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The Heralds of Hydrogen: The economic sectors that are driving the hydrogen economy in Europe

I. Introduction

The 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.[1] Since then, many new projects have started and many investment programmes reaching into the billions of euros have been announced, such as the earmarked fund of €9 billion for hydrogen as part of the COVID-19 recovery effort by the German government.[2] Yet, uncertainty remains about the precise role of hydrogen in European visions of the energy transition. 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 stand out among supporters of the hydrogen transition? What is the role of small and medium-sized enterprises (SMEs)?

These are all relevant questions. The momentum for hydrogen comes at a time when policymakers at the subnational, national and supranational level are faced with the task of reviving their economies in response to the COVID-19 crisis. The European Commission revealed its official hydrogen strategy in July 2020.[3] Hydrogen is supposed to become one of the key pillars of the European Green Deal, announced just before the COVID-19 crisis started. Many national policymakers are working on hydrogen too, with recent strategies published in France and Germany, for example. At the same time, waves of enthusiasm for hydrogen have subsided in the past, and the European Commissioner responsible for the Green Deal, Frans Timmermans, also warns that hydrogen is no silver bullet.[4]

This paper provides a snapshot of the economic sectors that support the hydrogen economy, and why they do so. It analyses membership data of 39 hydrogen associations across Europe (see Annex I for a list of these associations and their geographic location), classifying 1,670 membership entries according to their business activities, and then analyses the background to and reasoning for members' support for these associations. The dataset gives some insight into individual companies' influence and

[1] IEA, 'The Future of Hydrogen', Special Report for G20 Japan (Paris: International Energy Agency, June 2019).
[2] Christoph Steitz, Tom Kaeckenhoff, and Edward Taylor, 'Germany Earmarks $10 Billion for Hydrogen Expansion', Reuters, 4 June 2020, https://www.reuters.com/article/us-health-coronavirus-germany-stimulus-idUSKBN23B10L.
[3] European Commission, *A Hydrogen Strategy for a Climate-Neutral Europe – Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions* (Brussels: European Commission, 2020).
[4] Dave Keating, 'Timmermans Sees "pivotal Role for Hydrogen" in Meeting EU Climate Goals', euractiv.com, 25 November 2019, https://www.euractiv.com/section/energy-environment/news/timmermans-sees-pivotal-role-for-hydrogen-in-meeting-eu-climate-goals/.

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sheds light on the breadth of the emerging hydrogen coalition, the varying interests that motivate it, and the investment it can generate.

The paper categorizes membership directory data on all non-public entities registered in hydrogen associations across Europe.[5] These associations aim to promote hydrogen projects and cooperation between interested parties, and can function as lobby groups in support of the hydrogen transition.[6] Business activity is registered according to the Statistical Classification of Economic Activities in the European Community, commonly known as NACE.[7] There are various validity problems with this method,[8] but these may be expected when analysing sectors rather than conducting company-by-company analysis. The information on association membership is used to construct an overview of the various sectors that support hydrogen and their geographic background. The paper then looks at these actors' motivation. This is done with literature research, such as by going through annual reports, financial reports, sustainability reports, press releases, news articles, and existing literature on the sector's or actor's connection to hydrogen.

II. Background

Hydrogen has several perceived benefits as a component of the energy transition.[9] It can complement the flow-based nature of electricity (as it is non-intermittent and a storage medium), diversify energy input, and, crucially, decarbonize hard-to-abate activities in sectors such as heavy industry and transport. This all while being relatively compatible with Europe's highly developed natural gas infrastructure. Its permanent availability is a major advantage given the seasonal and daily variations in the availability of some renewables, such as wind and solar energy, as well as seasonal variations in energy demand. Moreover, it can replace hydrocarbons in (for instance) aviation, shipping, rail and heavy road transport, as well as those in the chemical, iron, steel, and cement industries. The International Renewable Energy Agency (IRENA) notes that hydrogen as a competitive feedstock can avoid carbon leakage from heavy industries moving elsewhere.[10] However, its drawbacks should not be downplayed. Examples are efficiency losses and high flammability, or discussions about the desirability of the carbon capture and storage (CCS) technologies needed for blue hydrogen specifically.

[5] Europe according to the UN Statistical Division's M49 definition, which for instance includes Russia. Hydrogen and fuel cell associations can focus on the international, national, or subnational level.

[6] Activities may vary. Hydrogen Europe mentions industry representation, lobbying and advocacy as key activities, but also shares regulatory updates with its members and maintains a legal database (HyLaw). Its industry and research arms are two of the three members in 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 and spends approximately €100 million per year on hydrogen projects. Other influential associations, such as EnergieAgentur North Rhine Westphalia, Afhypac in France, HYPOS in Eastern Germany, PTE in Spain, and DWV in Germany all follow similar models, although mostly without Hydrogen Europe's investment capacity. Many have permanent staff members who work on media and political advocacy. Most are public-private partnerships with close ties to different government levels and public institutions.

[7] Eurostat, *NACE Rev. 2: Statistical Classification of Economic Activities in the European Community* (Luxembourg: Office for Official Publications of the European Communities, 2008).

[8] There are several prominent flaws. First, companies choose their own classification and can classify similar activities differently. There have been some manual changes (notably of Nouryon and pipeline transporters like GRTgaz and Gasunie) to correct this. Second, many companies have multiple different business activities. Third, large companies tend to be registered as "head office activities". Fourth, subsidiaries might be registered as conducting different activities. To deal with this, same-name subsidiaries are registered exactly like the headquarters location, and "activities of head offices" are changed to those of a registered subsidiary at the discretion of the author. If not, companies like Deutsche Bahn, EDF, Hyundai, and Shell would all be registered as doing the same business activity.

[9] There are different "types" of hydrogen. Virtually all of the 70 million tonnes (Mt) of hydrogen produced globally each year is carbon-intensive "grey" hydrogen, for which 830 Mt CO_2 is emitted according to the IEA's World Energy Outlook 2019. Europe accounts for roughly 10% of global hydrogen production, according to Navigant's 2019 Gas for Climate report. This is different for blue hydrogen (produced with carbon capture and storage [CCS]), which could become financially feasible in the short term and can kickstart the development of hydrogen infrastructure, but is unlikely to be completely decarbonized. Only green hydrogen (by electrolysis using renewable electricity) can make that claim, which makes it the long-term goal.

[10] IRENA, 'Hydrogen from Renewable Power: Technology Outlook for the Energy Transition' (Abu Dhabi: International Renewable Energy Agency, September 2018).

Understanding the interests behind hydrogen is a topic that has received relatively little attention. The IEA names 'renewable electricity suppliers, industrial gas producers, electricity and gas companies, 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.[11] Others focus on the role of the oil and gas sectors and automotive industries. This is understandable, as some[12] have noted that blue hydrogen has various direct benefits for oil and gas companies, pipeline owners, and even the coal industry.[13] BP and Shell in particular have been in the spotlight as long-time backers.[14] Norwegian oil and gas companies, notably Equinor, have pushed for blue hydrogen to sustain demand for natural gas and its infrastructure.[15] Supporters of 'clean coal' technologies are in a similar position.[16] The existence of both blue and green hydrogen makes it possible for actors with different interests to support the same overarching development, i.e. the hydrogen transition.[17] Hydrogen is perceived by some environmental groups through a green lens and promoted as such, while others see hydrogen as blue and capable of propping up the oil, gas, and coal industry in a decarbonising world. This creates the potential for coalitions between oil and gas majors as well as environmentalists and renewable energy companies, reflected in the variety of sectors present in table 1.

The geographic background of the interest in hydrogen is also relevant. Research by A. N. Madsen and P. D. Andersen on hydrogen clusters in Europe records a geographically relatively dispersed set of clusters in Europe, although heavily skewed towards Western Europe.[18] Notable regional clusters they mention are southern Scandinavia, North Rhine-Westphalia in Germany, Aragon in northeast Spain, and northern Italy. They see little opportunity for clustering in areas with existing hydrogen facilities and pipelines, and greater opportunity for innovative regions with strong representation of the chemical, energy, manufacturing, oil and gas, automotive, and aerospace industries. This is different from the IEA's view, which expects more activity in (coastal) industrial clusters, and areas with existing natural gas infrastructure, rather than from innovation clusters.[19] National governmental policy also plays a role. France, Germany, the Netherlands, and Norway, for instance, have official national hydrogen strategies.[20] Italy has no concrete strategy (although it has recently set out guidelines for a national

[11] IEA, 'The Future of Hydrogen', Special Report for G20 Japan (Paris: International Energy Agency, June 2019), p. 19.
[12] Florian Kern et al., 'The Political Economy of Carbon Capture and Storage: An Analysis of Two Demonstration Projects' *Technological Forecasting and Social Change* 102 (January): pp. 250–60, https://doi.org/10.1016/j.techfore.2015.09.010; Nils Markusson, Atsushi Ishii, and Jennie C. Stephens, 'The Social and Political Complexities of Learning in Carbon Capture and Storage Demonstration Projects', *Global Environmental Change* 21, No. 2 (May 2011): pp. 293–302, https://doi.org/10.1016/j.gloenvcha.2011.01.010; James Meadowcroft and Oluf Langhelle, eds., *Caching the Carbon: The Politics and Policy of Carbon Capture and Storage* (Cheltenham, UK ; Northampton, MA, USA: Edward Elgar, 2009).
[13] Benefits being, for instance, cheap/free CO_2 in pipelines that can be used for enhanced oil recovery, the sustained demand for natural gas, the ability to sell CO_2 emission rights, and the continued use of pipelines for CCS purposes rather than becoming stranded assets.
[14] Mustafa Balat and Mehmet Balat, 'Political, Economic and Environmental Impacts of Biomass-Based Hydrogen', *International Journal of Hydrogen Energy* 34, No. 9 (May 2009): pp. 3589–3603, https://doi.org/10.1016/j.ijhydene.2009.02.067; Meadowcroft and Langhelle, *Caching the Carbon*; Royal Dutch Shell and Wuppertal Institut, 'Shell Hydrogen Study: Energy of the Future? Sustainable Mobility through Fuel Cells and H_2' (Hamburg: Shell Deutschland Oil GmbH, 2017).
[15] Meadowcroft and Langhelle, *Caching the Carbon*.
[16] David G. Victor, Thomas C. Heller, and Nadeja M. Victor, 'Political Economy and the Hydrogen Revolution', Working Paper (Stanford, CA: Center for Environmental Science and Policy, Stanford University, September 2003); Carl-Jochen Winter, 'Into the Hydrogen Energy Economy - Milestones', *International Journal of Hydrogen Energy* 30, No. 7 (July 2005): pp. 681–85, https://doi.org/10.1016/j.ijhydene.2004.12.011.
[17] R. Moliner, M. J. Lázaro, and I. Suelves, 'Analysis of the Strategies for Bridging the Gap towards the Hydrogen Economy', *International Journal of Hydrogen Energy* 41, No. 43 (November 2016): pp. 19500–508, https://doi.org/10.1016/j.ijhydene.2016.06.202.
[18] Anne Nygaard Madsen and Per Dannemand Andersen, 'Innovative Regions and Industrial Clusters in Hydrogen and Fuel Cell Technology', *Energy Policy* 38, No. 10 (October 2010): pp. 5372–81, https://doi.org/10.1016/j.enpol.2009.03.040.
[19] IEA, 'The Future of Hydrogen', p. 177.
[20] Tina Bru, 'Hydrogen in Norway', Taleartikkel, Regjeringen.no (regjeringen.no, 3 June 2020), https://www.regjeringen.no/en/aktuelt/hydrogen-in-norway/id2704905/; German Federal Ministry for Economic Affairs and Energy, *The National Hydrogen Strategy* (Berlin: German Federal Ministry for Economic Affairs and Energy, 2020); Government of the Netherlands, 'Government Strategy on Hydrogen (Cabinet Vision)' (The Hague: Government of the Netherlands, 26 March 2020); Ministère de la Transition Écologique et Solidaire, *Plan de Déploiement de l'hydrogène Pour La Transition Énergétique* (Paris: Ministère de la Transition Écologique et Solidaire, 2018).

hydrogen strategy),[21] Spain has opened a public consultation, and the UK is still working on a strategy although the government is already funding projects and has ambitious plans for a conversion of the gas network in northern England. There are wide differences between views on the role of blue and green hydrogen. Norway and the Netherlands are much more receptive to blue hydrogen in their strategies, and France and Germany much less so – to the extent of ignoring the choice altogether. The European Commission's strategy is similarly opaque on the role of blue hydrogen.[22] This has raised questions about the viability of, for instance, the German and the Commission's strategy.[23]

III. Sectors Supporting Hydrogen in Europe

To some degree the support from economic sectors depends on their geographical location (see table 2). This is valid both at the national level and at the regional or cluster level. Government hydrogen strategies and support for hydrogen projects at various levels of government are a major factor in this. Most association members are from the larger economies, with approximately 70% from Germany, France, the UK, and Spain. Underrepresented are Russia (with no registered entities at all) and Eastern Europe at large, as well as Italy with less than 1.5% of all registrations despite its large economy. Relatively well-represented countries in Central and Eastern Europe include the Czech Republic, Hungary, Slovakia, and the Baltic states. These are also countries where natural gas plays a significant role in the energy system. Germany is clearly overrepresented, even considering its large economy.[24] It is responsible for almost 40% of all registrations, approaching double the number of registrations of France, Italy, and the UK combined. France and the UK are underrepresented relative to Germany and Spain. Well-represented regions appear to be the Iberian peninsula, Benelux, and the Nordics (minus Finland).

