0.54* |
| *(Real estate activities)* | *6* | *0.36* |

Source: author.

# Chapter 7: Economic Geography

1 It is important to realise that to some degree the support from economic sectors depends on their geographic background. Which economic sectors support hydrogen seems linked to where this question is asked. This is valid both for the national level, as well as for the regional or cluster level. Governmental hydrogen strategies and support for hydrogen projects at various levels of government are a major factor in this, in the context of more and stricter climate regulations and increasing public pressure for change.

## 7.1 National Level

2 The number of entities from a country that are members of hydrogen associations can be crudely predicted by economic size and development, using the following formula: N entities in hydrogen associations = 0.09 x GDP (in bn USD) - 11, $R^2$ = 0.68, $\alpha$ =.05, $p$ = 0.000. This is based on IMF (2019) nominal GDP data (current USD) for 2018, and the number of registrations in hydrogen associations of companies from 39 European countries.[1] Notwithstanding the very crude nature of such calculations and the many confounding variables, they indicate which countries are expected to have sizeable hydrogen interests.

3 More importantly, this gives a rough indication of the countries that are relatively under- and overrepresented. The biggest negative outlier of the larger European economies is Russia, with no registered entities, emblematic of the lack in representation of Eastern Europe at large. Relatively well-performing countries in Central and Eastern Europe include Czech Republic, Hungary, Slovakia and the Baltic states. These are also countries where natural gas plays a significant role in the energy system. This also makes Italy, where natural gas plays a key role too, an outlier. It constitutes less than 1.5% of the registered entities, despite its large economy. Germany is clearly overrepresented, even considering its large economy. It is responsible for almost 40% of all registrations, approaching double the number of registrations of France, Italy, and the United Kingdom combined. France and the United Kingdom also underperform, especially relative to Germany and Spain. High performing regions appear to be the Iberian Peninsula, Benelux, and the Nordics minus Finland. Taken

together, this seems to confirm the IEA’s focus on a North Sea Region as a potential future hydrogen hub.

4 The link with GDP also means that most association members are from the bigger economies, with Italy and Russia as negative outliers. Approximately 70% come from Germany, France, the United Kingdom and Spain. Germany (N=605, 36.23% of total) is especially well-represented, partially explained by the high number of hydrogen associations. A caveat is that its largest association, under the EnergieAgentur NRW, also has companies active in electromobility beyond fuel cells and hydrogen in its portfolio. However, even when this association is excluded, Germany remains a clear overperformer. The cluster overlap is large in Germany, and it has a broad array of SMEs that partake in them.

5 The composition of countries’ lists of hydrogen association members is also very different. Germany and Spain both have some influential companies that are present in multiple hydrogen associations, but most of the registrations in these countries are SMEs. Siemens and the large carmakers are examples of these influential companies for Germany; Abengoa and Enagás for Spain. This is different for the UK and especially France. There are several companies headquartered in both countries that are very significant components of each country’s presence in hydrogen coalitions across Europe. These companies can have very different sizes. Examples of influential companies include chemical industry giants Air Liquide (member of 18 associations), and the now UK-headquartered Linde (16). Such key roles are also reserved for Engie (6) and its subsidiaries Storengy (4) and GRTgaz (3), as well as Électricité de France (EDF; 2) and its subsidiary Areva, which in turn owns Areva H2Gen (8) and Areva Stockage d’Énergie (2). They are complemented by some smaller companies that are very active in hydrogen coalitions, such as UK-based ITM Power (8), and France-based McPhy (8). Both France and the UK have considerably less diversity than Germany and Spain.

## 7.2 Hydrogen Clusters

6 The active role of regional and local governments in hydrogen associations also helps identify clusters of interest. This is notably the case for North Rhine-Westphalia and the East German states that support HYPOS, but large (N>50) associations are also present in Aragon, Hesse, Flanders[2], Scotland, and smaller associations (N<50) in Bayern, Cologne, Hamburg, London, the Ruhr Area, Wales, and Southern Germany. The density in Germany is particularly high. One such example is Cologne, which has a local association, (Hydrogen Cologne), a regional association (H2 Netzwerk Ruhr), and a state-level association (EnergieAgentur NRW). This is still aside from DWV and Hydrogen Europe at the national and European level respectively.

7 As such, the activity and density of hydrogen networks quite closely corresponds to the IEA’s (2019c, pp. 179–180) vision of the North Sea Region as a high-potential region for the hydrogen economy to take off. The combined membership of associations from Cologne, Flanders, Hamburg, London, North Rhine-Westphalia, the Ruhr Area, and Scotland, with national associations from Denmark, Iceland, the Netherlands,[3] Norway, and the UK covers 45% of all European-based hydrogen association entities. Adding France, Germany and Sweden, countries that are only partially connected to the North Sea Region, increases the coverage to 58%. This also fits with the existing literature

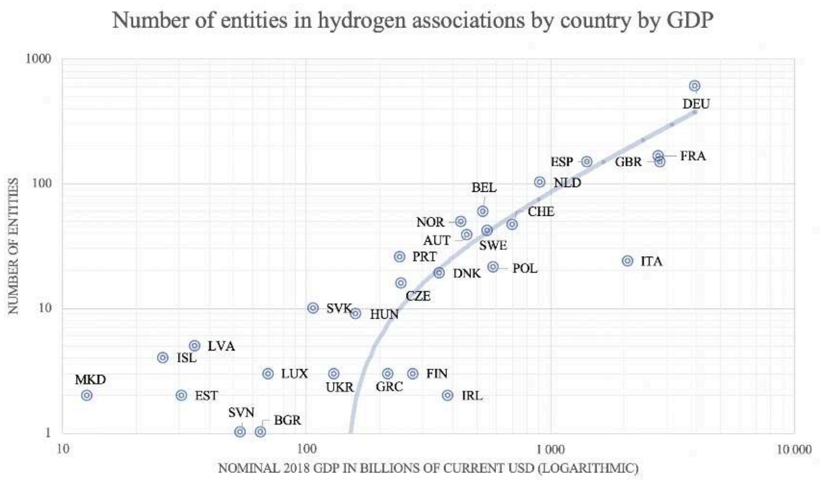
(Madsen & Andersen, 2010) on Aragon, North Rhine-Westphalia, and southern Scandinavia as emerging lead regions, although much less so for various northern Italian regions.

Table 3: Overview of registered entities by country background for countries with more than five entities.

| Country | Number of entities | % total |
|---|---|---|
| Germany | 605 | 36.23 |
| France | 167 | 10 |
| Spain | 149 | 8.92 |
| United Kingdom | 149 | 8.92 |
| Netherlands | 102 | 6.11 |
| Belgium | 59 | 3.53 |
| Norway | 49 | 2.93 |
| Switzerland | 47 | 2.81 |
| Sweden | 42 | 2.51 |
| United States | 40 | 2.4 |
| Austria | 38 | 2.28 |
| Japan | 33 | 1.98 |
| Portugal | 26 | 1.56 |
| Italy | 24 | 1.44 |
| Poland | 21 | 1.26 |
| Denmark | 19 | 1.14 |
| Czech Republic | 16 | 0.96 |
| South Korea | 13 | 0.78 |
| Slovakia | 10 | 0.6 |
| Hungary | 9 | 0.54 |
| Canada | 8 | 0.48 |
| Latvia | 5 | 0.3 |

Source: Author.

Figure 5. Graph showing number of entities in hydrogen associations by country by GDP. GDP based on IMF figures (2019).




Source: Author.

# FOOTNOTES

**1.** All European countries by the UN M49 standard, minus Andorra, Holy See, Liechtenstein, Monaco, and the Faroe Islands.

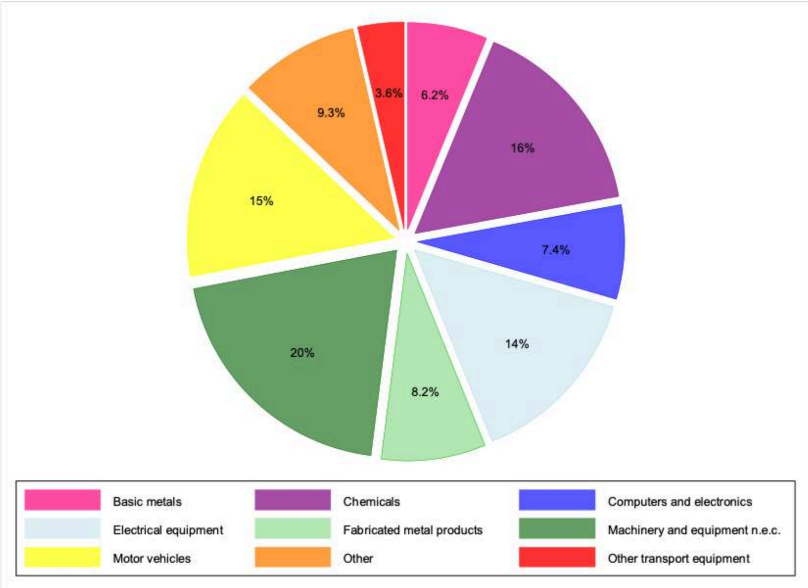
**2.** The only Belgian hydrogen association is WaterstofNet, which covers Flanders and the South of the Netherlands together.

**3.** The Netherlands has several associations: H2 Platform, the Nederlandse Waterstof en Brandstofcel Associatie (NWBA), and the Waterstof Coalitie. The binational WaterstofNet is considered as the Flemish association, see above.

# Chapter 8: Manufacturing

1 The biggest economic section in the hydrogen coalitions is manufacturing (N=611, 36.59%).[1] It is a diverse section, largely split among four larger divisions. These are manufacturers of machinery and equipment not elsewhere classified (n.e.c.) (N=122, 19.97%), motor vehicles, trailer and semi-trailers (N=92, 15.06%), chemicals and chemical products (N=97, 15.88%), and electrical equipment (N=88, 14.40%), together accounting for roughly 65% of manufacturing. In the analyses, manufacturers of machinery and equipment n.e.c. are merged with those of electrical equipment, repair and installation of machinery, and manufacturers of computers, electronic and optical products, as they support hydrogen for mostly the same reasons. The fact that some divisions have fewer registrations does not mean they should not be considered, and some have influential companies among them. Manufacturers of other transport equipment, (N=22, 3.60%) is an example of this: it includes aircraft industry duopolists Airbus and Boeing, the large shipyards Chantiers de l'Atlantique and Fincantieri, the naval constructor Naval Group, the train builder Alstom, and the heavy/industrial transport multinational CNH Industrial. The participation of major companies from these sectors should not be ignored in the larger picture of the hydrogen transition.

Figure 6: Pie chart for manufacturing




## 8.1 Machinery and Electronic or Electrical Equipment

2 Manufacturers in the divisions of electrical equipment; computer, electronic and optical products; repair and installation of machinery; and other machinery and equipment together constitute the largest group of manufacturers in support of hydrogen (N=255, 41.73%). Their number attains 277 with the inclusion of wholesale and retail traders specialised in this sector. Although these divisions specialise in different manufacturing products, their roles and motivations are largely similar. They produce (amongst others) electrolysers, compressors, regulators, taps, valves, PEM fuel cells, sensors, powertrains, fuelling systems, pumps and engines. Some of the most active companies among the different coalitions include Siemens (10), ITM Power (8 registrations), Hydrogenics (8), Nel Hydrogen (7), Swagelok (7), and Ballard Power Systems (7). Although most are SMEs, there is a sizeable number of large multinationals among them. The largest and most actively participating of these is Siemens, but other examples include ABB, Atlas Copco, Liebherr, Rolls Royce, Sandvik, Schaeffler, Swagelok, Vestas and Yanmar.

3 The motivation for these divisions is relatively straightforward: the perspective of sales and market growth. This can also be derived from official statements made by companies such as Swagelok (Shankar, 2019), Siemens (2018), and Sandvik (2016). Swagelok's expertise in producing leak prevention and storage safety solutions would, for instance, be in higher demand if more hydrogen infrastructure is constructed. Siemens would benefit from increased demand for large industrial electrolysers, as it is one of the few producers (with its "SILYZER") thereof. Sandvik can mass-produce specific solutions with coated steel in fuel cell plates. This is also very clear for companies like Hydrogenics (industrial hydrogen generators and fuel cells), Nel Hydrogen (electrolysers), ITM Power (electrolysers), and Ballard Power Systems (fuel cell stacks). A transition to a more hydrogen-based economy would rapidly increase these companies' revenues. This is applicable to most entities in this sector.

## 8.2 Metals and Non-Metallic Mineral Products

4 The manufacturers of basic metals, fabricated metal products, and non-metallic mineral products combined make up the second-largest group of manufacturers (N=99, 16.20%). They consist of companies in different metal and mineral-related industries, which can be broadly split between commodity producers (basic metals & non-metallic mineral products) and intermediate/final good producers (fabricated metals). The commodity producers are big steel producers such as ArcelorMittal, Thyssenkrupp, Tata Steel, US Steel, Salzgitter and Voestalpine, but also precious metals manufacturer Umicore, and a few cement, concrete, brick, and limestone manufacturers. The fabricated metals producers in the hydrogen context focus mostly on storage tanks, cylinders, and the machining and coating of metals, with companies such as NPROXX, Calvera Maquinaria e Instalaciones, and Resato.

5 There are several ongoing large projects in the steel industry, using recent research (e.g. Otto et al., 2017), that experiment with hydrogen as a replacement for carbon-based feedstocks in high-temperature blast furnaces. Big projects are for instance undertaken by Swedish-Finnish steel company SSAB,[2] ArcelorMittal (2019), UK-based Primetal Technologies (2019) and thyssenkrupp (2019). Similar research is ongoing in the cement industry (e.g. Ellis et al., 2019), but the cement industry is practically absent from hydrogen coalitions bar for the Secil Group and Vicat. European and global top-10 cement manufacturers (Edwards, 2017) such as LafargeHolcim (Switzerland), HeidelbergCement (Germany), CRH (Ireland) and Buzzi Unicem (Italy) are absent, despite increasing attention on their emissions (e.g. European Commission, 2017) and aforementioned research developments.

