

Chapter 2

2021 Hydrogen supply and demand

September 2021



Disclaimer

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¹ The data only reflects end of 2019 as some of the sources did not have 2020 data available during the data collection process.

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Executive Summary

- Purpose:** The purpose of the hydrogen supply and demand data stream is to track changes in the structure of hydrogen supply capacity and demand in Europe. This report is mainly focused on presenting the current landscape that will allow for future year-on-year comparisons to assess the progress Europe is making with regards to deployment of clean hydrogen production capacity as well as development of demand for clean hydrogen from emerging new hydrogen applications in industry or mobility sectors.
- Scope:** The following report contains data about **hydrogen production capacity and consumption in EU countries**, together with **Switzerland, Norway, Iceland, and the United Kingdom**. Hydrogen production capacity is presented by country and by production technology, whereas the hydrogen consumption data is presented by country and by end-use sector. The analysis undertaken for this report was completed using data reflecting end of 2019.
- Key Findings:** The current hydrogen market (on both the demand and supply side) is dominated by ammonia and refining industries with three countries (DE, NL, PL) responsible for almost half of hydrogen consumption. Hydrogen is overwhelmingly produced by reforming of fossil fuels (mostly natural gas). Clean hydrogen production capacities are currently insignificant with hydrogen produced from natural gas coupled with carbon capture at 0.5% and hydrogen produced from water electrolysis at 0.14% of total production capacity.

Total hydrogen production capacity in the included countries at the end of 2019 has been estimated at **28,854 tonnes per day or 10.5 Mt per year²**. The corresponding consumption of hydrogen has been estimated at **8.4 Mt (330 TWh_{HV})**, which means an average capacity utilization of 80%.

The biggest share of hydrogen demand comes from refineries, which were responsible for 49% of total hydrogen use, followed by the ammonia industry with 31%. Together these two sectors consumed almost 4/5 of total hydrogen consumption in the covered European countries. About 13% was consumed by the chemical industry including methanol production constituting 5%. **Emerging hydrogen applications, like the transportation sector comprised a small portion of the market at 0.02% as of 2019.**

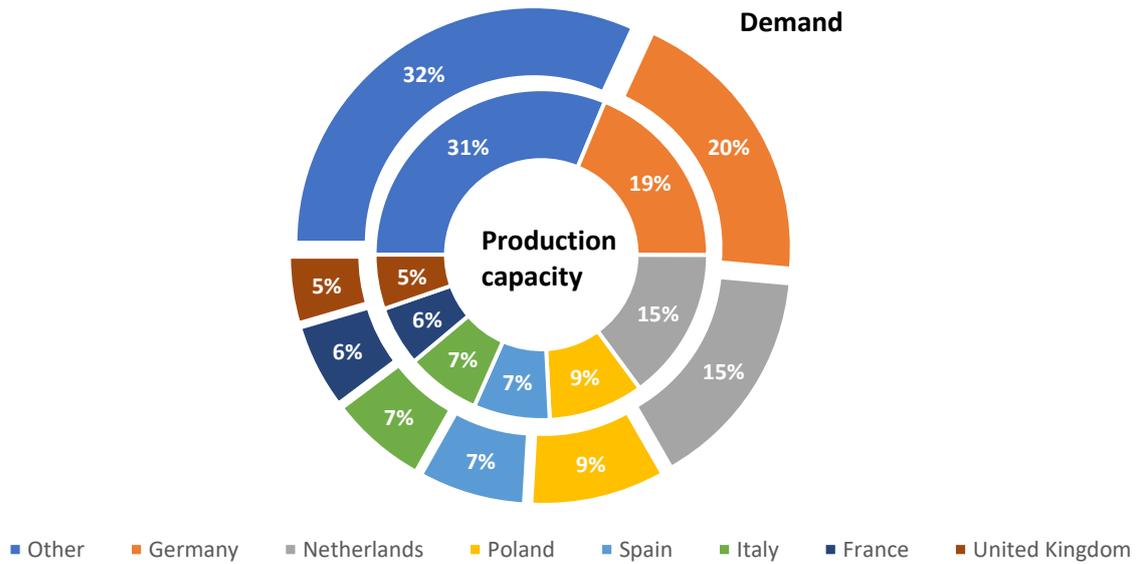
On-site captive hydrogen production was by far the most common method of hydrogen supply, comprising **20,702 tonnes per day (72%)** of all hydrogen production capacity with by-product production of **3,982 tonnes per day³** and merchant production of **3,900 tonnes per day constituting 14%** of production capacity each.