The composition of hydrogen associations also differs by country. Germany and Spain have influential companies that are present in multiple associations, but most are SMEs. Siemens and the large carmakers are examples of these influential companies for Germany, as Abengoa and Enagás are for Spain. This is different for the UK and especially France. There are several companies headquartered in either country that are very significant components of each countries' presence in hydrogen coalitions across Europe. These companies can have very different sizes. Examples of influential companies include chemical industry giants Air Liquide and now UK-headquartered Linde. Other examples are Engie and its subsidiaries Storengy and GRTgaz, as well as Électricité de France (EDF) and its subsidiary Areva, which in turn owns Areva H2Gen and Areva Stockage d'Énergie. They are complemented by some very active smaller companies, such as UK-based ITM Power, and France-based McPhy.

Subnational associations help identify clusters of interest. This is notably the case for North Rhine-Westphalia and the eastern German states that support Hydrogen Power Storage & Solutions East Germany (HYPOS), but large associations are also present in Aragon, Hesse, Flanders,[25] Scotland, and smaller associations in Bavaria, Cologne, Hamburg, London, the Ruhr area, Wales, and southern Germany. The density in Germany is particularly high. Take Cologne, which can boast associations at

[21] Stephen Jewkes (2020), 'Italy drafts guidelines for national hydrogen strategy, document shows', Reuters, 16 November, https://www.reuters.com/article/italy-hydrogen/italy-drafts-guidelines-for-national-hydrogen-strategy-document-shows-idUKL8N2I24CZ.

[22] European Commission, *A Hydrogen Strategy for a Climate-Neutral Europe – Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*.

[23] Ralf Dickel, 'Blue Hydrogen as an Enabler of Green Hydrogen: The Case of Germany', OIES Paper (Oxford: Oxford Institute for Energy Studies, May 2020); Alex Barnes, 'Can the Current EU Regulatory Framework Deliver Decarbonisation of Gas', Energy Insights (Oxford: Oxford Institute for Energy Studies, June 2020).

[24] The high German number, with over 600 entities, is 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 a broad array of SMEs take part in them.

[25] The only Belgian hydrogen association is WaterstofNet, which covers Flanders and the south of the Netherlands together.

the local, regional, state, national, and European level.[26] The activity and density of hydrogen networks quite closely corresponds to the IEA's vision of the North Sea Region as one with a high potential for the hydrogen economy to take off.[27]

Table 1: Overview of statistical divisions and number of registered companies in each division

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 companies	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 companies (mid-/downstream)	70	4.19
Oil and gas industry	53	3.17
Land transport	24	1.44
Ports and warehousing	13	0.78

Source: author, based on hydrogen association data and NACE business activity registrations (specifications in footnotes in paper for every division, where relevant).

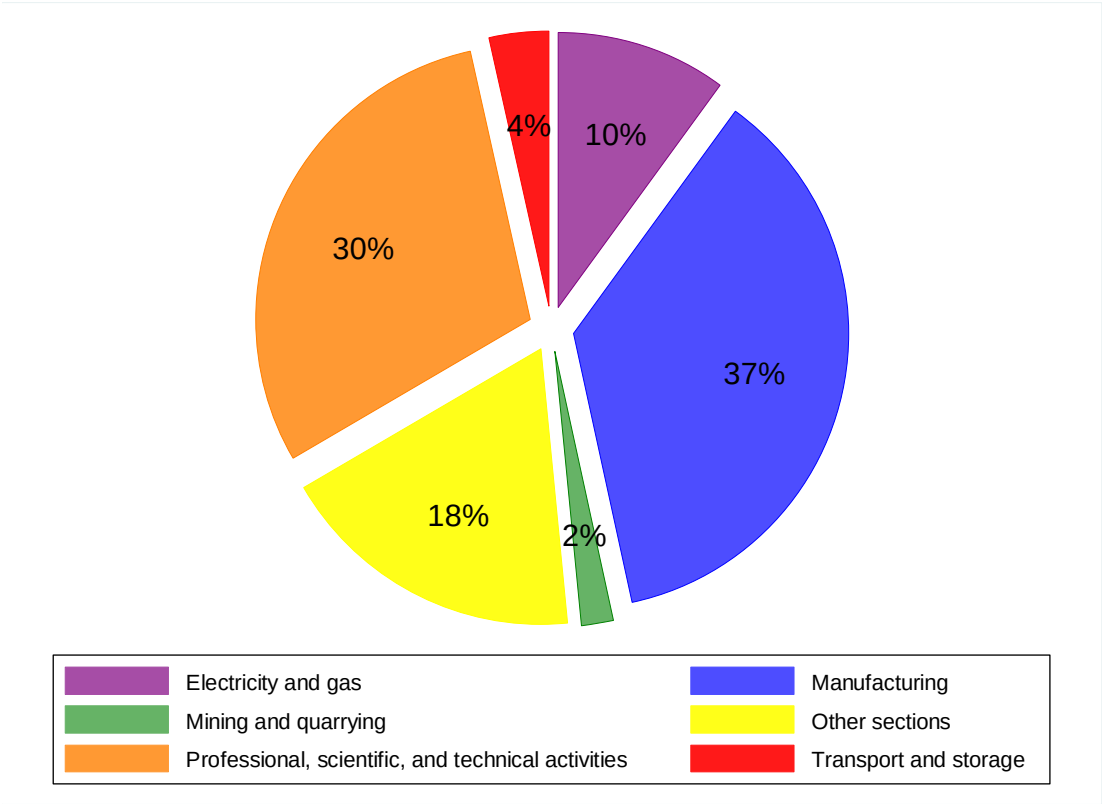
Table 2: Overview of registered entities by country for countries with more than five entities

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, based on hydrogen association data and location of company headquarters.

[26] Hydrogen Cologne, H2 Netzwerk Ruhr, EnergieAgentur NRW, the Deutsche Wasserstoff- und Brennstoffzellen-Verband, and Hydrogen Europe respectively.
[27] IEA, 'The Future of Hydrogen', pp. 179–80.

Figure 1: Distribution of companies registered in associations by section



Source: author, based on hydrogen association data and business activity registrations.

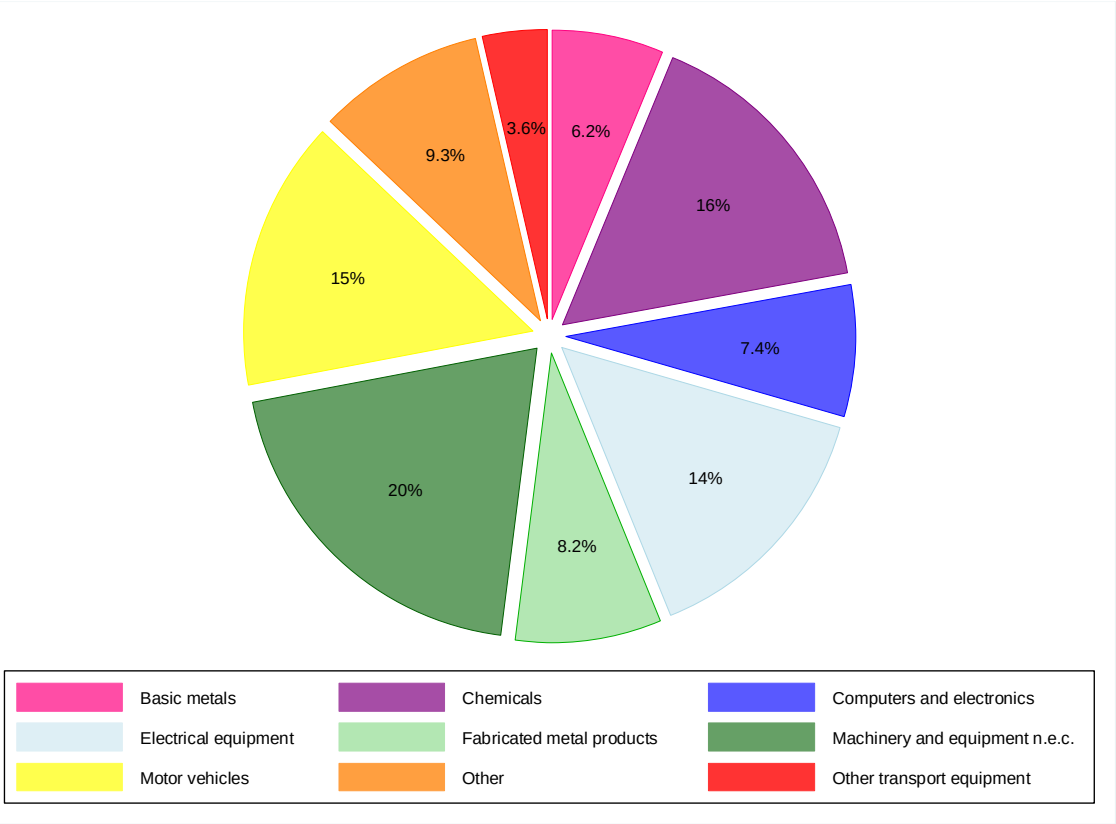
Manufacturing

The section with the largest representation is manufacturing, with more than 600 registrations (Figure 1).[28] It is a diverse section whose representation is largely split between four divisions. These are: manufacturers of machinery and equipment not elsewhere classified (n.e.c.); motor vehicles, trailers and semi-trailers; chemicals and chemical products; and electrical equipment. Together they account for roughly 65% of manufacturing's representation (Figure 2).[29] That some divisions are smaller does not mean they do not have influential companies among them. Manufacturers of other transport equipment are one example: this division includes aircraft industry duopolists Airbus and Boeing, the large shipyards Chantiers de l'Atlantique and Fincantieri, as well as defence group Naval Group, train builder Alstom, and the heavy/industrial transport multinational CNH Industrial.

[28] This only includes entities registered under NACE section C: Manufacturing. Entities that are registered in two (or more) associations, are counted as two (or more) registrations.

[29] 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. Wholesale and retail traders specialized in this sector are also included.

Figure 2: Divisions of manufacturing representation



Source: author, based on hydrogen association data and business activity registrations.

Machinery and Electronic or Electrical equipment

The 277 manufacturers in this division[30] constitute the largest group of manufacturers in support of hydrogen. Although they specialize in different products, their motivations and roles are largely similar. They produce (amongst others) electrolysers, compressors, regulators, taps, valves, PEM (proton-exchange membrane) fuel cells, sensors, powertrains, fuelling systems, pumps, and engines. Some of the most active companies include Siemens, ITM Power, Hydrogenics, Nel Hydrogen, Swagelok, and Ballard Power Systems. 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, Fronius International, Haskel, Liebherr, Rolls-Royce, Sandvik, Schaeffler, Swagelok, Vestas, and Yanmar.

The interest for these companies is straightforward: sales and market growth. This is clear from reports by companies such as Swagelok, Siemens, and Sandvik.[31] For instance, hydrogen infrastructure investment creates demand for Swagelok's expertise in producing leak prevention and storage safety solutions. Siemens benefits from increased demand for large industrial electrolysers, as it is one of the few producers of them (with its 'SILYZER'). Sandvik can mass-produce specific solutions with coated steel in fuel cell plates and deliver fittings for the hydrogen refuelling stations (HRSs) delivered by Linde. This is similarly the case for companies like Hydrogenics (industrial hydrogen generators and fuel cells), Ballard Power Systems (fuel cell stacks), McPhy, Nel Hydrogen, and ITM Power (all electrolysers). A

[30] See above note for specific makeup.
[31] Sandvik, 'Save the Planet: Use More Fuel (Cells)', 2016, https://www.materials.sandvik/en/campaigns/fuelcells/; Siemens AG, *Hydrogen Solutions: Your Partner for Sustainable Hydrogen Generation* (Erlangen: Siemens AG, 2018); Shiv Shankar, 'Meeting the Needs of Hydrogen Vehicles and Zero-Emissions Technology at ACT Expo', Swagelok, 12 June 2019, https://www.swagelok.com/en/blog/meeting-the-needs-of-hydrogen-vehicles-act-expo.

hydrogen-based economy would increase these companies' revenues. This is applicable to most of the sector.