6 The motivations to support hydrogen projects differ for the two groups. The fabricated metals producers are in a similar position to the companies producing machinery and electronic or electrical equipment: more hydrogen investment and a bigger market for hydrogen would lead to sales growth of storage tanks, metal machining, and similar products.

7 For the steel producers and the few cement producers in the coalitions, there are very different interests at stake. The steel and cement industry together is one of the biggest greenhouse gas (GHG) emission sources, with an estimate of 94 Mt of $CO_2$ emissions, mostly from the production of heat (FCH JU, 2019b, p. 38). This is approximately similar to the total emissions of Belgium or the Czech Republic (IEA, 2018a). This exposes these sectors to increasing public and regulatory pressure, as well as financial pressure, to find ways to decarbonise (RWE, 2019; thyssenkrupp Steel Europe, 2019). It should be noted that the steel industry and the cement industry also have very different production processes, where $CO_2$ is emitted at different stages of the process. While both have high heat requirements, steel production processes using blast furnace also intrinsically emit $CO_2$.

8 Annual reports from companies in the steel sector explicitly note the business operation risks from EU-ETS costs, and possible revisions thereof in 2021 (ArcelorMittal, 2020, p. 19; Thyssenkrupp, 2019, p. 140; Voestalpine AG, 2020, p. 54). The relevance of this can be exemplified by putting the increase in Voestalpine's annual "environmental expenditure" from €257.7 million to €299.1 million, attributed almost solely to EU-ETS costs, in the context of a pre-tax profit of €646 million (Voestalpine

AG, 2020). To add to this, many actors in the steel industry still receive significant discounts on, or even free, $CO_2$ allowances. This is an additional carbon-related risk, as these discounts can be taken away by regulators. The large price volatility of carbon emissions can significantly affect profitability in the longer term, in a sector with already very tight margins.

## 8.3 Chemicals and Chemical Products

9 The third-largest presence among manufacturers is that of chemical companies (N=97, 15.88%), reaching 99 when chemical wholesale companies are added. This should not raise many eyebrows. Support from the largest companies in the industrial gas industry[3] makes for half of the entities registered as chemicals manufacturers. Particularly prominent are Air Liquide (18 registrations), Linde (16) and its subsidiary BOC (3), Nouryon (6), and Air Products & Chemicals (5). In general, close to 80% of the chemicals manufacturers in the hydrogen associations come from the manufacturing of industrial gas specifically. Both Linde (n.d.) and Air Liquide (2017) are very explicit in their goal of promoting the hydrogen economy and the use of hydrogen in mobility, and are actively building HRSs around the world.

10 One clear reason for this sector to participate in hydrogen coalitions is that the sale of hydrogen is a core component of their business model. Industrial gas producers also already have the know-how in handling hydrogen that can be translated into returns. Air Liquide (2017, p. 38) states in its 2017 Annual Report: “Air Liquide is present throughout the hydrogen energy value chain and is actively working to promote this fuel source on an international level. The Group made significant progress in 2017, further strengthening its position in this highly promising market.” Industrial gas producers benefit as they are natural partners in the construction of a large network of HRSs for FCVs, and have been key stakeholders in hydrogen initiatives ranging from steel production (Air Liquide, 2019) to hydrogen trains (Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr et al., 2017). On top of benefitting from selling hydrogen directly, the sector can also sell CCS technologies or benefit from increased demand for oxygen if clean coal were to succeed as a source for hydrogen production (Air Products & Chemicals Inc, 2019, p. 40).

11 Sales growth is not the only incentive to pursue a hydrogen transition in this sector. Continued reliance on carbon-intensive grey hydrogen production presents business risks in the long term. Linde’s (2018, p. 35) 2018 Annual Report explicitly states EU legislation on GHG emissions can impact growth from increased compliance costs, and that hydrogen production plants in the EU (and California) specifically are subject to cap-and-trade regulations on $CO_2$. This is echoed by the global leader in hydrogen production, Air Products & Chemicals (2019, p. 12), which notes that legislative pressure amongst others from the EU-ETS system puts pressure on their non-CCS (grey) hydrogen production. It states that increased public concern could lead to further pressure to reduce GHGs, and explicitly notes: “any legislation that limits or taxes GHG emissions could negatively impact our growth, increase our operating costs, or reduce demand for certain of our products (Air Products & Chemicals Inc, 2019, p. 12).” In other words, business expense risks from climate regulations are mitigated by moving from grey to blue and green hydrogen production.

## 8.4 Motor Vehicles

12 Manufacturers of motor vehicles, trailers and semi-trailers are the fourth-biggest group of manufacturers present in the various hydrogen coalitions (N=92, 15.06%). With the inclusion of vendors and maintenance of motor vehicles from the wholesale and retail trade sector, their number increases to 102. The country background of the manufacturers is also interesting, as it has a high proportion of non-European companies partaking. German manufacturers account for 28.26%, Japanese for slightly less at 16.30%, followed by South Korean manufacturers with 10.87%. Japan and South Korea are primarily represented by individual companies; Toyota (member of 13 associations) and Hyundai (10) respectively. These two companies are some of the most important actors supporting hydrogen coalitions.

13 Despite the popular focus on passenger cars, manufacturers of heavy motor vehicles will likely play a bigger role in the initial phase of the transition. Analysts expect that the advantages of FCVs over BEVs will be greatest in this sector, such as in weight, refuelling time, and range (IEA, 2019c, p. 137). Specialised lorry and bus manufacturers that support hydrogen coalitions include Van Hool, MAN, Evopro Busz, Iveco, VDL Bus & Coach, Solaris Bus & Coach, CaetanoBus, and Scania. Heavy vehicle manufacturers constitute well over 15% of the members from the sector, even when excluding non-specialised manufacturers with large heavy vehicle divisions (such as Daimler and Volvo).[4] There are also several large projects underway in this sector. Examples are the 300 FC buses of the Joint Initiative for Hydrogen Vehicles across Europe (Ruf, 2019), and a Swiss project for 1,600 hydrogen lorries manufactured by Hyundai. More hydrogen models for heavy vehicles are in development for the European market (IEA, 2019c, p. 129). Moreover, dedicated heavy-duty FCV and BEV manufacturers are emerging, such as Nikola in the United States.

14 Comparing the background of manufacturers supporting hydrogen to a general list of global motor vehicle manufacturers (International Organization of Motor Vehicle Manufacturers, 2017) highlights some more patterns. American carmakers and their subsidiaries are, except for two Ford research centres, absent. Although French components manufacturers (e.g. Plastic Omnium and Faurecia) are present in multiple associations, the big French carmakers themselves are absent.[5] These findings confirm previous reporting that most of the push for hydrogen in the automotive sector seems to come from Asian carmakers, led by Toyota and Hyundai (Buckland, 2019; Harding & Inagaki, 2017; Society of Motor Manufacturers and Traders, 2019). The only surprises here would be the relative obscurity of Honda and the relatively high participation rate of the German automakers.

Table 4: Largest motor vehicle manufacturers

| Country | Company | Vehicles manufactured 2016 | Vehicles Manufactured 2017 |
|---|---|---|---|
| Japan | Toyota | 10.213.486 | 10.466.051 |
| Germany | Volkswagen | 10.126.281 | 10.382.334 |
| South Korea | Hyundai | 7.889.538 | 7.218.391 |
| United States | General Motors | 6.971.710 | 6.856.880 |
| United States | Ford | 6.457.773 | 6.386.818 |
| Japan | Nissan | 5.556.241 | 5.769.277 |
| Japan | Honda | 4.999.266 | 5.236.842 |
| Italy | Fiat | 4.681.457 | 4.600.847 |
| France | Renault | 3.373.278 | 4.153.589 |
| France | PSA | 3.152.787 | 3.649.742 |
| Japan | Suzuki | 2.945.295 | 3.302.336 |
| China | SAIC | 2.564.786 | 2.866.913 |
| Germany | Daimler | 2.526.450 | 2.549.142 |
| Germany | BMW | 2.359.756 | 2.505.741 |
| China | Geely | 1.266.456 | 1.950.382 |

Source: International Organization of Motor Vehicle Manufacturers, 2017.

Table : Country background motor vehicle (parts) manufacturers (excl. retailers and maintenance).

| Country | Registered Entities | Percentage |
|---|---|---|
| Germany | 26 | 28.26 |
| Japan | 15 | 16.30 |
| South Korea | 10 | 10.87 |
| Austria | 8 | 8.70 |
| France | 7 | 7.61 |
| Belgium | 4 | 4.35 |
| United Kingdom | 4 | 4.35 |
| Italy | 3 | 3.26 |
| Netherlands | 2 | 2.17 |
| Poland | 2 | 2.17 |
| Portugal | 2 | 2.17 |
| Spain | 2 | 2.17 |
| Sweden | 2 | 2.17 |
| United States | 2 | 2.17 |
| Czech Republic | 1 | 1.09 |
| Hungary | 1 | 1.09 |
| India | 1 | 1.09 |

Source: Author.

15 The question then becomes what the explanation is for these differences. The economic arguments put forward by Toyota's Head of Fuel Cell System Development, Prof Katsuhiko Hirose, are instructive (Schmitt, 2019). They amount to a belief in the economic advantages of FCV over BEV technology, such as the large weight difference between batteries and fuel cells,[6] a very large cost advantage of fuel cells compared to batteries and battery production (mostly because of much lower raw resource costs), and more room for economies of scale. Toyota doubts the long-term success of BEVs because of the physical limitations in further improving batteries to become lighter and capable of supporting much longer ranges: Toyota had not produced a pure BEV until it began investing more in BEVs, which was only in recent years (Harding & Inagaki, 2017). On top of this, Toyota's large investment and long-standing commitment to FCVs creates a certain technological path dependency.

16 These concerns about range and refuelling time are more pressing for heavy-duty lorries and buses. As noted, many analysts (IEA, 2019c; Kast et al., 2017; Lambert, 2020) estimate that FCVs will become competitive, especially in heavier vehicles designed to have longer ranges. Refuelling infrastructure is the biggest constraint to achieving this competitiveness in road transport, which is again easier dealt with by commercial fleets. The substantial portion of heavy motor vehicle manufacturers that support hydrogen coalitions appears to confirm these hypotheses.

17 The main counterarguments that explain why other manufacturers remain on the fence are lower energy efficiencies of FCVs (in the range of 50% [BMW, 2020)]), the currently still high costs and particularly the lack of infrastructure. Infrastructure remains virtually absent in Europe with only several dozen[7] HRSs across the entire EU as of 1 January 2019. This compares to over 140,000 electric charging stations (European Automobile Manufacturers' Association, 2019). There are plans to change this, for instance by building 750 HRSs before 2025, and there is a roadmap for over 3,500 stations by 2030 (FCH JU, 2019b). The estimated infrastructural needs per 1 million FCVs (approx. 400 HRSs) are far lower than for 1 million BEVs, which would need a million private charging stations and up to 10,000 fast-charging stations (IEA, 2019c, p. 133).

18 In contrast, by November 2019 Volkswagen (2019) had officially stated that the debate between FCVs and BEVs was "a clear case" and that despite ongoing research the company was officially focusing on BEVs for the masses. The concerns noted earlier were named as a motivation, with a focus on BEVs' higher energy efficiency, and Volkswagen's view that hydrogen is better suited to stationary settings than cars (Volkswagen AG, 2019). Renault (2020), the PSA Group (2019), BMW (2020) and Daimler (n.d.) see slightly more merit in the future of hydrogen and have more developed plans for releasing hydrogen-powered models onto the market. Manufacturers must judge the viability of a hydrogen future vision compared to one for electric mobility and they are doing so differently. This is the key reason behind the different policies between for instance Volkswagen and Ford on the one hand, and Toyota and Hyundai on the other.

## FOOTNOTES

**1.** This only includes entities registered under NACE section C: Manufacturing.

**2.** In a consortium called HYBRIT with mining company LKAB and Vattenfall.

**3.** Air Liquide, Air Products and Chemicals, BASF, Linde and Taiyo Nippon Sanso Corporation (Technavio, 2019).

**4.** Additionally, both Volvo and Daimler appear primarily interested in hydrogen for heavy vehicles.

**5.** It is possible to argue that PSA-subsidiary Opel's membership of Hidrogeno Aragon changes this.

**6.** Hirose exemplifies this by stating that a battery-electric truck of 40 tonnes with a 500km range needs 8 tonnes of battery: "you want to transport goods, not a huge battery. A fuel cell stack is much lighter and easier to handle (Schmitt, 2019)."

**7.** There are some different figures on the number of currently available HRSs, the European Automobile Manufacturers' Association (2019) names 47, the Fuel Cells and Hydrogen Joint Undertaking (2019b) names 120 and the IEA (2019c, p. 128) names approximately 170.

# Chapter 9: Professional, Scientific & Technical Activities

1 The professional, scientific and technical activities section is the second largest in terms of the number of registered entities (N=499, 29.88%). It is very diverse and contains companies ranging from independent individual energy consultants to large multinational engineering companies. Many corporate headquarters of multinationals active in different sections were registered in this section as activities of head offices before manual corrections were made. Architectural and engineering activities make up over half the registrations in the section (N=260, 52.10%), with most of the remainder consisting of scientific research and development (N=113, 22.65%), the activities of head offices and management consultancy (N=68, 13.63%) and other professional, scientific and technical activities (N=35, 7.01%).