Germany was, by a significant margin, the largest European market for hydrogen, with 20% of total European hydrogen production capacity and 20% of total demand. Together with the Netherlands, Poland, and Spain, these four countries were responsible for 51.3 % of the hydrogen demand and 50.4% of production capacity.

² Excluding by-product hydrogen in the coke oven gas

³ Excluding by-product hydrogen in the coke oven gas

Figure 1. Total hydrogen production capacity and consumption by country in 2019



Source: Fuel Cells and Hydrogen Observatory

The most common method of producing hydrogen is steam reforming of natural gas (SMR). Less common are partial oxidation (POX) and autothermal reforming (ATR). SMR and natural gas are widely used for all applications including oil refining, ammonia synthesis, or any other bulk hydrogen production. Even though natural gas is the most common feedstock, steam reforming is also used with other feedstocks, which include also liquid hydrocarbons like LPG or naphtha.

Out of the 326 identified hydrogen production plants which were using fossil fuels as feedstock, only three were using carbon capture technologies:

- Grupo Sappio hydrogen production unit in Mantova, Italy with a capacity of around 1,500 Nm³/h that started operating in 2016.
- Air Liquide Cryocap installation in Port Jerome, France, capturing CO₂ from hydrogen supplied to an Exxon refinery, with a capacity of around 50,000 Nm³/h that started operating in 2015.
- Shell refinery in Rotterdam, Netherlands where CO₂ from hydrogen production is captured and sold for agricultural use as part of the OCAP project since 2004.

Total share of hydrogen production from fossil fuels with CCS/CCU was around 131 tonnes per day equating to 0.5% of the total hydrogen generation capacity.

By the end of 2019, 95 operational power-to-hydrogen (water electrolytic) projects were identified for hydrogen production. Total power of those electrolyzers was **92 MW** equalling to hydrogen generation capacity of **~1.7 t of electrolytic hydrogen per hour (0.14% of total production capacity)**. This represents a 33% increase in capacity compared to 69 MW operating in 2018.

1. Hydrogen production capacity

1.1. Summary

Hydrogen production capacity analysis has been undertaken, building on work completed by the [Roads2HyCom](#) project and ongoing work by the Hydrogen Analysis Resource Centre (HyARC). Results of this data collection include **536 hydrogen production sites**, which have been categorised by:

- type of production (captive, merchant, by-product);
- technology;
- application (only for captive hydrogen production capacity);
- country.

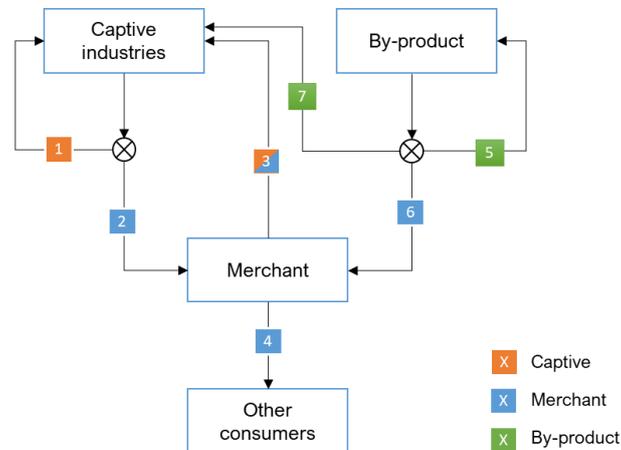
The hydrogen production plants have been divided into three main categories: captive production facilities⁴, merchant production facilities⁵ and plants where production of hydrogen is a by-product of other processes. It should be noted though, that in some cases, the boundaries between different hydrogen streams are extremely blurry. The reason is that in many cases many types of installations are clustered within the same area and it is not uncommon for an industrial park to contain all three types of installations. In this case, the flow of hydrogen between installations is more a result of current capacity utilization than a fixed design and can therefore change over time. For example, a captive hydrogen generation unit (HGU) can be used to supply hydrogen to merchant companies during times when it is underutilized for its primary purpose. As a result, the amount of hydrogen that can be used for merchant supply from excess hydrogen from captive industries, varies depending on the actual demand for hydrogen from its primary use.