Estimates of the sector's annual expected investment need to consider that intermediate goods like pumps and tube fittings can also serve different markets. Many hydrogen proponents in this sector are SMEs. Despite having relatively large R&D departments for their size, their business model relies on hydrogen investment from other sectors. ITM Power has annual R&D expenditure of €2.6 million (£2.33 million) on sales revenue of €5.1 million (£4.6 million), McPhy spends €2.5 million on R&D with revenue of €11.4 million, and Nel Hydrogen €2.1 million (NOK 22.6 million) on revenue of €54 million (NOK 569 million).[32] Larger firms spend more, but there are large variations and precise budgets are unclear. ABB, Atlas Copco, and Vestas, for instance, do not mention hydrogen in their annual and sustainability reports of 2018 and 2019 at all, making it difficult to establish how much they spend on hydrogen – if anything at all.[33] Manufacturers that focus on heavy-duty, maritime and aircraft engines seem enthusiastic, such as Liebherr, Rolls-Royce, and Schaeffler.[34] Schaeffler is explicitly investing in the technology, with a new hydrogen business unit and a central role in its €849 million 2019 R&D programme.[35] The biggest investor is Siemens, which has for 2018 and 2019 featured hydrogen as one of its 13 'Company Core Technologies' within its €5.7 billion R&D programme.

Metals and Non-Metallic Mineral Products

The 99 entities that engage in the manufacture of basic metals, fabricated metal products, and non-metallic mineral products combined make up the second-largest group of manufacturers represented in associations. They consist of companies in different metal and mineral-related industries, which can be broadly split between commodity producers (basic metals and non-metallic mineral products) and intermediate/final goods producers (fabricated metals). The commodity producers are major steel producers like 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. Several large projects in the steel industry are experimenting with recent research on hydrogen as a replacement for fossil feedstocks in blast furnaces.[36] Several large projects are being conducted by SSAB, [37] ArcelorMittal, Primetal Technologies, and ThyssenKrupp.[38] Similar projects are being pursued in the cement industry,[39] which is absent from

[32] McPhy, *McPhy Universal Registration Document 2019* (La Motte-Fanjas, France: McPhy, 2020); Nel Hydrogen, *NEL 2019 Annual Report* (Oslo: Nel Hydrogen, 2020); ITM Power, *ITM Power 2019 Annual Report and Financial Statements* (Sheffield: ITM Power, 2019).

[33] Atlas Copco, *Atlas Copco Annual Report 2018* (Stockholm: Atlas Copco, 2019); Atlas Copco, *Atlas Copco Annual Report 2019* (Stockholm: Atlas Copco, 2020); Vestas, *Vestas Annual Report 2018* (Aarhus: Vestas, 2019); Vestas, *Annual Report 2019* (Aarhus: Vestas, 2020); ABB, *ABB Annual Report 2018: Shaping a Leader Focused in Digital Industries* (Zurich: ABB, 2018); ABB, *ABB Sustainability Report 2018: Shaping a Sustainable World* (Zurich: ABB, 2019); ABB, *ABB Annual Report 2019* (Zurich: ABB, 2019); ABB, *ABB Group Sustainability Report 2019: Leading Solutions for a Sustainable Future* (Zurich: ABB, 2019).

[34] Schaeffler, *Schaeffler Annual Report 2019* (Herzogenaurach, Germany: Schaeffler, 2020); Rolls-Royce, *2019 Annual Report Rolls-Royce Holdings* (London: Rolls-Royce, 2020); Liebherr, *Liebherr Annual Report 2018* (Bulle, Switzerland: Liebherr, 2019).

[35] Schaeffler, *Schaeffler Annual Report 2019*, p. 11.

[36] For example Alexander Otto et al., 'Power-to-steel: Reducing CO_2 through the integration of renewable energy and hydrogen into the German steel industry', *Energies* 10, No. 4 (1 April 2017): pp. 451, https://doi.org/10.3390/en10040451.

[37] In a consortium called HYBRIT with mining company LKAB and Vattenfall.

[38] ThyssenKrupp Steel Europe, 'World first in Duisburg as NRW Economics Minister Pinkwart launches tests at Thyssenkrupp into blast furnace use of hydrogen' (ThyssenKrupp, 11 November 2019), https://www.thyssenkrupp-steel.com/en/newsroom/press-releases/world-first-in-duisburg.html; ArcelorMittal, 'ArcelorMittal commissions Midrex to design demonstration plant', ArcelorMittal, 16 September 2019, /media/news-articles/2019-sep-16-arcelormittal-commissions-midrex-to-design-demonstration-plant/; Primetals Technologies, 'Primetals Technologies develops break-through technology for carbon-free, hydrogen-based direct reduction for iron ore fines' (Primetal Technologies, 26 June 2019).

[39] For example Leah D. Ellis et al., 'Toward electrochemical synthesis of cement—An electrolyzer-based process for decarbonating CaCO3 while producing useful gas streams', *Proceedings of the National Academy of Sciences*, 16 September 2019, 201821673, https://doi.org/10.1073/pnas.1821673116.

associations bar the Secil Group and Vicat. The top European and global cement manufacturers are absent, despite their emissions increasingly coming under the spotlight.[40]

Hydrogen interests differ for the two metal groups. Makers of fabricated metals are in a similar position to machinery manufacturers: more hydrogen demand leads to sales growth in storage tanks, metal machining, and similar products. For steel producers and the cement producers, their interests are very different. With annual CO_2 emissions of 94 Mt in Europe, the steel and cement industries together constitute one of the top polluters, mostly for heat production.[41] This is similar to the total emissions of Belgium or the Czech Republic.[42] These industries are exposed to increasing public, regulatory, and financial pressure to decarbonize.[43] That said, the steel and cement industries have different production processes, where CO_2 is emitted at different stages of the process. Annual reports in the steel sector explicitly state the business risks from EU emissions trading system (ETS) costs, and possible future revisions.[44] Take Voestalpine for instance, where the increase in annual 'environmental expenditure' from €257.7 million in 2018 to €299.1 million in 2019 attributed almost solely to EU ETS costs, can be put in in the context of a pre-tax profit of €646 million.[45] Many steel industry actors for now still benefit from discounted or free CO_2 allowances. However, these discounts could be discontinued. The high volatility of carbon prices can significantly affect corporate profitability in the longer term, in a sector that already has very tight margins.

Some steel companies have stated investment estimates for achieving hydrogen-based decarbonization (usually with 2050 as target). ArcelorMittal estimates that converting to hydrogen-based direct reduction of iron ore would cost €30-40 billion, and has committed around €300 million to R&D for its decarbonization.[46] Thyssenkrupp is planning an investment of €10 billion over the next 30 years, anticipating forthcoming EU rules.[47] Both companies' decarbonization roadmaps require governments to create incentives for, and stimulate, climate-neutral steel.[48] Despite these companies' interest, many current demonstration projects are heavily subsidized by government with little private investment. Major projects, such as the €18 million H2FUTURE project involving Voestalpine,[49] are almost exclusively financed with government funding. However, this is likely to change if companies follow the decarbonization roadmaps they lay out. Hydrogen investment could soon amount to several billion euros per year, although this is likely to depend on the extent to which policymakers are willing to protect the sector from carbon-intensive competition.

Chemicals and Chemical Products

Chemical companies are the third-largest manufacturing sector by representation, reaching 99 when chemical wholesale companies are added. Support from the largest companies in the industrial gas

[40] Such as LafargeHolcim in Switzerland, HeidelbergCement in Germany, CRH in Ireland, and Buzzi Unicem in Italy. Increasing attention is evident from the European Commission, 'Competitiveness of the European cement and lime sectors' (Brussels: European Commission, December 2017).
[41] FCH JU, 'Hydrogen Roadmap Europe – A Sustainable Pathway for the European Energy Transition' (Fuel Cells and Hydrogen Joint Undertaking, 6 February 2019), p. 38.
[42] IEA, 'Data and statistics: CO_2 emissions – Total CO_2 emissions', IEA Data Services, 2018, https://www.iea.org/data-and-statistics.
[43] RWE, 'How hydrogen could change the face of steel production as we know it | en:former', *En-former* (blog), 29 May 2019, https://www.en-former.com/en/hydrogen-revolution-steel-production/; ThyssenKrupp Steel Europe, 'World first in Duisburg as NRW Economics Minister Pinkwart launches tests at Thyssenkrupp into blast furnace use of hydrogen'.
[44] ArcelorMittal, *Annual Report 2019* (Luxembourg: ArcelorMittal, 2020), p. 19; thyssenkrupp, *Annual Report 2018/2019* (Essen: thyssenkrupp AG, 2019), p. 140; voestalpine AG, *Annual Report 2018/19* (Linz: voestalpine AG, 2020), p. 54.
[45] voestalpine AG, *Annual Report 2018/19*.
[46] ArcelorMittal, *Climate Action in Europe: Our Carbon Emissions Reduction Roadmap: 30% by 2030 and Carbon Neutral by 2050* (Luxembourg: ArcelorMittal, 2020).
[47] Kevin Knitterscheidt, 'Green energy: ThyssenKrupp steels itself for a carbon-free future', Handelsblatt, 23 January 2019, https://www.handelsblatt.com/english/companies/green-energy-thyssenkrupp-steels-itself-for-a-carbon-free-future/23894808.html.
[48] ArcelorMittal, *Climate Action in Europe: Our Carbon Emissions Reduction Roadmap: 30% by 2030 and Carbon Neutral by 2050*; ThyssenKrupp Steel Europe, *Decarbonisation of the Steel Production – Climate Strategy of Thyssenkrupp* (Essen: thyssenkrupp AG, 2020).
[49] *H2FUTURE: World's Largest 'Green' Hydrogen Pilot Facility Successfully Commences Operation* (Linz: H2Future, 2019).

industry makes for half of the registrations. Particularly prominent are Air Liquide, Linde and its subsidiary BOC, Nouryon, and Air Products & Chemicals. These few companies are present in almost all associations. In general, close to 80% of the chemical manufacturers in the hydrogen associations produce industrial gas specifically. Both Linde and Air Liquide are very active and explicit in their goal to promote the hydrogen economy.[50] One clear interest is that selling hydrogen is a core component of their business. Industrial gas producers also have the know-how in handling hydrogen that can be translated into returns. Air Liquide in its 2017 annual report states: '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.'[51] Linde and Air Liquide benefit as natural partners in the construction of HRSs and are key stakeholders in industries ranging from steel to trains.[52] Moreover, they can sell CCS technologies, and benefit from increased oxygen demand if clean coal succeeds as a source.[53]

Sales growth is not the only incentive. Continued reliance on carbon-intensive grey hydrogen presents business risks. Linde explicitly states that EU legislation on GHG emissions could reduce growth by increasing compliance costs, and that hydrogen production plants in the EU are subject to cap-and-trade regulations on CO_2.[54] The global leader in hydrogen production, Air Products & Chemicals,[55] echoes this by noting that legislative pressure from the EU ETS puts pressure on their grey hydrogen production. Increased public concern could lead to further pressure to reduce GHG, and it explicitly says that: '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.'[56] In other words, business risks from climate regulations are mitigated by moving from grey to blue and green hydrogen production.

The sector's investment record shows that it takes the hydrogen transition seriously. Air Liquide spent €480 million on biomethane and hydrogen mobility during the 2014-2019 period,[57] and has taken stakes in fuel cell companies, such as a 18.6% stake in Hydrogenics for €18 million.[58] Linde invested €50 million in a joint venture with green hydrogen-focused ITM Power, part of its objective to invest €1 billion in decarbonization initiatives over the period 2018-2028.[59] It spends an additional approximate €50 million per year on decarbonization R&D. Air Products & Chemicals and Nouryon have less clear strategies, but their competitors provide an insight into the sector's strategic thinking. Hydrogen investment by this sector does not mean investment in green hydrogen, as there is still substantial investment in grey hydrogen.