2 As this section's business classifications are diffuse and overlap within the section and with others, it is treated as one. Consulting and engineering bureaus can, for instance, be found in each of the different classifications. Companies doing engineering activities overlap with companies operating in the construction section (N=50, 2.99% of total), and activities of head offices with the section of administrative activities (N=28, 1.68% of total). With these, the number of companies in a combined section would increase further (N=577, 34.55%).

3 The average size of companies varies greatly but consists predominantly of SMEs. Companies are generally less internationally active than in other sections, although there are still some, especially larger organisations, that are active in multiple associations. Some publicly-listed fuel cell producers also fall into this group, such as McPhy (8 registrations), Proton Motor Fuel Cell (8), Ceres Power (2), and Powercell (2). Other important categories are large (energy) engineering firms such as Abengoa (4) and the Arup Group (2), and institutions for testing, inspection and certification such as TÜV (8), Kiwa (4), and DNV GL (3). Further of note are Areva H2Gen and Areva Stockage d'Énergie, both subsidiaries of Électricité de France, and taken together active in ten associations.

4 The section, including construction, often appears as (sub)contractor in hydrogen projects across Europe. Fuel cell producers and smaller size hydrogen specialists can be

contracted to cooperate in building electrolysers or fuel cell systems, with the funding coming mostly from other parties. One example of this is McPhy, which despite its relatively modest revenue – €11.9 million in 2019 (McPhy, 2020) – is still involved in numerous projects across Europe. The professional, scientific and technical activities section is interesting in the hydrogen coalition exactly because it represents a relatively broad (economic) support base for hydrogen beyond high-profile multinationals. The combination of small engineering bureaus with fuel cell start-ups, consultancy bureaus, and certification companies, makes participation from the section worthy of note.

Figure 7: Pie chart for professional, scientific and technical activities.

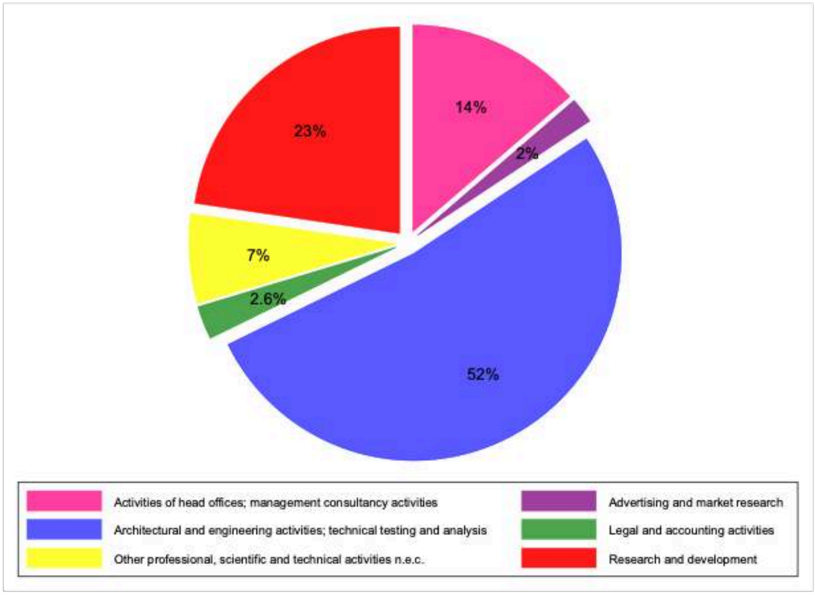
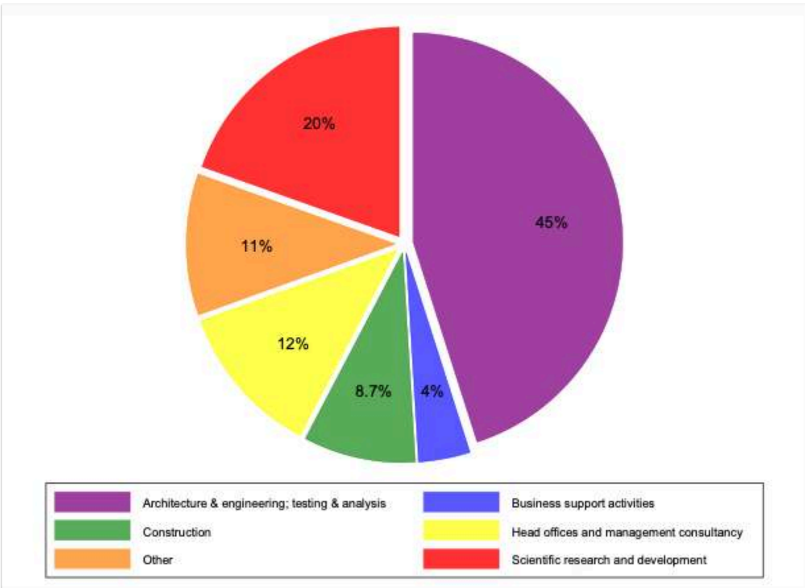



Figure 8: Pie chart for professional, scientific and technical activities; construction; administrative and support activities.



5 The motivation for most companies in this sector to support the hydrogen transition is straightforward: business and market growth. The start-ups based around hydrogen and fuel cell technology stand to benefit from the take-off of a (green) hydrogen market, and the success of the transition is very closely tied to their success as a business. Contrary to many more diversified multinationals or sectors (e.g. chemicals, energy, automotive), many companies in this section are small and have hydrogen technology as a primary business activity. This is also reflected in the stock performance of several fuel cell producers, which has profited a lot from the renewed momentum and interest in hydrogen (Sanderson, 2020).

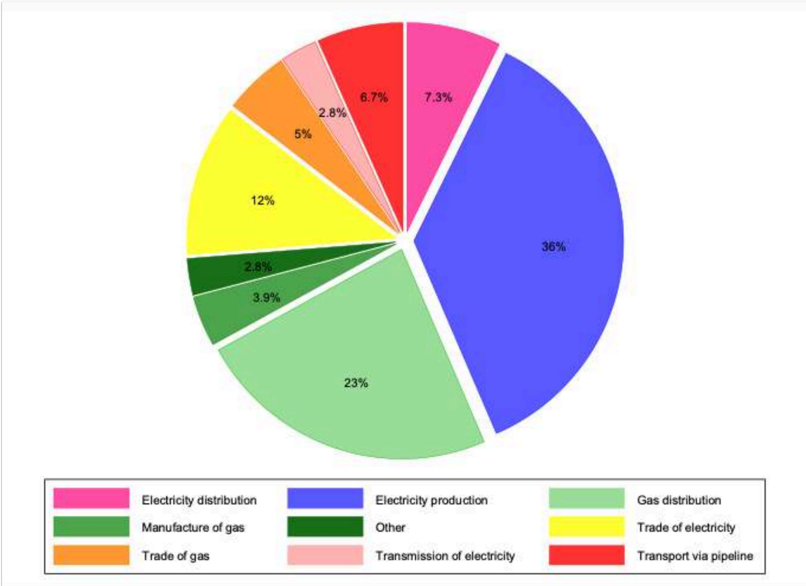
6 A similar business expansion motivation exists for other companies in this section, such as those working in testing and consultancy, and those in adjacent sections (i.e. construction, and administrative support). To take Kiwa (n.d.-b, n.d.-a) as an example, its expertise in education about hydrogen handling, safety procedures, certification, and related knowledge-based support tasks provides a potential future market at various points in the value chain. There are many engineering complexities and technical challenges that come with the hydrogen transition. Professional support services, engineers and construction companies with experience in this field that enables them to solve these challenges will likely benefit from market growth.

# Chapter 10: Electricity and Gas

1 The electricity and gas section is the third-largest section, albeit considerably smaller in number than the previous two sections (N=179, 10.72%).[1] However, because of the market structure of utilities, they tend to be very large companies, often with local, regional or national monopolies on electricity and gas production, transmission and/or distribution. The separation between electricity and gas companies in the utility market is often artificial, as many large companies are involved in both and are only registered under one primary activity. Engie (trade of gas through mains), EDP – Energias de Portugal (production of electricity), Vattenfall (trade of electricity), and Iberdrola (distribution of electricity) are examples of this. In the context of the hydrogen transition, the sector's participation can mostly be divided between gas and electricity interests.

2 This section includes companies that transport natural gas via pipeline. Natural gas transmission operators are categorised as "distribution/trade of gas through mains", or as transport via pipeline under the economic section of transport and storage. This adds another group of companies, including GRTgaz, Teréga, Gasunie, and Northern Gas Networks.

Figure 9: Pie chart for electricity and gas




## 10.1 Natural Gas

3 Companies involved in the natural gas industry[2] constitute slightly less than half of the entities in this section (N=70, 39.11%). Many of the companies have regional or national monopolies on gas transmission, such as Snam in Italy, Fluxys in Belgium, the Public Gas Corporation of Greece (DEPA) in Greece, GAZ-System in Poland, GRTgaz, Engie, and Teréga in France, Enagás in Spain, ONTRAS Gastransport, Open Grid Europe, and Thyssengas in Germany, Gasunie in the Netherlands, Ervia in Ireland, Ørsted in Denmark, and SGN and Northern Gas Networks in the UK. In Austria and Germany, several local operators are included, such as those in Essen, Schwaben, Vienna, and others.

4 Several operators are experimenting with power-to-gas, usually in the form of demonstration projects (see e.g. Wulf et al., 2018). Operators (e.g. GRTgaz, GAZ-System, Snam, Gasunie, Enagás) are also experimenting with blending hydrogen into the natural gas system. Europe's biggest pipeline operator, Italy-based Snam, invested €1.4 billion in its SnamTec division (approx. 20% of total investment), publicly connecting this to the development of hydrogen projects (Reuters, 2019; Snam, 2019a).[3] It is explicitly thinking about using existing gas infrastructure linking Italy with North Africa, where hydrogen can be produced for a much lower cost because of the potential abundance of solar-based renewable energy (McKinsey & Company, 2019; Snam, 2019b; van Wijk & Wouters, 2020).

5 Dutch gas operator Gasunie (2020a) has also expressed interest in ambitious hydrogen projects and is very explicit about its high expectations for hydrogen in Belgium, Germany and the Netherlands. It is part of a consortium[4] exploring a €500 million investment in a hydrogen value chain surrounding the Magnum power station near Groningen (Gasunie, 2020a) and is also part of a consortium[5] backing H-vision, a €2 billion blue hydrogen project to kickstart the hydrogen economy in Rotterdam (H-vision, 2019). The investment decision is pending, with the earliest expectation of a decision being 2021 (Port of Rotterdam, 2019). In early 2020 Gasunie announced its

most ambitious project to date with Royal Dutch Shell and Groningen Seaports. This concerns the NortH$_2$ plan (mentioned in the introduction), with a price tag of tens of billions of euros. It envisions a 10 GW offshore wind park with Europe's largest green hydrogen factory, which should start operations in 2027 (Gasunie, 2020a, 2020b; Van Dijk, 2020). Notwithstanding the announcement of these plans, the funding for them has not been secured, leaving their future in doubt (Financieel Dagblad, 2020; Van Dijk, 2020). The project would fall within the wider development strategy for a hydrogen cluster in the northeast of the Netherlands, for which allocated private investment until 2030 amounts to €2.8 billion (Samenwerkingsverband Noord-Nederland, 2019).

6 There are various motivations for natural gas companies to support hydrogen. Several business risks are a key factor: they include estimates of decreasing demand for natural gas in the long-term, increasingly regulated $CO_2$ emissions, and insufficiently diversified business models. More positive incentives are the prospect of new business and increasing the security of supply. Enagás (2019, p. 88) in its Anual Report marks the reduction in natural gas demand as a highly likely and impactful development. Gasunie (2020a, pp. 105; 143) and Fluxys Belgium (2018, p. 133) similarly expect lower demand for gas transport capacity, and the former mentions the partial or complete ending of using gas transport networks before 2070 as a potential risk. These downward trend estimates on the long-term future of natural gas in Europe are broadly in line with other research (e.g. see CătuȚi et al., 2019; IEA, 2019b, p. 180; Navigant, 2019, p. 78). Hydrogen would be one way in which gas infrastructure could remain in use and profitable despite decreasing demand for natural gas.

7 The increasing regulations on $CO_2$ emissions and/or carbon pricing are another factor, as in other sectors. This affects finances directly, for instance in the case of higher operating costs because of $CO_2$ emissions (Enagás, 2019, p. 88), but also indirectly through a wider societal-economic push for decarbonisation. This push reaches natural gas utilities via several layers of government (i.e. UN SDGs, European carbon reduction targets, national and local legislation), and also from direct societal pressure. Binding climate regulations have an impact on practically all companies involved in the natural gas industry (Enagás, 2019, p. 16; Ervia, 2018, p. 31; Fluxys Belgium, 2018, p. 133; Gasunie, 2020a, p. 143; SGN, 2020, p. 16; VNG, 2019, p. 50). On top of the binding nature of national and international legislation, many companies also frame emission reductions in a climate-conscious context. Hydrogen, together with other green gases (such as renewable biomethane) is a way to realise a zero-carbon energy system while retaining a profitable gas market.

8 Hydrogen or other green gases can also create new business opportunities. Snam (2019b), Gasunie (2020a, p. 48) and Enagás (2019, p. 18) all list hydrogen as a strategic business opportunity, Ørsted (2020, p. 25) names the potential of renewable hydrogen for new applications, and Engie (2018, p. 6) states that it is convinced hydrogen will be called upon in the energy transition. These positive incentives are more numerous than simple business growth. The transport of hydrogen (and other green gases, CCS and/or heat) is an opportunity for gas companies to diversify beyond the sale of natural gas, as Gasunie (2020a, p. 105) and VNG ONTRAS (2019, p. 47) note. Diversification to include hydrogen gas means creating more independent revenue streams, but it also provides for more security of energy supply. This is an opportunity given Europe's strained relationship with Russia, but also given the volatility of renewable energy generation.