⁴ On-site production of hydrogen for own consumption.

⁵ Hydrogen production dedicated for sales.

For the purpose of this analysis we have defined the boundaries between the three hydrogen production types as follows:

Figure 2. Definition of hydrogen production types by availability



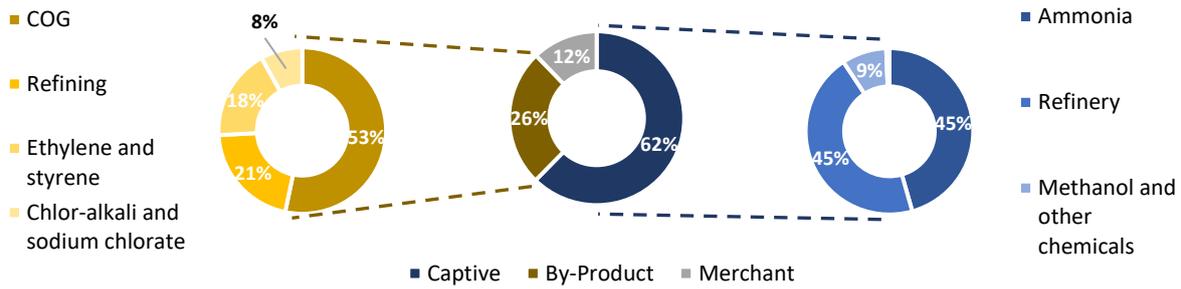
Where:

1. Captive hydrogen production on-site used exclusively for own consumption within the same facility.
2. Excess hydrogen production capacity in dedicated installations, that can be valorised and sold to external hydrogen merchant companies for resale. This has been applied only to installations, which are dedicated to supply hydrogen merchants.
3. Hydrogen produced in large industrial installations usually dedicated to serve a single customer or an industrial cluster. Usually produced in close vicinity or distributed with pipelines. Whenever we could identify that the installation was serving a single customer those installations were categorised as captive. In other cases, it was categorised as merchant.
4. Hydrogen produced for retail purposes and sold in relatively small volumes, that does not warrant building its own HGU. Usually distributed in compressed form, in cylinders or using tube trailers (200 bar), in few cases liquefied, also mostly using trucks.
5. By-product hydrogen that is vented to the atmosphere or used as feedstock for internal processes or for on-site energy generation.
6. By-product hydrogen that is purified and sold to merchants for further resale.
7. By-product hydrogen that is sold directly to nearby captive industry.

Total hydrogen production capacity in the covered European countries at the end of 2019 has been estimated at **33,125 tonnes per day**. Excluding coke oven gas hydrogen, the remaining capacity is **28,584 t per day**.

Sixty two percent (62%) of all hydrogen production capacity was designated for captive production. In reality it is even more than that, as a large portion of the merchant plants are dedicated entirely to supplying large industrial customers on-site, with only a small proportion of production capacity available to supply the wider market. By-product hydrogen provides 26% of total hydrogen production capacity, of which 53% is coke oven gas hydrogen.