Motor Vehicles

The 102 manufacturers of motor vehicles, trailers, and semi-trailers are the fourth-largest group of manufacturers.[60] Some key companies are non-European. German manufacturers account for 28%, Japanese for 16%, and South Korean for 11%. This is primarily because of Toyota and Hyundai, two important hydrogen supporters. Despite the popular focus on passenger cars, heavy vehicles are likely to play a greater role in the initial phase of the transition. Specialized lorry and bus manufacturers that

[50] Air Liquide, 'Positions Reinforced: 2017 Annual Report' (Paris: Air Liquide, 2017), https://www.airliquide.com/sites/airliquide.com/files/2018/05/15/2017-annual-report.pdf; Linde Group, 'The Driving Force: Managing Hydrogen Projects with Linde' (Pullach, Germany: Linde AG, n.d.), accessed 27 March 2020.
[51] Air Liquide, 'Positions Reinforced: 2017 Annual Report', p. 38.
[52] Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr et al., 'Joint press release: Minister Lies: "The (train) future begins in Lower Saxony"', 9 November 2017; Air Liquide, 'Air Liquide to deliver hydrogen for Thyssenkrupp's pioneering project for lower carbon steel production', Air Liquide, 22 July 2019, https://www.airliquide.com/china/air-liquide-deliver-hydrogen-thyssenkrupps-pioneering-project-lower-carbon-steel-production.
[53] Air Products & Chemicals Inc, *2019 Annual Report* (Allentown, USA: Air Products & Chemicals Inc, 2019), p. 40.
[54] Linde PLC, *One Linde: Annual Report 2018* (Guildford, UK: Linde PLC, 2018), p. 35.
[55] Air Products & Chemicals Inc, *2019 Annual Report*, p. 12.
[56] Air Products & Chemicals Inc, p. 12.
[57] Air Liquide, *Inventing the Future: 2019 Annual Report* (Paris: Air Liquide, 2020).
[58] Air Liquide, *Air Liquide Makes a Strategic Investment in the Production of Decarbonated Hydrogen by Electrolysis* (Paris, France: Air Liquide, 2019).
[59] Linde, *Sustainable Development Report 2019: Making Our World More Productive* (Guildford, UK: Linde, 2020).
[60] This includes vendors and maintenance companies of motor vehicles from the wholesale and retail trade sector.

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 membership from the sector, even when excluding non-specialized manufacturers with large heavy-vehicle divisions (such as Daimler and Volvo).[61] There are several large projects too, such as the 300 fuel cell buses of the Joint Initiative for Hydrogen Vehicles across Europe,[62] and a Swiss project for 1,600 Hyundai hydrogen lorries. More hydrogen heavy-vehicle models are in development for the European market, and companies specializing in heavy-duty fuel cell vehicles (FCVs) are emerging, such as Nikola in the US.[63]

US carmakers are absent except for two Ford research centres. Although French component makers (e.g. Plastic Omnium and Faurecia) are active, French carmakers themselves are almost absent.[64] Most of the push for hydrogen in the sector comes from Asian carmakers, led by Toyota and Hyundai. However, the absence of Honda and the high participation rate of the German automakers are interesting. The arguments put forward by Toyota's Head of Fuel Cell System Development, Prof. K. Hirose, help explain these differences.[65] They amount to a belief in the economic advantages of FCV over battery electric vehicle (BEV) technology, such as the large weight difference between batteries and fuel cells,[66] a very large cost advantage for fuel cells compared to batteries and battery production, and more room for economies of scale. Toyota doubts the long-term success of BEVs because of the limitations in further improving batteries to become lighter and support longer ranges, Toyota still has no mass-produced BEV, although it began investing more in BEVs recently.[67] Toyota's large investments and long-standing commitment to FCVs creates a certain path dependency too.

Range and refuelling concerns are more pressing for lorries and buses. As noted, many think FCVs will become particularly competitive as heavier, longer-range vehicles.[68] Refuelling infrastructure is the biggest constraint in the competition with BEVs, which is easier dealt with by commercial fleets. The substantial number of heavy motor vehicle manufacturers in the coalitions appears to confirm these hypotheses. The counterarguments that explain why other manufacturers remain on the fence are lower energy efficiencies of FCVs (in the range of 50%),[69] the (for now) high costs, and mostly the lack of infrastructure. There are only several dozen HRSs in the EU as of 1 January 2019.[70] This compares to over 140,000 electric charging stations.[71] There are plans to change this, for instance by building 750 HRSs before 2025, and there is a roadmap for 3,500+ stations by 2030.[72] The estimated infrastructural

[61] Additionally, both Volvo and Daimler appear primarily interested in hydrogen for heavy vehicles.
[62] Lisa Ruf, 'Hydrogen Cars, Vans and Buses: Overview of Flagship Demonstration Initatives in the Transport Sector' (Element Energy Ltd., 18 November 2019).
[63] IEA, 'The Future of Hydrogen', p. 129.
[64] It is possible to argue that PSA subsidiary Opel's membership of Hidrogeno Aragon changes this.
[65] Bertel Schmitt, 'Exclusive: Toyota hydrogen boss explains how fuel cells can achieve Corolla costs', *The Drive*, 18 January 2019, https://www.thedrive.com/tech/26050/exclusive-toyota-hydrogen-boss-explains-how-fuel-cells-can-achieve-corolla-costs.
[66] Hirose provides an example by stating that a battery electric truck of 40 tonnes with a 500 kilometre 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, see above note).
[67] Robin Harding and Kana Inagaki, 'Japan gambles on Toyota's hydrogen powered car', *Financial Times*, 28 March 2017, https://www.ft.com/content/328df346-10cb-11e7-a88c-50ba212dce4d.
[68] IEA, 'The Future of Hydrogen'; James Kast et al., 'Clean commercial transportation: medium and heavy duty fuel cell electric trucks', *International Journal of Hydrogen Energy* 42, No. 7 (16 February 2017): pp. 4508–17, https://doi.org/10.1016/j.ijhydene.2016.12.129; Martin Lambert, 'Hydrogen and decarbonisation of gas: False dawn or silver bullet', Energy Insights (Oxford: Oxford Institute for Energy Studies, March 2020), https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/03/Insight-66-Hydrogen-and-Decarbonisation-of-Gas.pdf?v=1ee0bf89c5d1.
[69] BMW, 'Hydrogen Cars, Fuel Cells, Etc.: What You Need to Know | BMW.Com', 17 March 2020, https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html.
[70] There are different figures on the number of HRSs currently available: the European Automobile Manufacturers Association's 2019 Progress Report states 47, the FCH JU's Roadmap Europe states 120, and the IEA's Future of Hydrogen states approximately 170.
[71] European Automobile Manufacturers Association, 'Making the transition to zero-emission mobility – Enabling factors for alternatively-powered cars in the EU: 2019 Progress Report' (Brussels: European Automobile Manufacturers Association, September 2019).
[72] FCH JU, 'Hydrogen Roadmap Europe – A sustainable pathway for the European energy transition'.

needs per 1 million FCVs (about 400 HRSs) are far lower than for 1 million BEVs, which need a million private charging stations and up to 10,000 fast-charging stations.[73]

Volkswagen has stated that the debate between FCVs and BEVs is 'a clear case' and will focus on BEVs.[74] BEVs' higher energy efficiency is emphasized, and Volkswagen views hydrogen as better suited to stationary settings.[75] Renault, the PSA Group, BMW, and Daimler see slightly more merit in the future of hydrogen and have more developed plans for launching hydrogen-powered models on the market.[76] Manufacturers must judge the viability of a hydrogen vision compared to one for electric mobility, and they are doing so differently. This in large part explains the differences in approaches.

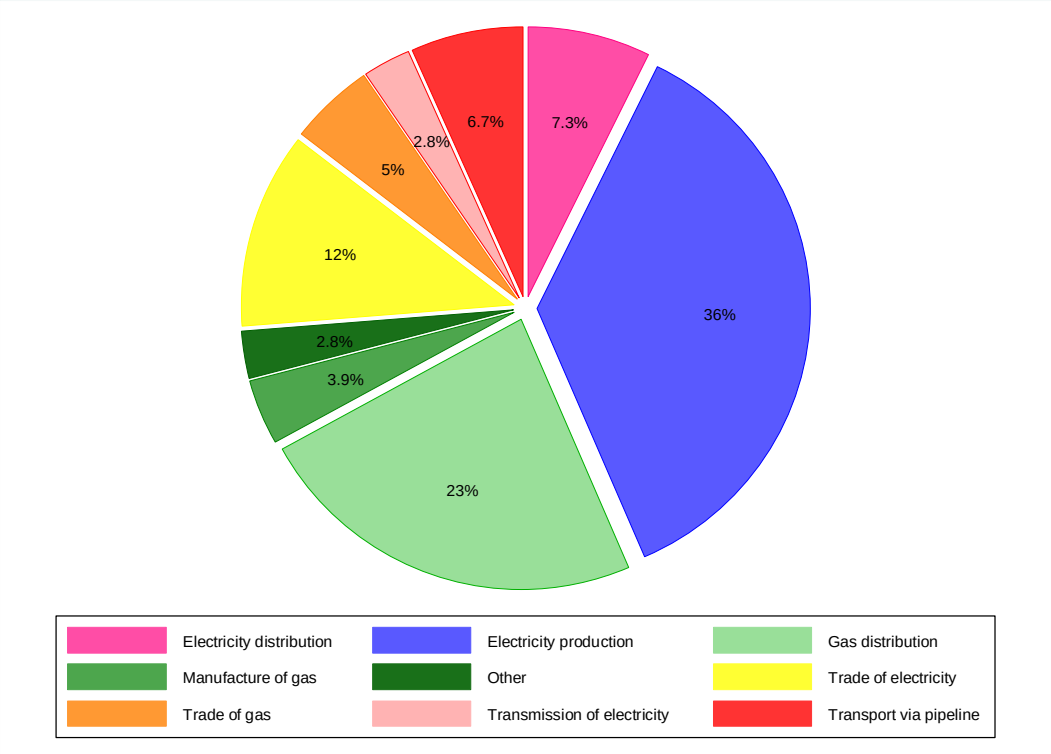
Estimated future investment by manufacturers of heavy-duty vehicles is significant. The parent company of Iveco, CNH Industrial, invested $250 million in Iveco's partnership with US-based FCV manufacturer Nikola, whose 2020 stock market debut raised $525 million in funding. Its market capitalization initially soared past those of Ford and Fiat Chrysler before settling at a level roughly equivalent to the PSA Group and Nissan by mid-2020.[77] Solaris's investment in the development of its Urbino 12 hydrogen bus has been rewarded with 57 orders within a year, and it has been in talks with the Greek government about an investment of up to €1 billion in green hydrogen for public transport.[78] For lighter-duty vehicles it is sensible to focus on Hyundai and Toyota for estimates of future investment. Hyundai has a hydrogen roadmap (FCEV Vision 2030) and has committed around €5.4 billion to hydrogen facility expansion and R&D.[79] Toyota has no public figures on hydrogen investment, but given hydrogen's key role in its sustainability strategy, the investment is likely to be of a similar size.[80]

Electricity and Gas

The 179 entities in the electricity and gas section make it the third-largest representation.[81] The categorical separation between electricity and gas companies can be artificial, because companies are registered under one primary business activity while in reality many are active in both fields.[82] In the context of the hydrogen transition, the sector's participation can mostly be divided between gas and electricity interests (Figure 3).

[73] IEA, 'The Future of Hydrogen', p. 133.
[74] Volkswagen AG, 'Hydrogen or battery? A clear case, until further notice', 7 November 2019, https://www.volkswagenag.com/en/news/stories/2019/08/hydrogen-or-battery--that-is-the-question.html#.
[75] Volkswagen AG.
[76] Daimler, 'Electromobility: Fuel cell & hydrogen are a part of it', Daimler, accessed 18 April 2020, https://www.daimler.com/innovation/case/electric/fuel-cell-hydrogen-electromobility.html; BMW, 'Hydrogen cars, fuel cells, etc.'; Groupe PSA, 'Groupe PSA to step up the momentum of its push to pass strategic plan for the second phase, 2019-2021', 26 February 2019, /en/groupe-psa-step-momentum-its-push-pass-strategic-plan-second-phase-2019-2021; Groupe Renault, 'Electric cars vs hydrogen vs hybrid: What are the differences?', Easy Electric Life, 20 January 2020, https://easyelectriclife.groupe.renault.com/en/outlook/technology/electric-hybrid-hydrogen-understanding-the-differences/.
[77] CNH Industrial, *Annual Report at December 31, 2019* (Amsterdam: CNH Industrial, 2019), p. 5. It is also registered independently as a manufacturer of other transport equipment.
[78] Ηλίας Μπέλλος, 'Σχέδιο 1 δισ. για μονάδα παραγωγής υδρογόνου στη Δυτική Μακεδονία', 28 April 2020, https://www.kathimerini.gr/economy/local/1075546/schedio-1-dis-gia-monada-paragogis-ydrogonoy-sti-dytiki-makedonia; Solaris, 'Solaris hydrogen bus tested in Paris', Solaris, 22 October 2020, https://www.solarisbus.com/en/busmania/solaris-hydrogen-bus-tested-in-paris-1152.
[79] Hyundai, *Hyundai Motor Group Reveals 'FCEV Vision 2030'* (Seoul: Hyundai, 2018).
[80] Toyota, *Sustainability Data Book 2019* (Tokyo: Toyota, 2019).
[81] 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. This adds another group of companies, including GRTgaz, Teréga, Gasunie, and Northern Gas Networks.
[82] Engie (trade of gas through mains), EDP (production of electricity), Vattenfall (trade of electricity), and Iberdrola (distribution of electricity) are examples of this.