## 10.2 Electricity

9 Virtually all the remaining companies in this section are active in the electricity sector (N=106, 59.22%). It includes some of the largest companies in several countries, with examples being Vattenfall, EDP – Energias de Portugal, EDF – Électricité de France, Iberdrola, Innogy, Statkraft, Endesa, SSE, and PGE – Polska Grupa Energetyczna. This picture is further complicated by the many ties between some of the companies, with for instance Scottish Power and Endesa falling under Iberdrola and Enel (unregistered) respectively. Moreover, some of the largest European companies in this sector, such as Enel, are absent from hydrogen associations. As with natural gas, there are many different companies and few have a particularly big pan-European presence in different hydrogen associations, with possible exceptions being Vattenfall (5), PitPoint (4), and Innogy Renewables (3). Willingness from the electricity sector to take part in the hydrogen transition is important, as the availability of enough (renewable) electricity will be a decisive factor in the future of green hydrogen.

10 Despite the higher number of registered entities in the electricity sector than in the natural gas sector, the electricity sector does not seem to be as invested in the promotion of the hydrogen transition. This runs counter to the IEA's (2019c, p. 19) conclusions about the hydrogen coalition consisting of renewable electricity suppliers as well as electricity (and gas) utilities. For most large electricity companies, hydrogen appears to be a technology with potential that needs to be further researched – but not a noteworthy component of the current business strategy. In annual reports from E.ON (2020), EDF (2020), EDP – Energias de Portugal (2018, 2019),[6] Enel (2020), Innogy (2019), Vattenfall (2019a), Statkraft (2019), Iberdrola (2020), Endesa (2018b, 2018a) and PGE Polska Grupa Energetyczna (2018) there is no or very limited attention to hydrogen. Verbund (2020) is one of the very few that devote serious attention to green hydrogen, complemented by Vattenfall (2019a, p. 2) stating the concrete goal of 100 MW in green hydrogen by 2025. Fortum (2018) and Vattenfall (2018, 2019b) have hydrogen position papers but mostly focus on the necessary EU-policies to kickstart the transition. There do not appear to be concrete investment agendas for hydrogen, and hydrogen mostly remains something for R&D departments as reflected in EDF (2020, p. 98), Fortum (2019a, p. 5), and Statkraft reports (2019, p. 25), and implied by Iberdrola (2019, p. 381) calling it an immature technology.[7]

11 The average scale of these projects also does not (yet) imply a high will to invest. An example is Vattenfall's concrete target of 100 MW green hydrogen. Half of this will come from the 50 MW HySynGas project in northern Germany, which mostly relies on funding from the German Federal Ministry for Economy and Energy (ARGE Netz et al., 2019). The HYBRIT (n.d.) project on decarbonising steel is a public-private partnership, with the Swedish government funding 35% of the 1.4 billion SEK (€130 million) total investment.[8] The planned Wind2HyRail-project relied on European funding, and fell through at the request of the consortium (FCH JU, 2019c), and the SEK 6 million (€550,000) planning phase for an 18 MW hydrogen gas plant in Gothenburg with Preem has been 50% financed by the Swedish Energy Agency (Vattenfall & Preem, 2018). An investment decision on the large H2M-project in Eemshaven (the Netherlands) with Gasunie and Equinor is still pending. These are all relatively small sums in the context of Vattenfall's (n.d.) 2020 and 2021 total investments of SEK 58 billion (€5.3 billion).

12 Electricity producers were expected to be motivated to support hydrogen on the basis of hydrogen being seen as a versatile technology that can help stabilise the volatility that comes with high levels of renewable-based electricity production (IEA, 2019b, p. 588). Approximately 3,600 terawatt-hours (TWh) of electricity is needed to increase the share of hydrogen produced through electrolysis from 2% to 100%, which is more than the EU produces annually (IEA, 2019c). Navigant (2019, p. 21) estimates green hydrogen produced from excess electricity production in the EU to reach 19 billion cubic metres of natural gas equivalent by 2050. For electricity producers, this would thus be a promising technology to ensure that surplus capacity can be absorbed, and dispatchability remains high.

13 These incentives to solve the long-term challenges of seasonal and short-term intermittency are still accepted by electricity producers (e.g. EDF, 2020, p. 98; EDP - Energias de Portugal, 2018, p. 39, 2019, p. 36). Yet, potential problems resulting from renewables' lack of dispatchability appear to be challenges of the second order: for the moment investment in renewables precedes investment in the way they are integrated into the market. Several companies with considerable renewable portfolios have enough renewable facilities and geographic spread to mitigate the dispatchability risks from a business risk perspective (Enel, 2020, p. 64; Iberdrola, 2020, p. 84; Statkraft, 2019, p. 12). Others are based in areas where hydropower can already provide enough flexibility to accommodate intermittent renewables, as is (or would be) the case in the Alpine region, the Balkans, the Nordics, and to a lesser extent the Iberian Peninsula. In some cases, (intermittent) renewables remain a negligible share of total electricity generation as other options are set to remain dominant for the time being, as is the case in Poland (coal) and France (nuclear). Even where intermittent renewables' dispatchability is acknowledged as a serious business risk, such as by Innogy (2019, p. 100) in Germany or EDP – Energias de Portugal (2019, p. 36), hydrogen is simply not really considered as a solution in the power sector – and is not once named in annual reports.

14 Whereas electricity producers remain on the fence about the potential of hydrogen in the power sector, they see more use for green hydrogen in decarbonising industrial feedstocks. Verbund (2020, pp. 95–96), Vattenfall (2019a, pp. 55; 64), Fortum (2019b, p. 25) and Ørsted (2020, p. 5) are particularly explicit in this. For Verbund and Vattenfall, this practice of "sector coupling" is especially developed in combination with the steel industry, as noted earlier on the projects involving Voestalpine in Austria and HYBRIT in Sweden. It appears likely that other electricity producers will also (proactively) partake in similar projects that aim to decarbonise heavy industries through green hydrogen.

15 As in other sectors, pressure from governments and the increasingly strict climate regulations seem to be key motivations for electricity producers that do explicitly consider hydrogen. The involvement of Verbund (2020, pp. 95–96) is closely linked to Austria's climate target of 100% renewable electricity by 2030. Vattenfall (2019a, p. 28) links its hydrogen projects in the Netherlands to the Dutch Climate Act and Climate Agreement. Fortum (2019b, p. 25), too, links the development of hydrogen closely to mitigating business risk scenarios based on big climate risks and heavy government interventions. More regulations, such as through more ambitious climate policies in the EU or Russia, create bigger business risks. In this scenario green hydrogen is also mostly used to decarbonise hard-to-abate sectors. Still, for many large electricity

companies with similar obligations, hydrogen remains a niche technology, albeit with potential and worthy of further research.

## FOOTNOTES

**1.** This includes the entities registered under NACE section D: Electricity, gas, steam and air conditioning supply; as well as NACE H49.5(.0): transport via pipeline.

**2.** Distribution of gaseous fuels through mains; manufacture of gas; trade of gas through mains; transport via pipeline.

**3.** It is not clear how much of this will actually be invested in hydrogen projects; a large proportion of this money is also meant for other environmental sustainability projects and efficiency gains (Snam, 2019c).

**4.** Consisting of Equinor, Gasunie and Vattenfall.

**5.** Consisting of Air Liquide, BP, Deltalinqs, EBN, Engie, Equinor, GasTerra, Gasunie, Linde, OCI Nitrogen, the Port of Rotterdam, Royal Dutch Shell, TAQA, TNO, Uniper and Royal Vopak.

**6.** There is no mention of hydrogen in EDP's 2018 and 2019 annual reports, , each over 400 pages in length.

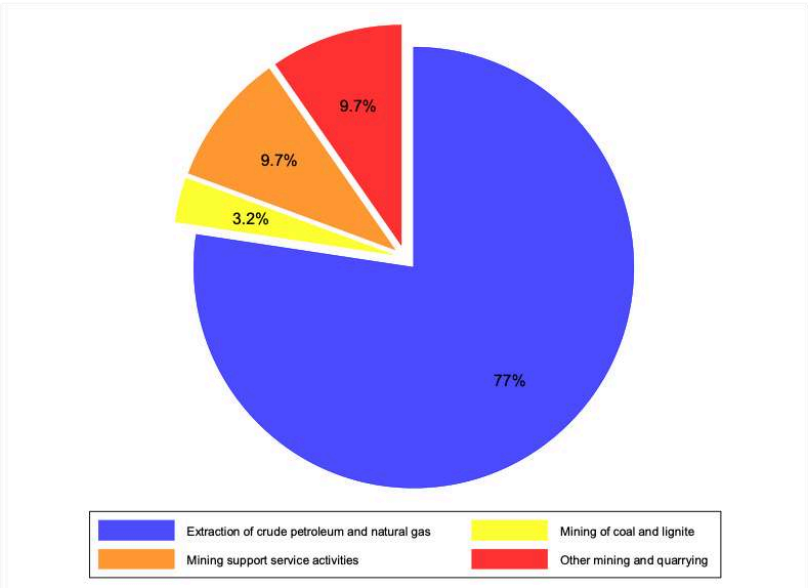
**7.** Which is the only time hydrogen is mentioned in its 510 page 2019 Sustainability Report.

**8.** The other 65% is split equally between a consortium: LKAB, SSAB, and Vattenfall.

# Chapter 11: Mining and Quarrying

1 The mining and quarrying section has very few registrations (N=31, 1.86%).[1] Yet, the support of large integrated oil and gas companies, as well as refineries,[2] draws a lot of attention (Balat & Balat, 2009; Meadowcroft & Langhelle, 2009; Royal Dutch Shell & Wuppertal Institut, 2017). Before focusing on the oil and gas sector, which constitutes over 75% of this section's hydrogen association members, it should be noted that several mining companies are present, including JastrzĘbska Spółka WĘglowa (JSW) and Anglo American. This is in line with previous predictions of the coal industry coming out in favour of (blue) hydrogen (see e.g. Victor et al., 2003; Winter, 2005). Although JSW is an influential company in Poland, it is a relatively isolated example. So far, the coal industry (and clean coal technologies) appears to be a relatively insignificant component of the momentum for hydrogen in Europe. This is slightly at odds with previous expectations from the literature.

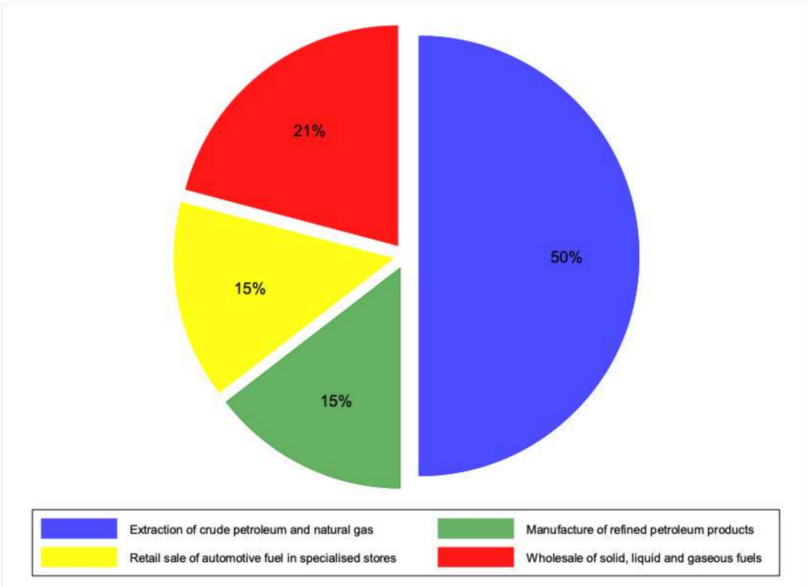
Figure 10: Pie chart for mining and quarrying



## 11.1. Oil and Gas Industry

2 Three-quarters of the mining and quarrying section consists of companies involved in the extraction of crude petroleum and natural gas. The focus on extraction is, however, artificial. The large oil and gas companies are particularly present throughout the entire value chain. For this reason, these paragraphs include several other business activities along the oil value chain: mining support activities, manufacturing of refined petroleum, the retail sale of automotive fuel, and the wholesale of solid, liquid and gaseous fuels.[3] With all these included, the sector becomes bigger than the overarching section of mining and quarrying (N=48).

Figure 11: Pie chart for oil and gas industry




3 A primary reason why this sector matters is that on top of a few relatively local tank station companies, the majority are very large multinationals. Examples include Total, Kuwait Petroleum International, Shell, Equinor, Lotos, Polskie PGNiG, Galp, Repsol, BP, Petrofac, Baker Hughes and OMV. These are some of the largest companies in Europe. Three out of the four largest European companies by revenue in 2019 (Fortune, 2019) fall into this category and are members of several hydrogen associations: Shell (6), BP (3) and Total (3). It includes the largest companies by revenue of Austria, France, the Netherlands, the UK, and Norway; and among the three largest of Poland, Spain and Portugal – with Italy's largest company (Eni) absent from hydrogen association lists but still explicitly supportive (Eni, 2019).

4 A second reason why their support is important is because refineries are one of the largest consumers of hydrogen, responsible for roughly a third of global hydrogen consumption (IEA, 2019c, p. 91). This gives them natural clout with regard to hydrogen. Hydrogen is responsible for roughly 20% of refineries' $CO_2$ emissions (IEA, 2019c, p. 91). This means that companies in this sector can use blue and green hydrogen to decarbonise a globally significant chunk of their emissions and are also crucial in the decarbonisation of other sectors.