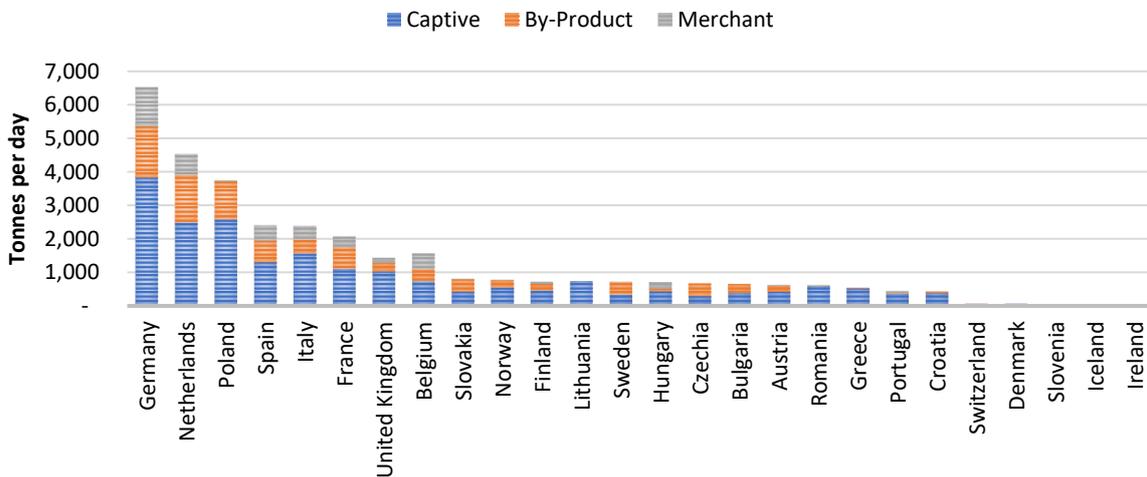
Figure 3. Structure of hydrogen production capacity



Source: Fuel Cells and Hydrogen Observatory

With almost 6,524 t per day (20% of total), Germany has by far the largest hydrogen production capacity from among the analysed countries. The Netherlands follows with 4,523 t per day (14% of total). Other countries with significant hydrogen production capacity are Poland (3,741 t per day, 11%), Spain (2,402, 7%), Italy (2,386, 7%), France (2,071, 6%), and United Kingdom (1,429, 6%).⁶

Figure 4. Total hydrogen production capacity by country



Source: Fuel Cells and Hydrogen Observatory

1.2. Captive production

On-site captive hydrogen production is by far the most common method of hydrogen supply for large hydrogen consumers. This is mainly the case for refineries, ammonia plants, methanol, and hydrogen peroxide production plants. In all those cases, the high volume of hydrogen consumed, justifies the investment in a dedicated HGU. The predominant technology for this type of installations is hydrocarbon reforming – mostly steam methane reforming (SMR).

1.2.1. Refining

The oil refining sector is the biggest hydrogen producer and consumer in the EU. Hydrogen in refineries is used for the purpose of hydrotreating and hydrocracking processes. Hydrotreatment is one of the key stages of the diesel refining process and relates to several processes such as hydrogenation, hydrodesulphurization, hydrodenitrification and hydrodemetalization. Hydrocracking involves the

⁶ Including by-product hydrogen in the coke oven gas

transformation of long and unsaturated products into products with a lower molecular weight than the feed.

Hydrocracking is by far the most common hydrogen consuming process, needing around 300 Nm³ H₂/t of product. Hydrotreating processes usually require only around 20-50 Nm³ H₂/t of product. It is also important to note that refineries not only consume but also produce hydrogen at various stages of crude oil refining, with the most hydrogen yield being generated during catalytic reformulation which produces hydrogen at a rate of 200 Nm³ H₂/t crude oil [1].

The volume of production can be substantial to the point that refineries that do not use hydrocracking usually are self-sufficient in terms of hydrogen consumption and do not require any additional dedicated hydrogen production.

All large EU refineries use fossil fuels (most commonly natural gas) as a feedstock to produce hydrogen through one of the following processes:

- reforming operations for hydrotreating;
- steam reforming or autothermal reforming of light ends or natural gas;
- partial oxidation (gasification) of heavy oil fractions.

Refineries with the simplest configuration may produce enough hydrogen only through catalytic reforming. Complex plants with extensive hydrotreating and/or hydrocracking operations typically require more hydrogen than is produced by their catalytic reforming units and it is those refineries that have dedicated HGU's. The feed of the hydrogen plant consists of hydrocarbons in the range from natural gas to heavy residue oils and coke. The conventional steam reforming process produces a hydrogen product of a maximum of 97 – 98 % v/v purity and higher if a purification process is applied (99.9 – 99.999 % v/v) [2].