Figure 3: Divisions of electricity and gas representation



Source: author, based on hydrogen association data and business activity registrations.

Natural Gas

Natural gas companies (i.e. those active in the mid- and downstream segments of the natural gas market)[83] constitute almost half of the electricity and gas section. Many have local, regional, or national monopolies on gas transmission.[84] Support for hydrogen is driven by concerns about the long-term decline of demand for natural gas,[85] increasingly regulated CO_2 emissions, and lack of diversification. Hydrogen offers an alternative that combines the possibility to retain gas infrastructure as an asset while creating new business and increasing security of supply. It also addresses the ever-stricter CO_2 regulations and/or carbon pricing. These affect the industry directly, e.g. via taxes,[86] and indirectly through a societal push for decarbonization. This push reaches natural gas companies via several layers of government (i.e. UN Sustainable Development Goals, EU climate targets, national and local legislation), and via direct societal pressure. Binding climate regulations affect practically all companies in the natural gas industry.[87]

[83] Distribution of gaseous fuels through mains; manufacture of gas; trade of gas through mains; transport via pipeline.
[84] 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 as well as Northern Gas Networks in the UK. Local operators include, for instance, those of Vienna and Essen.
[85] Enagas, *Annual Report 2018: Energy for the Future* (Madrid: Enagas, 2019), p. 88; Fluxys Belgium, *Annual Financial Report 2018* (Brussels: Fluxys, 2018), p. 133; Gasunie, *Gasunie Annual Report 2019* (Groningen: Gasunie, 2020), p. 105; p. 143.
[86] Enagas, *Annual Report 2018: Energy for the Future*, p. 88.
[87] Enagas, p. 16; Ervia, *Annual Report and Financial Statements* (Cork: Ervia, 2018), p. 31; Fluxys Belgium, *Annual Financial Report 2018*, p. 133; Gasunie, *Gasunie Annual Report 2019*, p. 143; SGN, *SGN Annual Report 2019* (Horley, UK: SGN, 2020), p. 16; VNG, *Strong Together – Unity in Diversity: Annual Report 2018* (Leipzig: VNG, 2019), p. 50.

Hydrogen is a strategic business opportunity, as listed by Snam, Gasunie, and Enagás, while Ørsted refers to its potential, and Engie notes its conviction about hydrogen's role in the energy transition.[88] This goes beyond revenue growth. The transport of hydrogen (and other green gases, CCS, and/or heat) is an opportunity to diversify.[89] Diversification creates more independent revenue streams, but also enhances security of energy supply. This is notable given the EU's strained ties with Russia, but also because of the volatility of renewable energy generation. Several operators are investing in power-to-gas experiments.[90] Operators are also experimenting with blending hydrogen into the natural gas system.[91] Snam – Europe's biggest pipeline operator – has invested €1.4 billion in its SnamTec division (about 20% of the company's total investment), publicly connecting this to hydrogen projects.[92] It is explicitly thinking about using the 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.[93]

Dutch gas operator Gasunie also has ambitious hydrogen plans and high expectations for hydrogen in Belgium, Germany, and the Netherlands.[94] It is part of both a consortium[95] that is exploring a €500 million investment in a hydrogen value chain around a power station near Groningen, and another[96] that is backing H-vision, a €2 billion blue hydrogen project to kickstart the hydrogen economy in Rotterdam.[97] The investment decision is pending.[98] In early 2020 Gasunie announced its most ambitious project to date with Shell and Groningen Seaports. This NorthH_2 plan has an estimated cost of tens of billions of euros, envisioning a 10 GW offshore wind park with Europe's largest green hydrogen factory, where operations should start in 2027.[99] However, funding for these plans has not been secured, leaving their future in doubt.[100] The project falls within the wider development strategy

[88] Engie, 'Press release ENGIE 2017 Results: A successful strategic repositioning poised for growth' (Engie, 8 March 2018), p. 6; Ørsted, *Ørsted Annual Report 2019* (Copenhagen: Ørsted, 2020), p. 25; Enagas, *Annual Report 2018: Energy for the Future*, p. 18; Snam, *The Hydrogen Challenge: The Potential of Hydrogen in Italy* (Milan: Snam, 2019); Gasunie, *Gasunie Annual Report 2019*, p. 48.
[89] Gasunie, *Gasunie Annual Report 2019*, p. 105; VNG, *Strong Together – Unity in Diversity: Annual Report 2018*, p. 47.
[90] See for example Christina Wulf, Jochen Linßen, and Petra Zapp, 'Review of power-to-gas projects in Europe', *Energy Procedia* 155 (November 2018): pp. 367–78, https://doi.org/10.1016/j.egypro.2018.11.041.
[91] For instance GRTgaz, GAZ-System, Snam, Gasunie, and Enagás.
[92] Reuters, 'Italy's Snam pledges to spend more money on green business', *Reuters*, 21 November 2019, https://www.reuters.com/article/us-snam-plan-idUSKBN1XV0SR; Snam, 'Snam and Hydrogen', Snam, 8 October 2019, https://www.snam.it/en/hydrogen_challenge/snam_hydrogen/. It is unclear how much will go to hydrogen projects; a lot goes to other projects. See: Snam, 'Snam: Increasing results, more investments in the energy transition in the 2019-2023 Plan', Snam, 21 November 2019, https://www.snam.it/en/Media/Press-releases/2019/Snam_increasing_results_2019-2023_plan.html.
[93] McKinsey & Company, 'Role of hydrogen in the energy transition and implications for Italy', 11 October 2019; Snam, *The Hydrogen Challenge: The potential of hydrogen in Italy*; A. J. M van Wijk and F. Wouters, 'Hydrogen: The bridge between Africa and Europe', in *Shaping an Inclusive Energy Transition*, eds. M.P.C. Weijnen and Z. Lukszo (Dordrecht, the Netherlands: Springer, 2020).
[94] Gasunie, *Gasunie Annual Report 2019*.
[95] With Equinor and Vattenfall.
[96] 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.
[97] H-vision, *Feasibility Study Report: Blue Hydrogen as Accelerator and Pioneer for Energy Transition in the Industry* (Rotterdam: H-vision, 2019); Gasunie, *Gasunie Annual Report 2019*.
[98] Port of Rotterdam, 'H-Vision kicks off the hydrogen economy in Rotterdam', Port of Rotterdam, 2 July 2019, https://www.portofrotterdam.com/en/news-and-press-releases/h-vision-kicks-off-the-hydrogen-economy-in-rotterdam.
[99] Gasunie, *Gasunie Annual Report 2019*; Gasunie, 'Europe's largest green hydrogen project starts in Groningen', Gasunie, 27 February 2020, https://www.gasunie.nl/en/news/europes-largest-green-hydrogen-project-starts-in-groningen; Bert Van Dijk, 'Shell en Gasunie plannen 's werelds grootste offshorewindpark in Groningen', *Financieel Dagblad*, 27 February 2020, https://fd.nl/ondernemen/1336289/shell-en-gasunie-plannen-wereldprimeur-voor-groningen-met-duurzaam-miljardenproject.
[100] Financieel Dagblad, 'Geen woorden maar daden nodig voor waterstofproject Noord-Nederland', FD.nl, 2 March 2020, https://fd.nl/opinie/1336625/geen-woorden-maar-daden-nodig-voor-waterstofproject-noord-nederland; Bert van Dijk, 'Plannen voor ambitieus offshore windpark met scepsis begroet', *Financieel Dagblad*, 1 March 2020, https://fd.nl/ondernemen/1336479/plannen-voor-ambitieus-offshore-windpark-met-scepsis-begroet.

for a hydrogen cluster in the northeast of the Netherlands, for which allocated private investment up to 2030 amounts to €2.8 billion.[101]

The range of these investment plans, even though often still unconfirmed, is a good indicator of the range of annual hydrogen investment that can be expected from natural gas companies in the coming years. Ambitious hydrogen investment plans, like those of Snam and Gasunie, are likely to become more common when considering the above factors.

Electricity

Most other companies in this section are active in the electricity sector. They include some of the largest companies in several countries, such as Vattenfall, EDP, EDF, Iberdrola, Innogy, Statkraft, Endesa, SSE, and PGE. The sector is important for the hydrogen transition, as the availability of (renewable) electricity is a decisive factor. However, despite the numerous electricity companies in hydrogen associations, they do not seem as invested in hydrogen as natural gas companies. Although the presence of renewable electricity suppliers and distributors confirms the IEA's view of them being hydrogen proponents, their relative lack of enthusiasm is worth noting.[102] For most electricity companies, it is a technology with potential but is not an important part of their business strategy. In annual reports from E.ON, EDF, EDP,[103] Enel, Innogy, Vattenfall, Statkraft, Iberdrola, Endesa, and PGE there is limited attention paid to hydrogen.[104] Verbund is one of the very few to devote serious attention to green hydrogen, complemented by Vattenfall's concrete goal of 100 MW green hydrogen capacity by 2025.[105] Fortum and Vattenfall have hydrogen position papers, but mostly focus on the EU policies necessary to kickstart the transition.[106] There appear to be no concrete investment agendas for hydrogen, and attention is mostly limited to R&D as reflected in EDF, Fortum, and Statkraft reports,[107] and implied by Iberdrola calling it an immature technology.[108]

Nor are demonstration projects being financed with much private funding. One example is Vattenfall's target of 100 MW green hydrogen capacity. Half of this will come from the 50 MW HySynGas project in Germany, that mostly relies on funding from the German Federal Ministry for Economy and Energy.[109] The HYBRIT steel decarbonization project sees the Swedish government fund 35% of the SEK 1.4 billion (€130 million) total investment.[110] The Wind2HyRail plan relied on EU funding, and fell through

[101] Samenwerkingsverband Noord-Nederland, *Investment Agenda Hydrogen Northern Netherlands: Heading for emission-free hydrogen at commercial scale* (Groningen: Samenwerkingsverband Noord-Nederland, 2019).
[102] IEA, 'The Future of Hydrogen', p. 19.
[103] There is no mention of hydrogen in EDP's annual reports of 2018 and 2019, each with well over 400 pages. Nor is it named in the 300+ pages of the 2017 and 2018 sustainability report (the 2019 version has not been published at the time of writing).
[104] E.ON, *Annual Report 2019* (Essen: E.ON, 2020); EDF, *Universal Registration Document* (Paris: EDF Group, 2020); EDP – Energias de Portugal, *Annual Report 2018* (Lisbon: EDP - Energias de Portugal, 2018); EDP – Energias de Portugal, *Annual Report 2019* (Lisbon: EDP - Energias de Portugal, 2019); Enel, *Consolidated Annual Report 2019* (Rome: Enel, 2020); Innogy, *Annual Report 2018* (Essen: Innogy, 2019); Vattenfall, *Annual and Sustainability Report 2019* (Solna, Sweden: Vattenfall, 2019); Statkraft, *Annual Report Statkraft 2019* (Oslo: Statkraft, 2019); Iberdrola, *Integrated Report 2020* (Madrid: Iberdrola, 2020); Endesa, *Sustainability Report 2018* (Madrid: Endesa, 2018); Endesa, *Activities Report 2018* (Madrid: Endesa, 2018); PGE Polska Grupa Energetyczna, *Q4 & 2018 Financial and Operating Results* (Warsaw: PGE Polska Grupa Energetyczna, 2018).
[105] Verbund, *Integrated Annual Report 2019* (Vienna: Verbund, 2020); Vattenfall, *Annual and Sustainability Report 2019*, p. 2.
[106] Fortum, 'EU strategy for long-term greenhouse gas emissions reductions: Fortum's key messages for the preparation of the strategy' (Fortum, 1 October 2018); Vattenfall, 'Green hydrogen for sector integration: 1st meeting of the Hydrogen Energy Network - Gunnar Groebler' (Vattenfall, 26 June 2019).
[107] EDF, *Universal Registration Document*, p. 98; Fortum, *CEO's Business Review* (Espoo, Finland: Fortum, 2019), p. 5; Statkraft, *Annual Report Statkraft 2019*, p. 25.
[108] Which is the only time hydrogen is mentioned in its 2019 sustainability report of 510 pages. Iberdrola, *Statement of Non-Financial Information: Sustainability Report – Financial Year 2019* (Madrid: Iberdrola, 2019), p. 381.
[109] ARGE Netz, Vattenfall, and MAN Energy Solutions, 'Pressemitteilung - HySynGas unter den Gewinnern des Ideenwettbewerbs Reallabore der Energiewende', 19 July 2019.
[110] The other 65% is split equally between a consortium of LKAB, SSAB, and Vattenfall; HYBRIT, 'HYBRIT toward fossil-free steel', Hybrit, accessed 27 April 2020, http://www.hybritdevelopment.com/hybrit-toward-fossil-free-steel.

at the request of the consortium,[111] and the SEK 6 million (€550,000) planning phase for an 18 MW hydrogen plant in Gothenburg with Preem has been 50% financed by the Swedish Energy Agency.[112] An investment decision on the H2M project in Eemshaven (the Netherlands) with Gasunie and Equinor is still pending. These are small sums in the context of Vattenfall's 2020 and 2021 total investments of SEK 58 billion (€5.3 billion).[113] There are exceptions, such as EDF taking a 20%+ stake in McPhy for €16 million, but these are relatively minor sums in comparison to both the sectors' other investments and the investment in hydrogen from other sectors.