5 Third, there seems to be serious interest in hydrogen beyond mere membership of coalitions. BP, Equinor, Shell and Total are all steering members who took part in the launching of the global Hydrogen Council. In annual and sustainability reports of these same four (BP, 2020b, 2020a; Equinor, 2020a, 2020b; Shell, 2020b, 2020a; Total, 2019, 2020) hydrogen is given considerable attention – more than from the large electricity companies, for instance. There appears to be a consensus about the role that hydrogen can play in the future energy system, although Shell, Repsol (2019), OMV (2020b, p. 76) and BP appear to be much more open to green hydrogen while Equinor emphasises blue hydrogen and CCS technologies.

6 However, the extent to which this translates into concrete investment is dubious. On the one hand, there is clearly some willingness to invest. In the mid-2000s, BP already put forward a serious proposal for a 350 MW blue hydrogen plant with a $1 billion price tag, which ultimately only fell through because of government delays (Macalister, 2007; Meadowcroft & Langhelle, 2009, p. 170). European oil companies have increasingly been "racing" to invest in clean energy, with notably Total and Shell taking steps (Abington & Gilblom, 2019). BP built a green hydrogen plant for its refinery in Lingen in 2018 and is exploring the possibility of a 250 MW green hydrogen plant in Rotterdam[4] (BP, 2019; IEA, 2019c, p. 97). Shell is partnering with Gasunie and Groningen Seaports in the North$H_2$ project mentioned before, besides smaller projects such as the 10 MW REFHYNE green hydrogen project for its Rheinland refinery (Shell, 2020b, p. 53). There is clear engagement in expanding the European HRS network, with the $400 million H2 MOBILITY scheme in Germany seemingly the most ambitious and developed plan in Europe.[5] OMV, Shell and Total are partners of this programme, [6]which is on course to deliver 100 HRSs in 2020 and aims to deliver 300 more by 2023 (H2 MOBILITY, 2020; Iwan, 2017).

7 On the other hand, many of these projects are mostly based on public money, and investments in hydrogen are negligible relative to total investments. The REFHYNE project highlighted by Shell is funded by the European Commission (IN4Climate.NRW, 2019; REFHYNE, 2018). Refilling stations in the UK, the Netherlands and Germany, for instance, are labelled successes, but are all predominantly financed through multi-million GBP/EUR subsidies either from national governments or mixed with European funding (Adelski, 2019; Shell, 2018b, 2018c; Thomas, 2018). The H2 MOBILITY project is also an example of this, as it is funded by the German Federal Ministry of Transport and Digital Infrastructure and several EU-level subsidies (H2 MOBILITY, 2020).

8 This has some wider implications, as it is not for a lack of own investment resources that the sector is waiting. Capital investments for 2019 alone were $28+ billion for Shell (2020a, p. 40), $15+ billion for BP (2020a, p. 113), $17+ billion net for Total (2020, p. 74) and $5+ billion for OMV (2020a, p. 63). In comparison, initial investments in electrolysers or CCS systems to produce hydrogen used in refineries are relatively small. The same goes for HRSs. OMV (2020b, p. 67) invested €1 million (0.02% of total investments) in future mobility assets. Even the very ambitious $400 million H2 MOBILITY project would be (much) less than 1% of the combined total investment of the companies listed above. Yet, the sector seems to depend on public investment to realise projects worth less than $15 million to begin creating the hydrogen market which they say is central to their own future. This is a different situation to that of automakers such as Toyota and Hyundai, where investments have seemingly been more aligned with strategic statements about the future of hydrogen.

9 There is also another factor at play in these investment decisions when it comes to building HRSs specifically: the absence of first-mover advantages. While the hydrogen market is still immature, HRSs are uncompetitive and a net cost for owners due to a lack of business. Moreover, when the market becomes competitive, the ease of building HRSs will mean existing HRSs will quickly be exposed to competition, further challenging their profitability. At the same time, early adopters may end up paying both higher construction costs due to lacking economies of scale, as well as risking the necessity that they need to pay extra for adapting HRSs to evolving regulations. Notwithstanding the legitimate profitability concerns of being the first to deploy HRSs on a large scale, the oil sector also shows little concrete willingness to change this status quo. It seems evident that while the oil sector may be serious about the long-term potential of hydrogen, it doesn't appear serious enough to put (relatively speaking) significant investment into its deployment, especially when there are no direct short-term returns.

10 A key motivation for large oil and gas companies to consider investing in (green) hydrogen to begin with is the sustainability of their business model during and after the energy transition. The increasingly narrow time frames for this transition are bad for the perceived viability of their business models. Shell is a good example of this. Its Sustainability Report (2020b), Energy Transition Report (2018a), and its Annual Report (2020a) tell the story of a company under increasing pressure from shareholders to make an investment case as a company that can remain profitable in the medium to long term when its core business (i.e. oil and gas) is expected to decline. Both BP and Shell have been and remain at the receiving end of activist shareholders who question this on environmental and business grounds. Large institutional shareholders such as the Church of England and major pension funds are part of a growing list of critical investors that influenced Shell to sharpen its climate targets (Burton, 2020; Vaughan, 2017, 2018a, 2018b). This also affects the ability of the sector to recruit young talent and attract consumers. Its three corporate sustainability pillars of responsible business, a sustainable energy future, and contributing to society can also be understood through this lens. Hydrogen is a way for the sector to attempt to clean up its image for the wider public and potential employees, and to present a viable long-term business model to investors. The energy giants either embrace alternative energies such as hydrogen or face long-term decline.

11 For refineries (both independent and as part of integrated companies), increasing carbon prices and pressure to decrease emissions are motivations to search for lower-carbon solutions for their use of hydrogen as feedstock. This is amplified by developments in the fuel sector that demand lower sulphur contents, which in turn require still more hydrogen input (IEA, 2019c, p. 96). The profit margins of refineries are already tight, and higher emissions prices carry business risks in the longer term. Relatively low-cost investments in CCS would lead to large emissions reductions and take away a large chunk of this risk. The installation of electrolysers and the provision of green hydrogen would eliminate these specific emissions costs.

12 Blue hydrogen in particular has some other major business benefits for oil companies (Equinor, 2020a, p. 48, 2020b, p. 27; IEA, 2019c, p. 96; Meadowcroft & Langhelle, 2009). As described in the literature overview, there is a 'double dividend' of being able to sell foregone emissions rights in combination with getting captured $CO_2$ that can be used for EOR. This ignores an obvious 'third dividend': oil and gas companies also retain a

market for their fossil fuel products (and related capital assets) with widespread deployment of CCS. In general, hydrogen would allow the creation of business along a completely new value chain (Equinor, 2020a, p. 48). This is a welcome perspective for oil companies facing calls for further diversification and questions about their long-term profitability.

13 The tank stations at the end of the value chain for fuels also see the potential of hydrogen. The rise of BEVs might mean that many customers will charge their vehicles at home rather than fuel them at tank stations. This threatens the viability of the current business model of tank stations. In a purely electric driving world, there is little use for tank stations. Fast-charging stations can be placed anywhere, and the infrastructural need for handling gasoline (including safety and quality control regulations) that justified specialised tank stations as a concept will be gone. The transition to hydrogen would create a situation where tank stations largely retain their current function and business model.

14 All the above incentives raise the question of why the oil and gas sector has remained so hesitant to put significant investments into hydrogen. One factor, already proposed as a possible barrier by the IEA (2019c, p. 96) and confirmed by BP, is the absence of real carbon pricing. The regulatory pressure on emissions as felt by, for instance, the chemical industry and the steel industry seems to be less acute in threatening the profit margins of the oil sector: BP (2020b, p. 27) states that "robust policies, including carbon pricing, will be required to incentivise the investment required to exponentially grow the use of hydrogen." OMV (2020a, p. 29) states that the legal environment is not there to support CCS in various countries, including in Austria, particularly considering storage. Equinor (2020b, p. 28) equally expects a big role for the government in triggering further investments in hydrogen. It appears that without public guarantees and direct public involvement, there is relatively little actual investment in hydrogen from the oil sector. This remains the case even though there is a clear business interest for the sector to engage directly in hydrogen to secure their long-term survival.

## FOOTNOTES

1. This number involves companies registered under NACE section B: Mining and quarrying.
2. Refineries do not fall under this economic section, but under NACE C19: Manufacture of coke and refined petroleum products. More on this in subsequent paragraphs.
3. These are the NACE divisions/groups/classes C19: Manufacture of coke and refined petroleum products, G46.7.1: Wholesale of solid, liquid and gaseous fuels and related products, and G47.3: Retail sale of automotive fuel in specialised stores. These are mostly refineries and tank stations. From G46.7.1 and G47.3 H2point, Green Planet Pesse, FaktorPlus Green Technology, and H2 Mobility Deutschland have been excluded, as they provide non-fossil fuels.
4. In a consortium with Nouryon and the Port of Rotterdam.
5. Itself member of two associations.
6. As well as Air Liquide, Daimler and Linde.

# Chapter 12: Transporting and Storage

1 The transporting and storage section has, like mining and quarrying, very few registered companies (N=59, 3.53%), but needs to be discussed because of the presence of key actors.[1] The main actors in the broader hydrogen coalitions here are in land transport (excl. pipelines), and the several major Benelux ports that fall under warehousing and support activities. It should be noted that some major airport companies, including London Heathrow Airport and Fraport (operating Frankfurt Airport among others), are also supportive of these coalitions. However, they mostly focus on decarbonising airport services (e.g. hydrogen airport buses), rather than a broader push for hydrogen in the aviation sector. This chapter discusses the motivations behind the support of land transport companies and the ports.

## 12.1 Land Transport

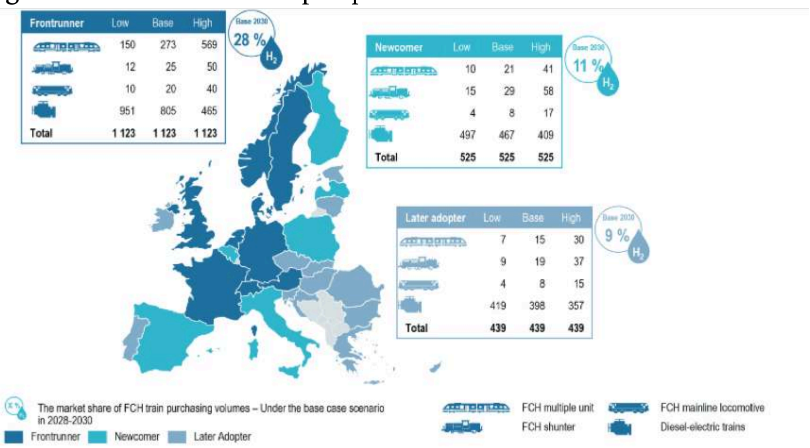
2 The companies registered under land transport (N=24, 51.06%) include interurban public transport heavyweights Deutsche Bahn, Transdev, RATP Group (which includes Paris' public transport), and SNCF (incl. subsidiary Keolis), as well as the national railway companies of Latvia (Latvijas DzelzceĻš) and Slovakia (Železničná spoločnosŤ Slovensko – ŽSSK). At the local level, it includes the public transport operators of Cologne, Gdansk, Gelsenkirchen, Lisbon, Riga, Tallinn, Wiesbaden, and Zaragoza. Generally, the difference is that the former focus on the operation of hydrogen trains, and the latter on hydrogen buses.

3 The motivation for local public transport operators to look for hydrogen mostly lies in the need to decarbonise bus transport. Transportation companies have looked to hydrogen as one way to do this, often supported by EU funding. The €16.1 million H2Nodes project began the operation of ten hydrogen trolley ("Hytrolley") buses in Riga and was also the opportunity to construct the first public HRS in Latvia (Rīgas satiksme, n.d., 2019). Reducing emissions from public transport is named as the motivation for the deployment of hydrogen buses in Gdansk (Orcholska, 2018), the 35 buses in Cologne as part of Projekt Null Emission (RVK, n.d.), and ten buses in Zaragoza

(J.H.P., 2019). This was also the case for previous projects, such as a project with hydrogen buses in Aberdeen.

4 The situation is a bit different for interurban transportation, which mostly concerns trains. One-fifth of traffic and 40% of the European mainline train network is still on diesel (IEA, 2019a). Given the very high costs of electrifying lower-intensity railroads, viable other fossil fuel alternatives are preferred to decarbonise them. Hydrogen rail ("hydrail") or Fuel Cell and Hydrogen (FCH) trains are being explored as an option to do this. French rail operators SNCF (2020, p. 8) and Keolis (2018, p. 9) are primarily motivated to explore hydrogen as an energy solution for the challenge of reducing the carbon intensity of the energy consumed. For Deutsche Bahn (2019, p. 121), the explanation for pursuing hydrogen solutions also lies in the environmental dimension of their regional business unit (which also includes buses), and the replacement of diesel there. FCH trains can already be price competitive in some regions (e.g. Scandinavia) for specific train types (FCH JU et al., 2019). The world's first FCH trains have been operating in Germany since 2018 (Deutsche Welle, 2018), France will start phasing them in by 2022 (SNCF, 2019), and similar projects are underway in Austria, Denmark, the Netherlands, Norway, Sweden and Switzerland (FCH JU et al., 2019).

Figure 13: FCH train market prospective




FCH JU et al., 2019, p. 14.

## 12.2 Ports & Warehousing

5 An additional small number of entities (N=13, 27.66%) form a cluster of independent Benelux ports that explicitly support the hydrogen coalition.[2] It includes the port authorities of Amsterdam, Antwerp, Bruges, Groningen, Rotterdam, and the North Sea Port that combines the ports of Terneuzen, Vlissingen and Ghent. It also includes storage companies Géométhane, Oiltanking and Royal Vopak in France, Germany and the Netherlands respectively. Various multibillion euro projects are being explored, with those in Groningen and Rotterdam at the most advanced stage. This goes beyond the decarbonisation of some direct port services with hydrogen, such as the introduction of hydrogen tugs in Antwerp.

6 The key reason for this (aside from emissions reductions) seems to be an acceptance of the changing role of the ports due to the energy transition. Europe's two largest ports

are examples of this. The ports of Antwerp and Rotterdam both function as key transport hubs connected to a dense and industrialised hinterland (incl. the Ruhr Area) and form the heart of the biggest cluster of heavy (petro)chemical industry in Europe. The share of fossil fuels in the energy mix is expected to decline in the long term, and the makeup of the feedstock of the industrial hinterland these ports serve will most likely change too. The ports need to anticipate these long-term changes to stay competitive, and this is one reason why they are actively looking into the deployment of hydrogen.

7 The decision to explore hydrogen as an option for these ports' futures is not very surprising. With 613 kilometres of dedicated hydrogen pipelines, Belgium already has by far the largest network in Europe (Port of Antwerp, n.d.). The Port of Antwerp is the central hub of this network, and multiple other ports (including Ghent, Bruges, Rotterdam, and Terneuzen) are directly connected to these hydrogen pipelines (Port of Rotterdam, 2016). Moreover, the Port of Antwerp already produces between 10-15% of all hydrogen manufactured in the EU, with other major production clusters (e.g. other Belgian clusters, Rotterdam, the Ruhr Area, Northern France) either directly connected or very close. This combines with the presence of various large wind fields, existing natural gas infrastructure (including LNG terminals), and large potential offshore storage sites to create opportunities for producing both blue and green hydrogen. Apart from the port infrastructure that facilitates the export and import of hydrogen by ship, the central position of the Benelux ports within Western Europe also allows access to a large market of potential hydrogen consumers.

Figure 14: Graph of hydrogen network in Belgium connecting Benelux ports


Port of Rotterdam, 2016, p. 39.

## FOOTNOTES

**1.** This includes all companies listed under NACE section H: Transporting and storage. Companies from H49.5: Transport via pipeline are excluded, as they were discussed in the chapter on electricity and gas.

**2.** They fall under H52: Warehousing and support activities for transportation.

# Chapter 13: Other Sections

1 So far, this paper has addressed over 80% of the entities that support the various hydrogen coalitions across Europe. Other sections, such as construction, administrative and support services, and parts of the wholesale and retail trade sector, have been addressed in previous chapters too. That still leaves approximately 12% unaddressed: this includes education (N=9, 0.54%), information and communication (N=18, 1.08%), real estate activities (N=6, 0.36%), water and waste management (N=21, 1.26%), wholesale and retail trade (excl. automotive fuel; N=75, 4.49%),[1] public administration and defence (N=14, 0.84%), financial and insurance activities (N=16, 0.96%) and other services activities (N=44, 2.63%). This does not mean that they play no role in the future of the hydrogen transition. In particular, the role of the financial sector, and membership organisations (under other service activities) deserves mentioning.

2 Only a very few entities working in the financial and insurance section are registered as members of hydrogen associations in Europe (N=16, 0.96%). This still includes some (very) large companies, such as Allianz, AXA and Bayern Landesbank, but most large financial and insurance companies remain absent. Nevertheless, this section will play an important role in enabling and pushing other sectors to invest in the hydrogen transition. Shareholder activism is an important motivation for large companies in carbon-intensive industries to move in the direction of hydrogen. Financial institutions as well as big investment funds can play a role in encouraging various industry leaders to put more emphasis on sustainability. Perhaps more importantly, the financial sector could be an important partner in generating the large investments needed for kickstarting the hydrogen economy. The support of investment funds for hydrogen projects could be an important catalyst for the realisation of its full potential.

3 Hydrogen also needs broad(er) societal support for it to succeed. Although not the focus of this paper, there are some membership organisations and environmentalist NGOs that are members of hydrogen associations (N=44, 2.63%).[2] Although some, such as the Bellona Foundation in Norway, also campaign in support of blue hydrogen, most, including Greenpeace for instance have put their faith specifically in green hydrogen. Most membership organisations, however, remain industry societies and regional economic fora or combinations thereof (e.g. Bayerischer Unternehmensverband Metall und Elektro or Energigass Norge). Although defining the precise level of support for the hydrogen transition from NGOs and environmentalist groups falls outside the scope of

this paper, their role in creating a broader base of public support for the hydrogen transition is undeniable.

---

## FOOTNOTES

**1.** Excluding G46.7.1: Wholesale of solid, liquid and gaseous fuels and related products, and G47.3: Retail sale of automotive fuel in specialised stores.

**2.** This includes entities classified under other personal service activities.

# Chapter 14: Conclusion

1 This paper has looked at 39 hydrogen associations across Europe to understand which economic sectors support the hydrogen transition in Europe, and why they do so. In direct response to the first part of the question, many sectors support the hydrogen transition. These include manufacturers of motor vehicles, chemicals, (electronic and electrical) machinery, electricity and gas companies, companies active in transport and storage (incl. ports), various oil and gas companies, as well companies engaged in professional, scientific, and technical activities. Particularly strong supporters are large natural gas utilities, large manufacturers of chemicals, lorry and bus makers, specifically Toyota and Hyundai from the motor vehicle manufacturers, and SMEs active in professional, scientific and technical activities as well as in manufacturing machinery and electronic or electrical equipment. Previous research on specific geographic clusters for hydrogen activity can largely be confirmed. The North Sea Region in particular is home to many major clusters, notably North Rhine-Westphalia in Germany, but also southern Scandinavia and Benelux. Another well-performing region is the Iberian Peninsula, notably Aragon. Eastern European countries, including Russia and Ukraine, are severely underrepresented, as are Italy and Greece.

2 Motivations for support differ. Sales and market growth are important for companies undertaking professional, scientific and technical activities, as well as manufacturers of chemicals, machinery and electronic or electrical equipment, and fabricated metals. The increasing cost of $CO_2$ through the ETS (particularly in 2018-19) combines with regulatory and societal pressure to decarbonise, and concerns from investors about the long-term profitability of sectors with high emissions. This makes hydrogen especially interesting for companies working in the energy, transport, steel and chemical industries. Another motivation is the ability to keep using existing facilities, relevant for ports, oil and gas companies, and natural gas utility companies. More sector-specific concerns are a technological belief held by some motor vehicle manufacturers in the advantages of FCVs over BEVs for private mobility, which is held more widely with regard to heavy road transport. Security of supply and diversifying the current business portfolio come up specifically for natural gas utility companies. Broader concerns about having to shift into other energy technologies as core business are reasons for interest from the oil and gas sector, and ports.

3 At the same time, it is not that clear whether all do as they say. In the oil and gas sector in particular, actual investments seem relatively minor, both in absolute and relative terms. Electricity utility companies and many European carmakers also seem to have limited interest or are hesitant to commit actual funding. Reasons for this in the mobility sector are particularly concerns about energy efficiency and the lack of infrastructure, while electricity companies appear relatively uninterested in hydrogen to cope with the intermittency of renewables, and mostly see hydrogen as input for hard-to-abate industrial sectors.

4 There are several broader conclusions that can be drawn from this paper. A key takeaway is that there is a very broad spectrum of economic actors that have clear interests in the success of the hydrogen transition. Another important message is that many high-emission sectors take the cost of carbon emissions seriously and can be counted on to support the hydrogen transition because of this. However, falling carbon emission costs due to the COVID-19 crisis could undermine this motivation, which is a realistic prospect without policy intervention. This introduces the last, and perhaps most important lesson: the hydrogen transition has begun, but needs continued policy support. Carbon intensive industries such as the steel and chemicals industry are clearly interested but need policy support to avoid carbon leakages if they commit. The gas grid is ready, and many operators and utility companies are eager, but they need clearance to experiment with blending in hydrogen. There are several clusters that can serve as models and nuclei for the future European hydrogen economy, but they will need public funding. The hydrogen coalitions now need governments to take the driver's seat.

# References


Abington, T., & Gilblom, K. (2019, October 2). *Shell Leads Big Oil in the Race to Invest in Clean Energy*. Bloomberg. https://www.bloomberg.com/news/articles/2019-09-04/shell-leads-big-oil-in-the-race-to-invest-in-clean-energy-tech

Adelski, A. (2019, October 1). *Shell et Air Liquide inaugurent la 75ème station hydrogène d'Allemagne*. H2mobile. https://www.h2-mobile.fr/actus/shell-air-liquide-inaugurent-75e-station-hydrogene-allemagne/

AFHYPAC. (n.d.). *Qui sommes-nous?* Afhypac. Retrieved 28 May 2020, from https://www.afhypac.org/association/presentation/

Air Liquide. (2017). *Positions Reinforced: 2017 Annual Report*. Air Liquide.

Air Liquide. (2019, July 22). *Air Liquide to deliver hydrogen for thyssenkrupp's pioneering project for lower carbon steel production*. Air Liquide. https://www.airliquide.com/china/air-liquide-deliver-hydrogen-thyssenkrupps-pioneering-project-lower-carbon-steel-production

Air Products & Chemicals Inc. (2019). *2019 Annual Report*. Air Products & Chemicals Inc.

ArcelorMittal. (2019, September 16). *ArcelorMittal commissions Midrex to design demonstration plant*. ArcelorMittal. /media/news-articles/2019-sep-16-arcelormittal-commissions-midrex-to-design-demonstration-plant/

ArcelorMittal. (2020). *Annual Report 2019*. ArcelorMittal.

ARGE Netz, Vattenfall, & MAN Energy Solutions. (2019). *Pressemitteilung—HySynGas unter den Gewinnern des Ideenwettbewerbs Reallabore der Energiewende*.

Balat, M., & Balat, M. (2009). Political, economic and environmental impacts of biomass-based hydrogen. *International Journal of Hydrogen Energy*, *34*(9), 3589–3603. https://doi.org/10.1016/j.ijhydene.2009.02.067

Barnes, A. (2020). *Can the current EU regulatory framework deliver decarbonisation of gas* (No. 71; Energy Insights). Oxford Institute for Energy Studies.

BMW. (2020, March 17). *Hydrogen cars, fuel cells, etc.: What you need to know | BMW.com*. https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html

BP. (2019, June 11). *BP joins the Hydrogen Council*. BP Global. https://www.bp.com/en/global/corporate/news-and-insights/bp-magazine/bp-joins-hydrogen-council.html

BP. (2020a). *BP Annual Report and Form 20-F 2019*. British Petroleum.

BP. (2020b). *BP Sustainability Report 2019*. British Petroleum.

Buckland, K. (2019, September 18). Explainer: Why Asia's biggest economies are backing hydrogen fuel cell cars. *Reuters*. https://www.reuters.com/article/us-autos-hydrogen-explainer-idUSKBN1W22VQ

Burton, L. (2020, May 2). Shell backers push for plan to replace leader Ben van Beurden after historic cut to payout. *The Telegraph*. https://www.telegraph.co.uk/business/2020/05/02/backers-push-plan-replace-leader-ben-van-beurden-historic-cut/

Castillo, A., & Gayme, D. F. (2014). Grid-scale energy storage applications in renewable energy integration: A survey. *Energy Conversion and Management*, *87*, 885–894. https://doi.org/10.1016/j.enconman.2014.07.063

CătuȚi, M., Egenhofer, C., & Elkerbout, M. (2019). *The future of gas in Europe: Review of recent studies on the future of gas* (2019/03). Center for European Policy Studies (CEPS).

Chatzimarkakis, J. (2020, February 21). *Why the European wind industry needs a Clean Hydrogen Coalition | Recharge*. Recharge | Latest Renewable Energy News. https://www.rechargenews.com/transition/why-the-european-wind-industry-needs-a-clean-hydrogen-coalition/2-1-760458

Contreras, A., Yigit, S., Özay, K., & Veziroglu, T. N. (1997). Hydrogen as aviation fuel: A comparison with hydrocarbon fuels. *International Journal of Hydrogen Energy*, *22*(10–11), 1053–1060. https://doi.org/10.1016/S0360-3199(97)00008-6

Daimler. (n.d.). *Electromobility: Fuel cell & hydrogen are a part of it*. Daimler. Retrieved 18 April 2020, from https://www.daimler.com/innovation/case/electric/fuel-cell-hydrogen-electromobility.html

De Boer, R. (2020, March 11). *Plan voor mega waterstoffabriek legt vinger op zere plek in energie- en klimaatbeleid*. Financieel Dagblad. https://fd.nl/opinie/1337742/plan-voor-mega-waterstoffabriek-legt-vinger-op-zere-plek-in-energie-en-klimaatbeleid

Deutsche Bahn. (2019). *Deutsche Bahn 2018 Integrated Report—On track towards a better railway*. Deutsche Bahn.

Deutsche Welle, D. (2018, September 17). *World's first hydrogen train rolls out in Germany*. Deutsche Welle. https://www.dw.com/en/worlds-first-hydrogen-train-rolls-out-in-germany/a-45525062

Dickel, R. (2020). *Blue hydrogen as an enabler of green hydrogen: The case of Germany* (NG 159; OIES Paper). Oxford Institute for Energy Studies.

DWV. (n.d.). *Über uns*. Deutscher Wasserstoff- Und Brennstoffzellen-Verband e. V. (DWV). Retrieved 29 May 2020, from https://www.dwv-info.de/about-us-new?lang=en

EDF. (2020). *Universal registration document*. EDF Group.

EDP - Energias de Portugal. (2018). *Annual Report 2018*. EDP - Energias de Portugal.

EDP - Energias de Portugal. (2019). *Annual Report 2019*. EDP - Energias de Portugal.