Electricity producers were expected to be supportive owing to hydrogen's ability to stabilize the volatility that comes with high levels of renewables-based electricity production.[114] Approximately 3,600 terawatt-hours (TWh) of electricity is needed to increase the global share of hydrogen produced through electrolysis from 2% to 100%, which is more than the EU produces annually.[115] Electricity companies still see the need to solve the long-term intermittency challenges as an issue.[116] However, it seems from the above that investment in developing these renewables is for now prioritized over investment in solving the intermittency problems that are expected to emerge. Some companies with large renewables portfolios have enough geographic spread to mitigate these challenges from a business risk perspective.[117] Others are based in areas where hydropower provides the flexibility to accommodate intermittent renewables.[118] In some cases, (intermittent) renewables remain negligible compared to other options that are set to remain dominant for the time being, as is the case in Poland (coal) and France (nuclear). Even where balancing intermittency is acknowledged as a major challenge, such as by Innogy in Germany or EDP in Portugal, hydrogen is simply not really considered as a solution in the power sector – and is not named once in annual reports.[119] EDP instead, for instance, looks towards demand-side management technologies, interconnectivity between electricity systems, and flexible consumption structures.[120]

Electricity producers see more use for green hydrogen in decarbonising industrial feedstocks than in the power sector. Verbund, Vattenfall, Fortum, and Ørsted are explicit in this.[121] For Verbund and Vattenfall, 'sector coupling' is especially relevant in the steel industry, as reflected in the projects involving Voestalpine in Austria and HYBRIT in Sweden. Other companies might join similar projects that aim to decarbonize heavy industries through green hydrogen.

Pressure from governments and stricter regulation seem key motivations for the electricity producers that do consider hydrogen. The involvement of Verbund is closely linked to Austria's 2030 climate target of 100% renewable electricity.[122] Vattenfall links its hydrogen projects in the Netherlands to the Dutch Climate Act and Climate Agreement, and Fortum, too, links hydrogen activities closely to mitigating business risk scenarios related to major government intervention.[123] More regulation, resulting from more ambitious climate policies in the EU or Russia, create greater business risks. Green hydrogen is

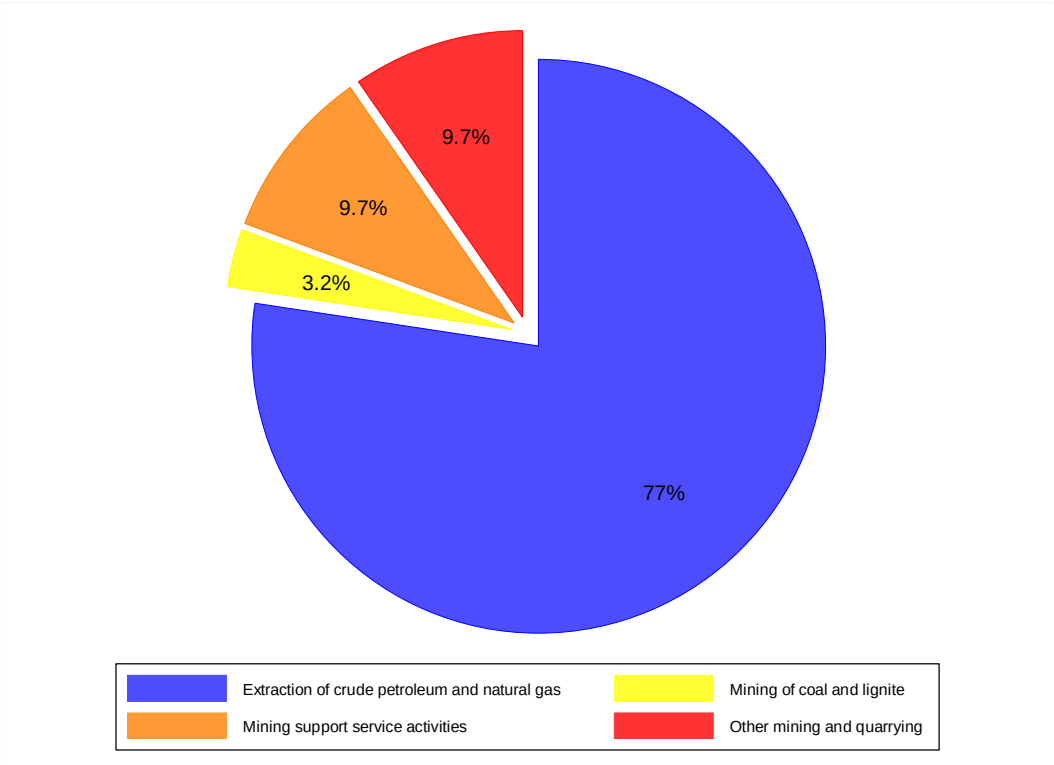
[111] FCH JU, *Report on the Budgetary and Financial Management 2018* (Brussels: Fuel Cells and Hydrogen Joint Undertaking, 2019).
[112] Vattenfall and Preem, 'Press release – Swedish Energy Agency supports Preem and Vattenfall's planned hydrogen gas plant in Gothenburg', 4 July 2018.
[113] Vattenfall, 'Our Investment Programme', Vattenfall, accessed 27 April 2020, https://group.vattenfall.com/investors/understanding-vattenfall/investment-plan.
[114] For example Barbara Widera, 'Renewable hydrogen implementations for combined energy storage, transportation and stationary applications', *Thermal Science and Engineering Progress*, No. 16 (2020): pp. 1–8.
[115] IEA, 'The Future of Hydrogen'.
[116] For example EDF, *Universal Registration Document*, p. 98; EDP – Energias de Portugal, *Annual Report 2018*, p. 39; EDP – Energias de Portugal, *Annual Report 2019*, p. 36.
[117] Enel, *Consolidated Annual Report 2019*, p. 64; Iberdrola, *Integrated Report 2020*, p. 84; Statkraft, *Annual Report Statkraft 2019*, p. 12.
[118] This is (or could be) the case in the Alpine region, the Balkans, the Nordics, and to a lesser extent the Iberian Peninsula.
[119] Innogy, *Annual Report 2018*, p. 100; EDP – Energias de Portugal, *Annual Report 2019*, p. 36.
[120] EDP – Energias de Portugal, *Annual Report 2019*, p. 36.
[121] Verbund, *Integrated Annual Report 2019*, pp. 95–96; Vattenfall, *Annual and Sustainability Report 2019*, p. 55; 64; Fortum, *Sustainability 2019* (Espoo, Finland: Fortum, 2019), p. 25; Ørsted, *Ørsted Annual Report 2019*, p. 5.
[122] *Integrated Annual Report 2019*, pp. 95–96.
[123] Vattenfall, *Annual and Sustainability Report 2019*, p. 28; Fortum, *Sustainability 2019*, p. 25.

also in this scenario mostly used to decarbonize hard-to-abate sectors. Still, for many electricity companies with similar obligations, hydrogen remains a niche technology, albeit with potential. It is difficult to anticipate the sector's projected hydrogen investment agenda. Companies from the sector participate in partnerships financed by others, but remain reluctant to commit the full scale of their own investment capabilities.

Mining and Quarrying

The mining and quarrying section has only 31 registrations.[124] Yet, the support of large oil and gas companies, as well as refineries, draws a lot of attention. Before focusing on the oil and gas sector, which constitutes over 75% of this section's hydrogen association members, it should be noted that there are several mining companies 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.[125] 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. That is less in line with the aforementioned expectations.

Figure 4: Divisions of mining and quarrying representation



Source: author, based on hydrogen association data and business activity registrations.

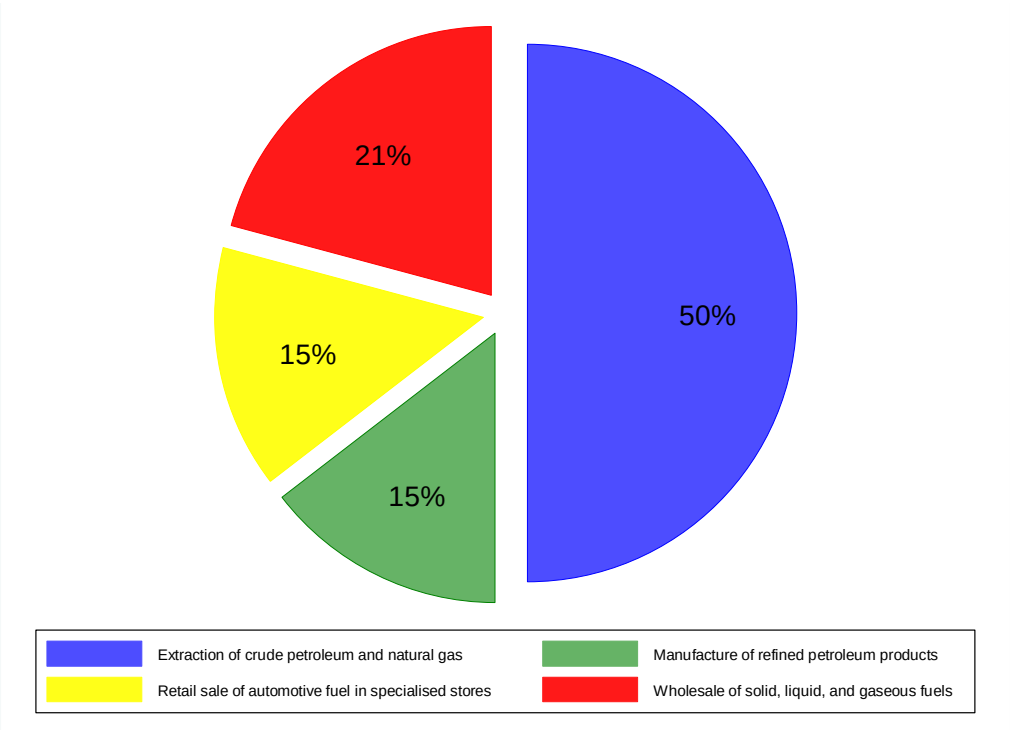
Oil and (Upstream) Natural Gas Industry

Three-quarters of the mining and quarrying section consists of companies involved in the petroleum value chain and the extraction of natural gas (Figure 4).[126] The focus on extraction is, however, artificial.

[124] This number involves companies registered under NACE section B: Mining and quarrying. Refineries do not fall under this economic section, but under NACE C19: Manufacture of coke and refined petroleum products. See note 127.
[125] See for example Victor, Heller, and Victor, 'Political Economy and the Hydrogen Revolution'; Winter, 'Into the Hydrogen Energy Economy?'.
[126] Mid- and downstream natural gas companies are part of the section on electricity and gas; this section concerns upstream activities. This is partly because a significant number of companies in this section are integrated companies that work on both oil and natural gas extraction.

The large oil and gas companies in particular are active throughout the entire value chain. For this reason, we have included in this section several other business activities, notably 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 (Figure 5).[127] With all these included, the sector numbers approximately 48 entities.

Figure 5: Divisions of oil and gas industry representation



This sector is critical despite the relatively small number of entities, because 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 fall in this category and are members of several hydrogen associations: Shell, BP, and Total.[128] 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. Furthermore, refineries are among the largest hydrogen consumers, responsible for a third of global hydrogen consumption, which naturally gives them clout.[129] Hydrogen production is responsible for roughly 20% of refineries' CO_2 emissions.[130] The oil and gas sector can use blue and green hydrogen to decrease its emissions by a significant amount, and is crucial in the decarbonization of other sectors.