Edwards, P. (2017, December 4). *Global Cement Top 100 Report 2017-2018*. Global Cement. https://www.globalcement.com/magazine/articles/1054-global-cement-top-100-report-2017-2018

Ellis, L. D., Badel, A. F., Chiang, M. L., Park, R. J.-Y., & Chiang, Y.-M. (2019). Toward electrochemical synthesis of cement—An electrolyzer-based process for decarbonating CaCO3 while producing useful gas streams. *Proceedings of the National Academy of Sciences*, 201821673. https://doi.org/10.1073/pnas.1821673116

Enagas. (2019). *Annual Report 2018: Energy for the Future*. Enagas.

Endesa. (2018a). *Activities Report 2018*. Endesa.

Endesa. (2018b). *Sustainability Report 2018*. Endesa.

Enel. (2020). *Consolidated Annual Report 2019*. Enel.

EnergieAgentur NRW. (2020). *Ziele des Netzwerks Brennstoffzelle und Wasserstoff NRW*. EnergieAgentur NRW. http://www.energieagentur.nrw/brennstoffzelle/brennstoffzelle-wasserstoff-elektromobilitaet/ziele_des_netzwerks_brennstoffzelle_und_wasserstoff_nrw

Engie. (2018). *Press Release ENGIE 2017 Results: A successful strategic repositioning poised for growth*. Engie.

Eni. (2019, June 3). *Toyota and Eni together on the road to hydrogen*. Eni. https://www.eni.com/en-IT/media/press-release/2019/06/toyota-and-eni-together-on-the-road-to-hydrogen.html

E.ON. (2020). *Annual Report 2019*. E.ON.

Equinor. (2020a). *2019 Annual report and Form 20-F*. Equinor.

Equinor. (2020b). *2019 Sustainability Report*. Equinor.

Ervia. (2018). *Annual Report and Financial Statements*. Ervia.

European Automobile Manufacturers Association. (2019). *Making the Transition to Zero-Emission Mobility—Enabling Factors for Alternatively-Powered Cars in the EU: 2019 Progress Report* (Progress Report). European Automobile Manufacturers Association.

European Commission. (2017). *Competitiveness of the European Cement and Lime Sectors*. European Commission.

European Commission. (2019a, December 11). *Press remarks by President von der Leyen on the occasion of the adoption of the European Green Deal Communication* [Text]. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/speech_19_6749

European Commission. (2019b). *The European Green Deal: Communication from the Commission to the European Parliament, the European Council, the Council, The European Economic and Social Committee and the Committee of the Regions*. European Commission.

Eurostat. (2008). *NACE rev. 2: Statistical classification of economic activities in the European Community*. Office for Official Publications of the European Communities.

FCH JU. (n.d.). *Who we are*. Fuel Cell and Hydrogen Joint Undertaking. Retrieved 28 May 2020, from https://www.fch.europa.eu/page/who-we-are

FCH JU. (2019a). *Hydrogen Roadmap Europe*. Fuel Cells and Hydrogen Joint Undertaking.

FCH JU. (2019b). *Hydrogen Roadmap Europe—A sustainable pathway for the European energy transition*. Fuel Cells and Hydrogen Joint Undertaking.

FCH JU. (2019c). *Report on the budgetary and financial management 2018*. Fuel Cells and Hydrogen Joint Undertaking.

FCH JU. (2019d). *Draft budget of Fuel Cells and Hydrogen Joint Undertaking for the financial year 2020 (version 29/10/2019)*. Fuel Cells and Hydrogen Joint Undertaking.

FCH JU, S2R JU, & Ronald Berger. (2019). *Study on the Use of Fuel Cells and Hydrogen in the Railway Environment*. Publications Office of the European Union; Shift2Rail Joint Undertaking; Fuel Cells and Hydrogen Joint Undertaking.

Financieel Dagblad. (2020, March 2). *Geen woorden maar daden nodig voor waterstofproject Noord-Nederland*. FD.Nl. https://fd.nl/opinie/1336625/geen-woorden-maar-daden-nodig-voor-waterstofproject-noord-nederland

Flamme, S., Benrath, D., Glanz, S., Hoffart, F., Pielow, C., Roos, M., Span, R., Wagner, H.-J., & Schönauer, A.-L. (2019). ELEGANCY: The Interdisciplinary Approach of the German Case Study to Enable a Low Carbon Economy by Hydrogen and CCS. *Energy Procedia*, *158*, 3709–3714. https://doi.org/10.1016/j.egypro.2019.01.887

Fleming, S., & Hollinger, P. (2020, March 8). *Europe to unveil EU-wide hydrogen fuel partnership*. Financial Times. https://www.ft.com/content/321633f2-6135-11ea-a6cd-df28cc3c6a68

Fluxys Belgium. (2018). *Annual Financial Report 2018*. Fluxys.

Fortum. (2018). *EU Strategy for Long-Term Greenhouse Gas Emissions Reductions: Fortum's key messages for the preparation of the strategy*. Fortum.

Fortum. (2019a). *CEO's Business Review*. Fortum.

Fortum. (2019b). *Sustainability 2019*. Fortum.

Fortune. (2019). *Global 500*. Fortune. https://fortune.com/global500/2019/

Franta, B. (2018, September 19). Shell and Exxon's secret 1980s climate change warnings. *The Guardian*. https://www.theguardian.com/environment/climate-consensus-97-per-cent/2018/sep/19/shell-and-exxons-secret-1980s-climate-change-warnings

Gasunie. (2020a). *Gasunie Annual Report 2019*. Gasunie.

Gasunie. (2020b, February 27). *Europe's largest green hydrogen project starts in Groningen*. Gasunie. https://www.gasunie.nl/en/news/europes-largest-green-hydrogen-project-starts-in-groningen

Government of the Netherlands. (2020). *Government Strategy on Hydrogen (Cabinet vision)*. Government of the Netherlands.

Groupe PSA. (2019, February 26). *Groupe PSA to step up the momentum of its Push to Pass strategic plan for the second phase, 2019-2021*. /en/groupe-psa-step-momentum-its-push-pass-strategic-plan-second-phase-2019-2021

Groupe Renault. (2020, January 20). *Electric cars vs hydrogen vs hybrid: What are the differences?* Easy Electric Life. https://easyelectriclife.groupe.renault.com/en/outlook/technology/electric-hybrid-hydrogen-understanding-the-differences/

H2 MOBILITY. (2020). *H2 MOBILITY: We are building the filling station network of the future.* H2 Mobility. https://h2.live/en/h2mobility

Harding, R., & Inagaki, K. (2017, March 28). *Japan gambles on Toyota's hydrogen powered car*. https://www.ft.com/content/328df346-10cb-11e7-a88c-50ba212dce4d

Hisschemöller, M., Bode, R., & van de Kerkhof, M. (2006). What governs the transition to a sustainable hydrogen economy? Articulating the relationship between technologies and political institutions. *Energy Policy*, *34*(11), 1227–1235. https://doi.org/10.1016/j.enpol.2005.12.005

H-vision. (2019). *Feasibility study report: Blue hydrogen as accelerator and pioneer for energy transition in the industry*. H-vision.

HYBRIT. (n.d.). *HYBRIT toward fossil-free steel*. Hybrit. Retrieved 27 April 2020, from http://www.hybritdevelopment.com/hybrit-toward-fossil-free-steel

Hydrogen Europe. (2020). *About us*. Hydrogen Europe. https://hydrogeneurope.eu/index.php/about-us-2

HyLaw. (2020). *About HyLAW*. HyLaw. https://www.hylaw.eu/about-hylaw

HYPOS. (n.d.). *HYPOS East Germany: Das Wasserstoffkonsortium*. Hydrogen Power Storage & Solutions East Germany. Retrieved 29 May 2020, from https://www.hypos-eastgermany.de/das-wasserstoffkonsortium/

Iberdrola. (2019). *Statement of Non-Financial Information: Sustainability Report—Financial Year 2019*. Iberdrola.

Iberdrola. (2020). *Integrated Report 2020*. Iberdrola.

IEA. (2018a). *Data & Statistics: CO2 emissions—Total CO2 emissions*. IEA Data Services. https://www.iea.org/data-and-statistics

IEA. (2018b). *World Energy Outlook 2018*. International Energy Agency.

IEA. (2019a). *The Future of Rail*. International Energy Agency.

IEA. (2019b). *World Energy Outlook 2019*. International Energy Agency.

IEA. (2019c). *The Future of Hydrogen* (Special Report G20 Japan). International Energy Agency.

IEA Energy Technology Network. (2019). *AFC TCP 2019 Survey on the Number of Fuel Cell Vehicles, Hydrogen Refueling Stations and Targets: Fuel Cell Vehicles as of End 2018*. IEA Technology Collaboration Programme.

IMF. (2019, October). *World Economic Outlook Data: October 2019—Gross domestic product, current prices, U.S. Dollars*. International Monetary Fund. https://www.imf.org/

IN4Climate.NRW. (2019). *REFHYNE: the world's largest PEM hydrogen electrolysis plant*. Refhyne. https://www.in4climate.nrw/en/best-practice/projekte/2019/translate-to-englisch-refhyne/

Innogy. (2019). *Annual Report 2018*. Innogy.

International Organization of Motor Vehicle Manufacturers. (2017). *World Motor Vehicle Production by Manufacturer 2017*. International Organization of Motor Vehicle Manufacturers.

IRENA. (2018). *Hydrogen from renewable power: Technology outlook for the energy transition* (p. 52). International Renewable Energy Agency.

Iwan, N. (2017). *H2 MOBILITY: Fuelling Hydrogen*. H2 Mobility.

Jain, I. P. (2009). Hydrogen the fuel for 21st century. *International Journal of Hydrogen Energy*, *34*(17), 7368–7378. https://doi.org/10.1016/j.ijhydene.2009.05.093

J.H.P. (2019, October 6). *El hidrógeno busca su sitio en la ciudad de Zaragoza*. El Periódico de Aragón. https://www.elperiodicodearagon.com/noticias/aragon/hidrogeno-busca-sitio-ciudad-zaragoza_1388947.html

Kast, J., Vijayagopal, R., Gangloff, J. J., & Marcinkoski, J. (2017). Clean commercial transportation: Medium and heavy duty fuel cell electric trucks. *International Journal of Hydrogen Energy*, *42*(7), 4508–4517. https://doi.org/10.1016/j.ijhydene.2016.12.129

Keating, D. (2019, November 25). *Timmermans sees 'pivotal role for hydrogen' in meeting EU climate goals*. Www.Euractiv.Com. https://www.euractiv.com/section/energy-environment/news/timmermans-sees-pivotal-role-for-hydrogen-in-meeting-eu-climate-goals/

Keolis. (2018). *2018 Annual Report: Building Inclusive and Sustainable Mobility*. Keolis.

Kern, F., Gaede, J., Meadowcroft, J., & Watson, J. (2016). The political economy of carbon capture and storage: An analysis of two demonstration projects. *Technological Forecasting and Social Change*, *102*, 250–260. https://doi.org/10.1016/j.techfore.2015.09.010

Khan, M. (2020, March 10). *Brussels powers up hydro investment*. Financial Times. https://www.ft.com/content/88d75388-6266-11ea-b3f3-fe4680ea68b5

Kiwa. (n.d.-a). *Kiwa and hydrogen*. Retrieved 30 April 2020, from /en/themes/hydrogen/kiwa-and-hydrogen/

Kiwa. (n.d.-b). *Kiwa's hydrogen services*. Retrieved 30 April 2020, from /en/themes/hydrogen/kiwas-hydrogen-services/

Kroposki, B., Johnson, B., Zhang, Y., Gevorgian, V., Denholm, P., Hodge, B.-M., & Hannegan, B. (2017). Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy. *IEEE Power and Energy Magazine*, *15*(2), 61–73. https://doi.org/10.1109/MPE.2016.2637122

Lambert, M. (2020). *Hydrogen and decarbonisation of gas: False dawn or silver bullet* (No. 66; Energy Insights). Oxford Institute for Energy Studies.

Linde Group. (n.d.). *The driving force: Managing hydrogen projects with Linde*. Linde AG.

Linde PLC. (2018). *One Linde: Annual Report 2018*. Linde PLC.

Macalister, T. (2007, May 25). *BP scraps £500m Scottish carbon capture scheme*. The Guardian. http://www.theguardian.com/business/2007/may/25/oilandpetrol.news

Madsen, A. N., & Andersen, P. D. (2010). Innovative regions and industrial clusters in hydrogen and fuel cell technology. *Energy Policy*, *38*(10), 5372–5381. https://doi.org/10.1016/j.enpol.2009.03.040

Mans, P., Alkemade, F., van der Valk, T., & Hekkert, M. P. (2008). Is cluster policy useful for the energy sector? Assessing self-declared hydrogen clusters in the Netherlands. *Energy Policy*, *36*(4), 1375–1385. https://doi.org/10.1016/j.enpol.2007.12.004

Markusson, N., Ishii, A., & Stephens, J. C. (2011). The social and political complexities of learning in carbon capture and storage demonstration projects. *Global Environmental Change*, *21*(2), 293–302. https://doi.org/10.1016/j.gloenvcha.2011.01.010

McDowall, W., & Eames, M. (2006). Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature. *Energy Policy*, *34*(11), 1236–1250. https://doi.org/10.1016/j.enpol.2005.12.006

McKinsey & Company. (2019). *Role of hydrogen in the energy transition and implications for Italy*.

McPhy. (2020, January 28). McPhy: Annual revenue 2019. *McPhy*. https://mcphy.com/en/press-releases/mcphy-annual-revenue-2019/

Meadowcroft, J. (2005). Environmental political economy, technological transitions and the state. *New Political Economy*, *10*(4), 479–498. https://doi.org/10.1080/13563460500344419

Meadowcroft, J., & Langhelle, O. (Eds.). (2009). *Caching the carbon: The politics and policy of carbon capture and storage*. Edward Elgar.

Melaina, M. W., Antonia, O., & Penev, M. (2013). *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues* (p. 131). National Renewable Energy Laboratory.