Another reason why the sector matters is that there seems to be serious interest in hydrogen beyond mere membership of coalitions. BP, Equinor, Shell, and Total are all founding and steering members of the Hydrogen Council. In annual and sustainability reports of these same four companies, hydrogen

[127] 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 filling stations. From G46.7.1 and G47.3 H2point, FaktorPlus Green Technology, and H2 Mobility Deutschland have been excluded, as they provide non-fossil fuels.
[128] Fortune, 'Global 500', Fortune, 2019, https://fortune.com/global500/2019/.
[129] IEA, 'The Future of Hydrogen', p. 91.
[130] IEA, p. 91.

receives considerable attention – more so than, for instance, from large electricity companies.[131] There appears to be consensus about the important role that hydrogen can play in the future energy system. Shell, Repsol, OMV, and BP appear to be much more open about green hydrogen, while Equinor emphasizes blue hydrogen.[132]

However, the extent to which this translates into concrete investment is not clear. There is clearly some willingness to invest. In the mid-2000s BP had already put forward a proposal for a 350 MW blue hydrogen plant with a $1 billion price tag, which ultimately only fell through because of government inaction.[133] BP built a green hydrogen plant for its refinery in Lingen, Germany, in 2018 and is exploring a 250 MW green hydrogen plant in Rotterdam.[134] Shell is partnering with Gasunie and Groningen Seaports in the NorthH_2 project, besides smaller projects such as the 10 MW REFHYNE green hydrogen project for its Rhineland refinery.[135] There is clear support for expanding the HRS network, with the $400 million German H2 MOBILITY project as one of the most ambitious plans. OMV, Shell, and Total are partners of this programme,[136] which is on course to deliver 100 HRSs in 2020 and aims to deliver 300 more by 2023.[137] These projects receive government support. The REFHYNE project highlighted by Shell is funded by the European Commission.[138] Refilling stations in (for instance) the UK, the Netherlands and Germany are named as successes, but are all predominantly financed through multi-million subsidies from national governments and/or the EU.[139] The H2 MOBILITY project, too, is funded by the German federal government and the EU.[140]

The sector is looking to hydrogen because of concerns about the sustainability of the business model during the energy transition. The increasingly narrow time frame for this transition raises questions from investors. Shell is an example: its sustainability, energy, and annual reports depict a company under pressure from shareholders to show that it can be profitable in the medium to long term when its core business is expected to decline.[141] BP and Shell are in the crosshairs of activist shareholders who

[131] BP, *BP Sustainability Report 2019* (London: British Petroleum, 2020); BP, *BP Annual Report and Form 20-F 2019* (London: British Petroleum, 2020); Equinor, *2019 Annual Report and Form 20-F* (Stavanger, Norway: Equinor, 2020); Equinor, *2019 Sustainability Report* (Stavanger, Norway: Equinor, 2020); Shell, *Sustainability Report 2019* (Rijswijk, Netherlands: Royal Dutch Shell, 2020); Shell, *Annual Report and Accounts for the Year Ended December 31, 2019* (Rijswijk, Netherlands: Royal Dutch Shell, 2020); Total, *Integrating Climate Into Our Strategy* (Courbevoie, France: Total, 2019); Total, *Universal Registration Document 2019 – Including the Annual Financial Report* (Courbevoie, France: Total, 2020).

[132] OMV, *Sustainability Report 2019* (Vienna: OMV, 2020), p. 76; Repsol, 'Repsol will be a net zero emissions company by 2050', Repsol, 2 December 2019, https://www.repsol.com/en/press-room/press-releases/2019/repsol-will-be-a-net-zero-emissions-company-by-2050.cshtml; Shell, *Sustainability Report 2019*, p. 53; BP, *BP Sustainability Report 2019*, p. 27; Equinor, *2019 Sustainability Report*, p. 27.

[133] Terry Macalister, 'BP scraps £500m Scottish carbon capture scheme', the Guardian, 25 May 2007, http://www.theguardian.com/business/2007/may/25/oilandpetrol.news; Meadowcroft and Langhelle, *Caching the Carbon*, p. 170.

[134] In a consortium with Nouryon and the Port of Rotterdam. BP, 'BP joins the Hydrogen Council', BP Global, 11 June 2019, https://www.bp.com/en/global/corporate/news-and-insights/bp-magazine/bp-joins-hydrogen-council.html; IEA, 'The Future of Hydrogen', p. 97.

[135] Shell, *Sustainability Report 2019*, p. 53.

[136] As well as Air Liquide, Daimler, and Linde.

[137] H2 MOBILITY, 'H2 MOBILITY: We are building the filling station network of the future.', H2 Mobility, 2020, https://h2.live/en/h2mobility; Nikolas Iwan, 'H2 MOBILITY: Fuelling Hydrogen' (H2 Mobility, 18 September 2017).

[138] IN4Climate.NRW, 'REFHYNE: The world's largest PEM hydrogen electrolysis plant', Refhyne, 2019, https://www.in4climate.nrw/en/best-practice/projekte/2019/translate-to-englisch-refhyne/; REFHYNE, 'About', REFHYNE, 28 February 2018, https://refhyne.eu/about/.

[139] Adeline Adelski, 'Shell et Air Liquide inaugurent la 75ème station hydrogène d'Allemagne', H2mobile, 1 October 2019, https://www.h2-mobile.fr/actus/shell-air-liquide-inaugurent-75e-station-hydrogene-allemagne/; Shell, 'Shell and ITM Power launch new hydrogen refuelling site at Beaconsfield', 27 March 2018, https://www.shell.co.uk/media/2018-media-releases/new-fuelling-station-at-beaconsfield.html; Shell, 'Shell bouwt mee aan netwerk van waterstofstations in Nederland', 21 August 2018, https://www.shell.nl/media/persberichten/2018-media-releases/shell-is-building-network-of-hydrogen-stations.html; Allister Thomas, 'Consortium including Shell given £8.8million grant to improve use of hydrogen vehicles - News for the oil and gas sector', *Energy Voice* (blog), 26 March 2018, https://www.energyvoice.com/otherenergy/167123/consortium-including-shell-given-8-8million-grant-to-improve-use-of-uk-hydrogen-vehicles/.

[140] H2 MOBILITY, 'H2 Mobility'.

[141] Shell, *Sustainability Report 2019*; Shell, *Shell Energy Transition Report* (Rijswijk, Netherlands: Royal Dutch Shell, 2018); Shell, *Annual Report and Accounts for the Year Ended December 31, 2019*.

question their longevity on environmental and business grounds, including institutional shareholders.[142] Blue hydrogen has other benefits for maintaining profitability too.[143] The rights to (now foregone) emissions can be sold, and captured CO_2 can be used for enhanced oil recovery. The widespread deployment of CCS also prolongs the life of the fossil fuel market (and related capital assets). Hydrogen would allow the creation of a business along a completely new value chain.[144] This is a welcome perspective for oil companies facing calls to diversify and questions about their long-term profitability.

Other actors in the oil value chain, notably refineries and fuel distributors, are looking at hydrogen because of similar profitability concerns. Rising carbon prices and pressure to decrease emissions are motivations for refineries to consider low(er)-carbon hydrogen, amplified by developments in the fuel sector that demand lower sulphur content, requiring more hydrogen input.[145] The profit margins of refineries are tight, and higher emission prices carry business risks. Investment in CCS allows large emission reductions and decreases this risk. Filling stations also see the potential of hydrogen. The rise of BEVs threatens their business model. In a BEV world, there is little use for traditional filling stations: fast-chargers can be located anywhere, and the infrastructural need to handle fossil fuels (including safety and quality control regulations) that justified specialized filling stations as a concept will be gone. The transition to hydrogen would create a situation where filling stations largely retain the function and business model they currently have.

It may appear odd then that the sector is so hesitant to invest more in this area. One explanation given by the IEA,[146] and confirmed by BP, is the absence of real carbon pricing. BP states that 'robust policies, including carbon pricing, will be required to incentivize the investment required to exponentially grow the use of hydrogen', OMV adds legal uncertainty (particularly regarding storage) for CCS in various countries, including in Austria, and Equinor also expects government action to trigger hydrogen investment.[147]

Transporting and Storage

With 47 entities this section has, like mining and quarrying, few registrations but some key actors.[148] The main actors are in land transport (excluding pipelines) and the major Benelux ports. Some major airports are members too, such as London Heathrow Airport and Fraport (operating amongst others Frankfurt Airport). However, they mostly focus on decarbonizing airport services (e.g. airport buses), rather than pushing for hydrogen in aviation. The following discusses the motivations behind the support from land transport companies and ports.

Land Transport

The 24 land transport companies include Deutsche Bahn, Transdev, RATP Group (including public transport in Paris), and SNCF (including subsidiary Keolis), as well as the national railway companies of Latvia (Latvijas Dzelzceļš) and Slovakia (ŽSSK). At the local level, it includes the public transport

[142] Lucy Burton, 'Shell backers push for plan to replace leader Ben van Beurden after historic cut to payout', *Daily Telegraph*, 2 May 2020, https://www.telegraph.co.uk/business/2020/05/02/backers-push-plan-replace-leader-ben-van-beurden-historic-cut/; Adam Vaughan, 'BP shareholders urged to reject chief's £9m pay package', *The Guardian*, 15 May 2017, http://www.theguardian.com/business/2017/may/15/bp-shareholders-urged-reject-executive-pay-package; Adam Vaughan, 'Shell faces shareholder challenge over climate change approach', *The Guardian*, 20 May 2018, http://www.theguardian.com/business/2018/may/20/shell-faces-shareholder-challenge-over-climate-change-approach-paris-climate-deal; Adam Vaughan, 'Shell investors revolt over pay and maintain pressure over climate change', *The Guardian*, 22 May 2018, https://www.theguardian.com/environment/2018/may/22/shell-climate-change-executive-pay-oil-carbon-emissions-agm.

[143] Equinor, *2019 Annual Report and Form 20-F*, 48; Equinor, *2019 Sustainability Report*, 27; IEA, 'The Future of Hydrogen', p. 96; Meadowcroft and Langhelle, *Caching the Carbon*.

[144] Equinor, *2019 Annual Report and Form 20-F*, p. 48.

[145] IEA, 'The Future of Hydrogen', p. 96.

[146] IEA, p. 96.

[147] Equinor, *2019 Sustainability Report*, p. 28; OMV, *Annual Report 2019* (Vienna: OMV, 2020), p. 29; BP, *BP Sustainability Report 2019*, p. 27.

[148] 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 text on electricity and gas.

operators of Cologne, Gdansk, Gelsenkirchen, Lisbon, Riga, Tallinn, Wiesbaden, and Zaragoza. Generally, the former focus on trains and the latter on buses. The motivation for local operators is simply to decarbonize bus transport. Companies see hydrogen as a solution, often with EU funding. The €16.1 million H2Nodes project introduced 10 hydrogen trolley ('Hytrolley') buses in Riga and constructed the first public HRS in Latvia.[149] Reducing public transport emissions is the motivation for hydrogen buses in Gdansk, 35 buses in Cologne as part of Projekt Null Emission, and 10 hydrogen buses in Zaragoza.[150] Previous projects, as in Aberdeen, had similar goals. The situation is somewhat different for interurban transport, which mostly concerns trains. One-fifth of traffic and 40% of the European mainline rail network is still diesel operated.[151] Given the high costs of electrifying lower-intensity railroads, viable decarbonization alternatives are preferred. Hydrogen rail ('hydrail') or fuel cell and hydrogen (FCH) trains are an option. French rail operators SNCF and Keolis see hydrogen as a solution to reduce the carbon intensity of consumed energy.[152] Deutsche Bahn is pursuing hydrogen to fulfil the environmental goals of its regional business unit (which includes buses), hoping to replace diesel.[153] FCH trains can already be price competitive in some regions (e.g. Scandinavia) for specific train types.[154] The first FCH trains have been operating in Germany since 2018, in France there is a €150 million order for 15 trains to start operating in 2022, and there are similar projects in Austria, Denmark, the Netherlands, Norway, Sweden, and Switzerland.[155]

Ports and warehousing

An additional 13 entities form a cluster of Benelux ports that explicitly support hydrogen.[156] 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 projects are being explored, with those in Groningen and Rotterdam at the most advanced stage. That is in addition to the decarbonization of some direct port services with hydrogen, such as the introduction of hydrogen tugs in Antwerp.