Ministère de la Transition Écologique et Solidaire. (2018). *Plan de déploiement de l'hydrogène pour la transition énergétique*. Ministère de la Transition Écologique et Solidaire.

Moliner, R., Lázaro, M. J., & Suelves, I. (2016). Analysis of the strategies for bridging the gap towards the Hydrogen Economy. *International Journal of Hydrogen Energy*, *41*(43), 19500–19508. https://doi.org/10.1016/j.ijhydene.2016.06.202

Navigant. (2019). *Gas for Climate. The optimal role for gas in a net zero emissions energy system* (p. 231). Navigant Netherlands.

Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr, Alstom, LNVG, & Linde Group. (2017). *Joint Press Release: Minister Lies: "The (train) future begins in Lower Saxony"*.

Oladini, D. (2018). *Hydrogen for Innovative Vehicles: Final Public Report* (No. 621219). Greater London Authority; European Commission; Fuel Cells and Hydrogen Joint Undertaking.

OMV. (2020a). *Annual Report 2019*. OMV.

OMV. (2020b). *Sustainability Report 2019*. OMV.

Orcholska, K. (2018). *Sustainable Urban Mobility Plan for Gdansk: 2030*. City Mobil net.

Ørsted. (2020). *Ørsted Annual Report 2019*. Ørsted.

Otto, A., Robinius, M., Grube, T., Schiebahn, S., Praktiknjo, A., & Stolten, D. (2017). Power-to-Steel: Reducing CO2 through the Integration of Renewable Energy and Hydrogen into the German Steel Industry. *Energies*, *10*(4), 451. https://doi.org/10.3390/en10040451

PGE Polska Grupa Energetyczna. (2018). *Q4 & 2018 Financial and Operating Results*. PGE Polska Grupa Energetyczna.

Pohl, H. W., & Malychev, V. V. (1997). Hydrogen in future civil aviation. *International Journal of Hydrogen Energy*, *22*(10–11), 1061–1069. https://doi.org/10.1016/S0360-3199(95)00140-9

Port of Antwerp. (n.d.). *Hydrogen Economy*. Port of Antwerp.

Port of Rotterdam. (2016). *Facts & Figures on the Rotterdam Energy Port and Petrochemical Cluster*. Havenbedrijf Rotterdam.

Port of Rotterdam. (2019, July 2). *H-vision kicks off the hydrogen economy in Rotterdam*. Port of Rotterdam. https://www.portofrotterdam.com/en/news-and-press-releases/h-vision-kicks-off-the-hydrogen-economy-in-rotterdam

Pratt, J. W., & Klebanoff, L. E. (2018). *Optimization of Zero Emission Hydrogen Fuel Cell Ferry Design With Comparisons to the SF-BREEZE.* (No. SAND2018-0421, 1513454; pp. SAND2018-0421, 1513454). Sandia National Laboratories (US Department of Energy). https://doi.org/10.2172/1513454

Primetals Technologies. (2019). *Primetals Technologies develops break-through technology for carbon-free, hydrogen-based direct reduction for iron ore fines*. Primetal Technologies.

PTE HPC. (n.d.). *Qué es la PTEHPC?* PTE HPC. Retrieved 29 May 2020, from http://www.ptehpc.org/

REFHYNE. (2018, February 28). *About*. REFHYNE. https://refhyne.eu/about/

Repsol. (2019, December 2). *Repsol will be a net zero emissions company by 2050*. Repsol. https://www.repsol.com/en/press-room/press-releases/2019/repsol-will-be-a-net-zero-emissions-company-by-2050.cshtml

Reuters. (2019, November 21). Italy's Snam pledges to spend more money on green business. *Reuters*. https://www.reuters.com/article/us-snam-plan-idUSKBN1XV0SR

Rīgas satiksme. (n.d.). *H2Nodes*.

Rīgas satiksme. (2019, December 18). *First hydrogen filling station in Baltics put into service*. https://www.rigassatiksme.lv/en/news/first-hydrogen-filling-station-in-baltics-put-into-service/

Royal Dutch Shell, & Wuppertal Institut. (2017). *Shell Hydrogen Study: Energy of the Future? Sustainable Mobility through Fuel Cells and H2*. Shell Deutschland Oil GmbH.

Ruf, L. (2019). *Hydrogen cars, vans and buses: Overview of flagship demonstration initatives in the transport sector*. Element Energy Ltd.

RVK. (n.d.). *Die Brennstoffzellen-Hybridbusse: Wasserstoff für den ÖPNV*. RVK. Retrieved 30 April 2020, from https://www.rvk.de/projekt-null-emission/die-brennstoffzellen-hybridbusse

RWE. (2019, May 29). How hydrogen could change the face of steel production as we know it | en:former. *En-former*. https://www.en-former.com/en/hydrogen-revolution-steel-production/

Samenwerkingsverband Noord-Nederland. (2019). *Investment Agenda Hydrogen Northern Netherlands: Heading for emission-free hydrogen at commercial scale*. Samenwerkingsverband Noord-Nederland.

Sanderson, H. (2020, February 4). *Investors hit the gas on hydrogen producers*. Financial Times. https://www.ft.com/content/5e837ff8-441b-11ea-a43a-c4b328d9061c

Sandvik. (2016). *Save the Planet: Use more fuel (cells)*. https://www.materials.sandvik/en/campaigns/fuelcells/

Schmitt, B. (2019, January 18). *Exclusive: Toyota Hydrogen Boss Explains How Fuel Cells Can Achieve Corolla Costs*. The Drive. https://www.thedrive.com/tech/26050/exclusive-toyota-hydrogen-boss-explains-how-fuel-cells-can-achieve-corolla-costs

SGN. (2020). *SGN Annual Report 2019*. SGN.

Shankar, S. (2019, June 12). *Meeting the Needs of Hydrogen Vehicles and Zero-Emissions Technology at ACT Expo*. Swagelok. https://www.swagelok.com/en/blog/meeting-the-needs-of-hydrogen-vehicles-act-expo

Shell. (2018a). *Shell Energy Transition Report*. Royal Dutch Shell.

Shell. (2018b, March 27). *Shell and ITM Power launch new hydrogen refuelling site at Beaconsfield*. https://www.shell.co.uk/media/2018-media-releases/new-fuelling-station-at-beaconsfield.html

Shell. (2018c, August 21). *Shell bouwt mee aan netwerk van waterstofstations in Nederland*. https://www.shell.nl/media/persberichten/2018-media-releases/shell-is-building-network-of-hydrogen-stations.html

Shell. (2020a). *Annual Report and Accounts for the Year Ended December 31, 2019*. Royal Dutch Shell.

Shell. (2020b). *Sustainability Report 2019*. Royal Dutch Shell.

Siemens AG. (2018). *Hydrogen Solutions: Your partner for sustainable hydrogen generation*. Siemens AG.

Snam. (2019a, October 8). *Snam and hydrogen*. Snam. https://www.snam.it/en/hydrogen_challenge/snam_hydrogen/

Snam. (2019b). *The Hydrogen Challenge: The potential of hydrogen in Italy*. Snam.

Snam. (2019c, November 21). *Snam: Increasing results, more investments in the energy transition in the 2019-2023 plan*. Snam. https://www.snam.it/en/Media/Press-releases/2019/Snam_increasing_results_2019-2023_plan.html

SNCF. (2019, August 29). *Le 1er train hydrogène en 2022*. SNCF.fr. https://www.sncf.com/fr/groupe/newsroom/1er-train-hydrogene-en-2022

SNCF. (2020). *SNCF Group Annual Financial Report*. SNCF.

Society of Motor Manufacturers and Traders. (2019). *Hydrogen Fuel Cell Electric Vehicles: A Quick Guide to the UK Market Technology and Infrastructure*. Society of Motor Manufacturers and Traders.

Statkraft. (2019). *Annual Report Statkraft 2019*. Statkraft. https://ml-eu.globenewswire.com/Resource/Download/a2c4feef-1d60-4dc6-adbe-5271e899ecfc

Steitz, C., Kaeckenhoff, T., & Taylor, E. (2020, June 4). *Germany earmarks $10 billion for hydrogen expansion*. Reuters. https://www.reuters.com/article/us-health-coronavirus-germany-stimulus-idUSKBN23B10L

Technavio. (2019). *Global Industrial Gases Market 2019-2023*. Technavio. https://www.technavio.com/report/global-industrial-gases-market-industry-analysis

Thomas, A. (2018, March 26). Consortium including Shell given £8.8million grant to improve use of hydrogen vehicles—News for the Oil and Gas Sector. *Energy Voice*. https://www.energyvoice.com/otherenergy/167123/consortium-including-shell-given-8-8million-grant-to-improve-use-of-uk-hydrogen-vehicles/

thyssenkrupp. (2019). *Annual Report 2018/2019*. thyssenkrupp AG.

thyssenkrupp Steel Europe. (2019). *World first in Duisburg as NRW economics minister Pinkwart launches tests at thyssenkrupp into blast furnace use of hydrogen*. thyssenkrupp. https://www.thyssenkrupp-steel.com/en/newsroom/press-releases/world-first-in-duisburg.html

Tina Bru. (2020, June 3). *Hydrogen in Norway* [Taleartikkel]. Regjeringen.No; regjeringen.no. https://www.regjeringen.no/en/aktuelt/hydrogen-in-norway/id2704905/

Torvanger, A., & Meadowcroft, J. (2011). The political economy of technology support: Making decisions about carbon capture and storage and low carbon energy technologies. *Global Environmental Change*, *21*(2), 303–312. https://doi.org/10.1016/j.gloenvcha.2011.01.017

Total. (2019). *Integrating Climate Into Our Strategy*. Total.

Total. (2020). *Universal Registration Document 2019—Including the Annual Financial Report*. Total.

Tronstad, T., Åstrand, H. H., Haugom, G. P., & Langfeldt, L. (2017). *Study on the Use of Fuel Cels in Shipping* (p. 108). DNV GL.

UNSD. (2020). *UNSD — Methodology*. Methodology. https://unstats.un.org/unsd/methodology/m49/

Van Dijk, B. (2020, February 27). *Shell en Gasunie plannen 's werelds grootste offshorewindpark in Groningen*. Financieel Dagblad. https://fd.nl/ondernemen/1336289/shell-en-gasunie-plannen-wereldprimeur-voor-groningen-met-duurzaam-miljardenproject

Van Dijk, B. (2020, March 1). *Plannen voor ambitieus offshore windpark met scepsis begroet*. Financieel Dagblad. https://fd.nl/ondernemen/1336479/plannen-voor-ambitieus-offshore-windpark-met-scepsis-begroet

van Wijk, A. J. M., & Wouters, F. (2020). Hydrogen: The Bridge between Africa and Europe. In M. P. C. Weijnen & Z. Lukszo (Eds.), *Shaping an Inclusive Energy Transition*. Springer.

van Zon, N. (2018). *Liquid Hydrogen Powered Commercial Aircraft*. Technical University of Delft: Faculty of Aerospace Engineering.

Vattenfall. (n.d.). *Our investment programme*. Vattenfall. Retrieved 27 April 2020, from https://group.vattenfall.com/investors/understanding-vattenfall/investment-plan

Vattenfall. (2018). *Vattenfall's views on hydrogen: Its contribution to move towards a fossil-free society & the EU legislative prerequisites*. Vattenfall.

Vattenfall. (2019a). *Annual and Sustainability Report 2019*. Vattenfall.

Vattenfall. (2019b). *Green Hydrogen for Sector Integration: 1st Meeting of the Hydrogen Energy Network—Gunnar Groebler*. Vattenfall.

Vattenfall, & Preem. (2018). *Press Release—Swedish Energy Agency supports Preem and Vattenfall's planned hydrogen gas plant in Gothenburg*.

Vaughan, A. (2017, May 15). *BP shareholders urged to reject chief's £9m pay package*. The Guardian. http://www.theguardian.com/business/2017/may/15/bp-shareholders-urged-reject-executive-pay-package

Vaughan, A. (2018a, May 20). *Shell faces shareholder challenge over climate change approach*. The Guardian. http://www.theguardian.com/business/2018/may/20/shell-faces-shareholder-challenge-over-climate-change-approach-paris-climate-deal

Vaughan, A. (2018b, May 22). Shell investors revolt over pay and maintain pressure over climate change. *The Guardian*. https://www.theguardian.com/environment/2018/may/22/shell-climate-change-executive-pay-oil-carbon-emissions-agm

Verbund. (2020). *Integrated Annual Report 2019*. Verbund.

Victor, D. G., Heller, T. C., & Victor, N. M. (2003). *Political Economy and the Hydrogen Revolution* (No. 17; Working Paper). Center for Environmental Science and Policy, Stanford University.

VNG. (2019). *Strong Together—Unity in Diversity: Annual Report 2018*. VNG.

Voestalpine AG. (2020). *Annual Report 2018/19*. Voestalpine AG.

Volkswagen AG. (2019, November 7). *Hydrogen or battery? A clear case, until further notice*. https://www.volkswagenag.com/en/news/stories/2019/08/hydrogen-or-battery--that-is-the-question.html#

Winter, C.-J. (2005). Into the hydrogen energy economy—Milestones. *International Journal of Hydrogen Energy*, *30*(7), 681–685. https://doi.org/10.1016/j.ijhydene.2004.12.011

Wulf, C., Linßen, J., & Zapp, P. (2018). Review of Power-to-Gas Projects in Europe. *Energy Procedia*, *155*, 367–378. https://doi.org/10.1016/j.egypro.2018.11.041

Zeniewski, P. (2019, March 13). *A long-term view of natural gas security in the European Union*. International Energy Agency. https://www.iea.org/commentaries/a-long-term-view-of-natural-gas-security-in-the-european-union