The key reason for this support (aside from emission reductions) seems to be an acceptance of the changing role for the ports because of 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 industrialized hinterland (including the Ruhr Area), and form the heart of the biggest cluster of heavy (petro)chemical industries 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 those long-term changes to stay competitive, and this is one reason why they are actively looking into the deployment of hydrogen. As ports generally fall under the ownership of local and/or national governments, it is difficult to differentiate between public

[149] Rīgas satiksme, 'H2Nodes', n.d., accessed 30 April 2020; Rīgas satiksme, 'First hydrogen filling station in Baltics put into service', p. 18 December 2019, https://www.rigassatiksme.lv/en/news/first-hydrogen-filling-station-in-baltics-put-into-service/.
[150] J.H.P., 'El hidrógeno busca su sitio en la ciudad de Zaragoza', *El Periódico de Aragón*, 6 October 2019, https://www.elperiodicodearagon.com/noticias/aragon/hidrogeno-busca-sitio-ciudad-zaragoza_1388947.html; RVK, 'Die Brennstoffzellen-Hybridbusse: Wasserstoff Für Den ÖPNV', RVK, accessed 30 April 2020, https://www.rvk.de/projekt-null-emission/die-brennstoffzellen-hybridbusse; Karolina Orcholska, 'Sustainable urban mobility plan for Gdansk: 2030' (City Mobil net, 2018).
[151] IEA, 'The Future of Rail' (Paris: International Energy Agency, 2019).
[152] *2018 Annual Report: Building Inclusive and Sustainable Mobility* (Paris: Keolis, 2018), p. 9; SNCF, *SNCF Group Annual Financial Report* (Saint-Denis, France: SNCF, 2020), p. 8.
[153] *Deutsche Bahn 2018 Integrated Report – On Track towards a Better Railway* (Berlin: Deutsche Bahn, 2019), p. 121.
[154] FCH JU, S2R JU, and Ronald Berger, 'Study on the use of fuel cells and hydrogen in the railway environment' (Luxembourg: Publications Office of the European Union; Shift2Rail Joint Undertaking; Fuel Cells and Hydrogen Joint Undertaking, April 2019).
[155] FCH JU, S2R JU, and Ronald Berger; Ouest-France, 'SNCF. Vers une commande « d'une quinzaine » de trains régionaux à hydrogène à Alstom', Ouest-France.fr, 29 August 2019, https://www.ouest-france.fr/economie/transports/sncf/sncf-vers-une-commande-d-une-quinzaine-de-trains-regionaux-hydrogene-alstom-6495985; Deutsche Deutsche Welle, 'World's first hydrogen train rolls out in Germany', Deutsche Welle, 17 September 2018, https://www.dw.com/en/worlds-first-hydrogen-train-rolls-out-in-germany/a-45525062.
[156] They fall under H52: Warehousing and support activities for transportation.

and private investment strategies for hydrogen – and annual hydrogen investment is likely to be mostly influenced by these respective governments' policies.

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.[157] 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.[158] Moreover, Antwerp already produces 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 farms, existing natural gas infrastructure (including LNG terminals), and large potential offshore storage sites to create opportunities for producing both blue and green hydrogen (Figure 6). 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 6: Map of hydrogen network in Belgium connecting Benelux ports

Source: Port of Rotterdam, 2016, p. 39.

Professional, Scientific and Technical Activities

With 577 entities, this section is the second-largest.[159] It ranges from independent energy consultants to large multinational engineering companies, although it is dominated by SMEs. Architectural and engineering activities make up over half of the registrations, with most of the remainder consisting of scientific R&D, the activities of head offices, and management consultancy and other professional, scientific, and technical activities. As this section's business classifications are diffuse and overlap within the section and with others, it is treated as one.[160]

[157] Port of Antwerp, 'Hydrogen Economy' (Port of Antwerp, n.d.), accessed 1 May 2020.
[158] Port of Rotterdam, *Facts & Figures on the Rotterdam Energy Port and Petrochemical Cluster* (Rotterdam: Havenbedrijf Rotterdam, 2016).
[159] This includes the construction section and administrative activities.
[160] Consulting and engineering businesses can, for instance, be found in each of the different classifications. Companies doing engineering activities overlap with companies operating in the construction section, and activities of head offices with the section for administrative activities – hence these sections are covered here too.

These companies are generally less internationally active than in other sections, although there are some that are active in multiple associations. These include some publicly listed fuel cell producers, such as McPhy, Proton Motor Fuel Cell, Ceres Power, and Powercell. Also included are large engineering firms like Abengoa and Arup Group, and institutions for testing, inspection and certification like TÜV, Kiwa, and DNV GL. Further of note are EDF subsidiaries Areva H2Gen and Areva Stockage d'Énergie. Members of this section often appear as (sub)contractors in hydrogen projects. Fuel cell producers and hydrogen specialists can be contracted to build electrolysers or fuel cell systems, with the funding coming mostly from other parties. The section is interesting because it shows a relatively broad support base, beyond big multinationals. The combination of small engineering companies with fuel cell start-ups, consultancies, and certification companies makes participation from the section worthy of note.

Most companies in this section support hydrogen to achieve business and market growth. The success of hydrogen and fuel cell start-ups is closely linked to a successful hydrogen transition. Many are small and have hydrogen technology as a core activity. This is reflected in the performance of several fuel cell producers, which have profited from renewed momentum.[161] The prospect of sales growth also goes for companies working in testing and consultancy, construction, and administrative support. Kiwa is an example: hydrogen's success would create more demand for its expertise in education about hydrogen handling, safety procedures, certification, and related knowledge-based support tasks.[162] The hydrogen transition poses many engineering challenges. Professional support services, engineers, and construction companies that have experience in solving such challenges would see demand rise.

The legitimacy gained by widening the hydrogen coalition and the added value of professional human resources in fields like engineering are invaluable components of the larger hydrogen coalition taking shape. Moreover, many start-ups in this sector can become investors in their own right as the hydrogen economy nears maturity.

Other Sections

So far, roughly 80% of the entities have been covered. That still leaves some unaddressed, such as education, information and communication, real estate activities, water and waste management, wholesale and retail trade (excluding automotive fuel),[163] public administration and defence, financial and insurance activities, and other service activities. This does not mean that they play no role in the hydrogen transition. In particular, the role of the financial sector and membership organizations (under other service activities) deserves mention.

Only 16 entities working in the financial and insurance sectors are registered as members of hydrogen associations in Europe. 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 be important 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 large investment funds can encourage industry leaders to put more emphasis on sustainability. Perhaps more importantly, the financial sector could be an important partner in enabling the investment needed to develop the hydrogen economy. The support of investment funds for hydrogen projects can catalyse the transition.

Hydrogen needs broad societal support for it to succeed. There are 44 membership organizations and environmental NGOs that are members of hydrogen associations.[164] Some campaign in support of blue hydrogen, such as the Bellona Foundation in Norway, but most have put their faith in green hydrogen,

[161] Henry Sanderson, 'Investors hit the gas on hydrogen producers', *Financial Times*, 4 February 2020, https://www.ft.com/content/5e837ff8-441b-11ea-a43a-c4b328d9061c.
[162] Kiwa, 'Kiwa's Hydrogen Services', accessed 30 April 2020, /en/themes/hydrogen/kiwas-hydrogen-services/; Kiwa, 'Kiwa and Hydrogen', accessed 30 April 2020, /en/themes/hydrogen/kiwa-and-hydrogen/.
[163] 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.
[164] This includes entities classified under other personal service activities.

including for instance Greenpeace. Most membership organizations, however, are industry societies, regional economic fora, or combinations thereof (e.g. Bayerischer Unternehmensverband Metall und Elektro, or Energigass Norge). Defining the support for the hydrogen transition among NGOs and environmental groups falls outside the scope of this paper. Still, their role in creating a broader base of support is undeniable.

Conclusion

This paper looked at 39 hydrogen associations across Europe to understand which economic sectors support the hydrogen transition in Europe, and why they do so. Several broad conclusions can be drawn from this paper.

It is clear that the support for hydrogen is broad and from a very wide spectrum of economic actors that have clear interests in the success of the hydrogen transition. These include manufacturers of motor vehicles, chemicals, (electronic and electrical) machinery, electricity and gas companies, companies active in transport and storage (including ports), and various oil and gas companies, as well as companies engaged in professional, scientific, and technical activities. Particularly strong supporters are large mid- and downstream natural gas companies, large manufacturers of chemicals, lorry and bus makers, Toyota and Hyundai as specific 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 the Benelux. Another well-performing region is the Iberian peninsula. Eastern Europe, including Russia and Ukraine, is underrepresented, as are Italy and Greece.

Motivations for support differ. Sales and market growth are important for companies pursuing professional, scientific, and technical activities, as well as manufacturers of chemicals, machinery, electronic or electrical equipment, and fabricated metals. The increasing cost of CO_2 combines with regulatory and societal pressure to decarbonize, 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 fixed assets, relevant for ports, oil and gas companies, and natural gas 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 regarding heavy road transport. Security of supply and diversifying the current business portfolio come up specifically for natural gas companies. Broader concerns about having to shift into other energy technologies as a core business are reasons for interest from the oil and gas sector, and ports.

However, the level of investment in hydrogen seems to be relatively low. Many electricity companies and European carmakers also seem to have limited interest or are hesitant to commit actual funding. Reasons for this in the mobility sector are in particular concerns about energy efficiency and the lack of infrastructure, while electricity companies appear more inclined towards other solutions (e.g. demand-side management and increased interconnectivity) to cope with the intermittency of renewables, and mostly see hydrogen as input for hard-to-abate industrial sectors. Much more (prospect for) annual hydrogen investment can be found in the basic metals sector, parts of the automotive sector (notably Toyota, Hyundai, and heavy-vehicle manufacturers), and the natural gas sector. They are followed by the chemicals (i.e. industrial gases) sector, with considerable sums being invested by machinery makers (often as intermediaries), and the transport sector.

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 (for instance in the aftermath of the COVID-19 crisis) could undermine this, which is a realistic prospect without well-crafted policy interventions.

Finally, and perhaps the most important lesson: the hydrogen transition has already begun – but it needs continued policy support and political commitment. Carbon-intensive industries such as the steel and chemicals are clearly interested and willing to invest billions, but need policy support to avoid carbon leakage to high-carbon competitors before 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. Hydrogen road vehicles still face many regulatory hurdles. There are several clusters that can serve as models and nuclei for the future European hydrogen economy, in different parts of Europe. However, these nuclei will need more public funding and regulatory support for them to grow.

Annex 1. Hydrogen associations with their geographic coverage

Hydrogen association	Geographic coverage
AeH2 – Asociación Española del Hidrógeno	Spain
Afhypac – l'Association française pour l'hydrogène et les piles à combustible	France
AP2H2 – Associação Portuguesa para a Promoção do Hidrogénio	Portugal
APPICE – Asociación Española de Pilas de Combustible	Spain
Brintbranchen – Hydrogen Denmark	Denmark
DWV – Deutsche Wasserstoff- und Brennstoffzellen-Verband	Germany
Energieagentur.NRW, Netzwerk Brennstoffzelle und Wasserstoff, Elektromobilität	North Rhine-Westphalia, Germany
H2-Netzwerk-Ruhr	Ruhr area, Germany
H2 Süd	Bavaria and Baden-Württemberg, Germany
H2.B – Zentrum Wasserstoff Bayern	Bavaria, Germany
H2BZ-Intiative Hessen – Die Wasserstoff- und Brennstoffzellen-Initative Hessen	Hessen, Germany
H2Hamburg – Wasserstoff-Gesellschaft Hamburg	Hamburg, Germany
H2IT – Associazione Italiana Idrogeno e Celle a Combustibile	Italy
H2LV – Latvijas Ūdeņraža Asociācija	Latvia
H2Platform	Netherlands
HFC – Magyar Hidrogén és Tüzelõanyag-cella Egyesület	Hungary
Ha – Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón	Aragon, Spain
HyCentA – Hydrogen Center Austria	Austria
HyCologne – Wasserstoff Region Rheinland	Cologne and Rhineland region, Germany
Hydrogen Europe	Europe
Hydrogen London	London, United Kingdom
Hydrogen Serbia	Serbia
Hydropole – The Swiss Hydrogen Association	Switzerland
HYPOS – Hydrogen Power Storage & Solutions East Germany	Eastern Germany, Germany
HYTEP – Česká vodíková technologická platforma	Czech Republic
Íslensk Nýorka	Iceland
Klaster Technologii Wodorowych	Poland
MAH2 - Македонската Водородна Асоцијација МА**H2**	North Macedonia
Norsk Hydrogenforum	Norway
NVAS – Národná vodíková asociácia Slovenska	Slovakia
NWBA – Nederlandse Waterstof & Brandstofcel Associatie	Netherlands

Plataforma Tecnológica Española del Hidrogeno y de las Pilas de Combustible	Spain
SHFCA – Scottish Hydrogen & Fuel Cell Association	Scotland, United Kingdom
UKHFCA – UK Hydrogen and Fuel Cell Association	United Kingdom
Ukrainian Hydrogen Council	Ukraine
Vätgas Sverige	Sweden
Waterstof Coalitie	Netherlands
WaterstofNet	Southern Netherlands and Flanders, Belgium
HyCymru – Wales Hydrogen Trade Association	Wales, United Kingdom