The total captive production capacity of HGU's installed at refineries (excluding merchant plants, even if dedicated to supply hydrogen to refineries) is approximately **9,376 t per day** split between **93 facilities**.

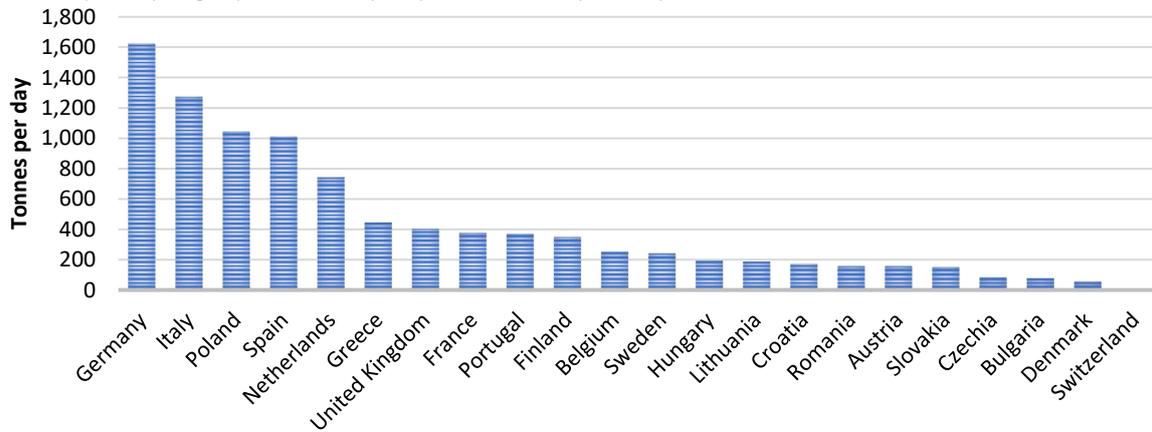
Germany has the largest share with 17% of total EU, EFTA, and UK hydrogen production capacity in refineries, followed by Italy (11%), Poland (11%), Spain, (11%), and the Netherlands (8%).

Figure 5. Captive hydrogen production units installed at refineries



Source: Fuel Cells and Hydrogen Observatory

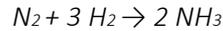
Figure 6. Captive hydrogen production capacity for refineries by country



Source: Fuel Cells and Hydrogen Observatory

1.2.2. Ammonia

Next to refineries, the ammonia industry is the second largest hydrogen consuming sector in the EU. The ammonia production process involves a synthesis of hydrogen with nitrogen according to the following formula:

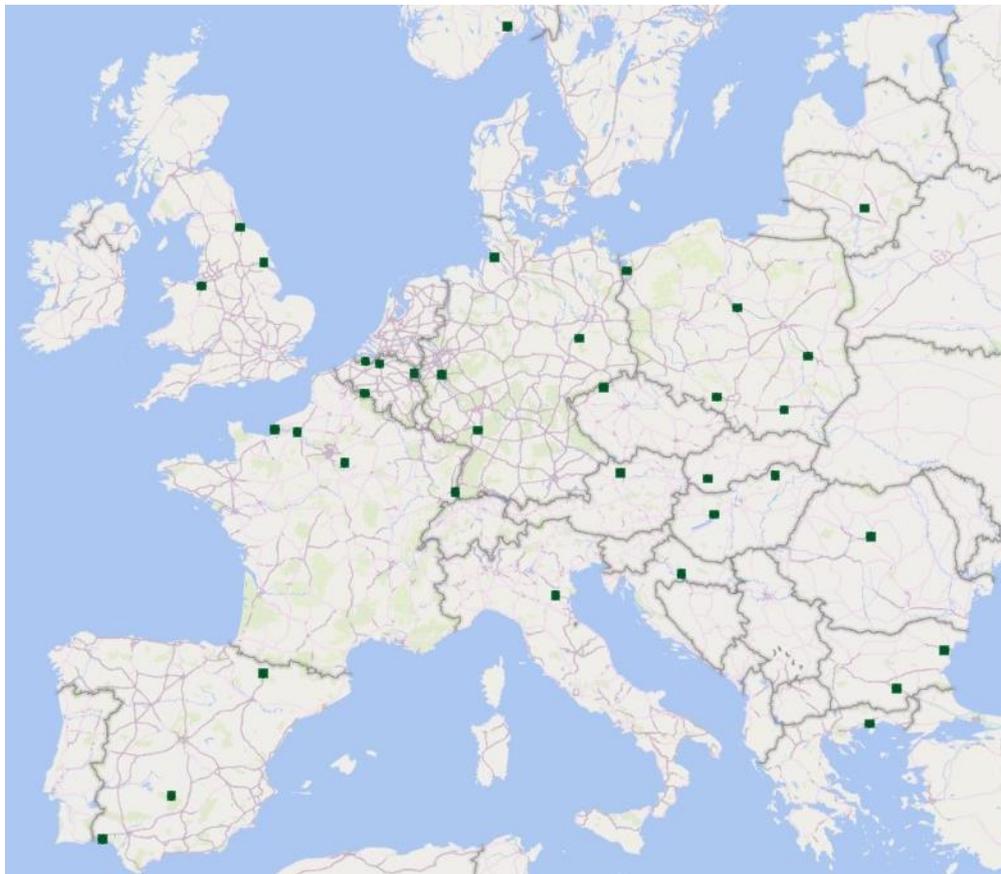


This process consumes about 175-180 kg of hydrogen per t of ammonia.

Total ammonia-related hydrogen production capacity in Europe was approximately **9,489 t per day** split between **36 facilities**. All of them were using either steam methane reforming or partial oxidation (POX) to generate hydrogen.

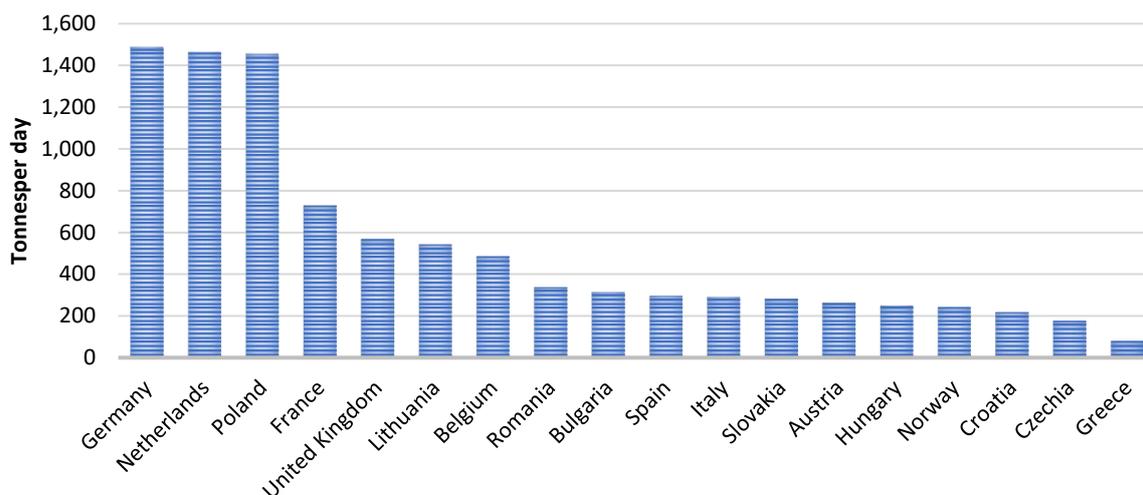
Similar to refining, Germany had the largest share with 16% of all Europe’s hydrogen production capacity dedicated to ammonia production, closely followed by the Netherlands (15%), Poland (15%), France (8%), and the United Kingdom (6%).

Figure 7. Captive hydrogen production units installed for ammonia production



Source: Fuel Cells and Hydrogen Observatory

Figure 8. Captive hydrogen production capacity for ammonia by country

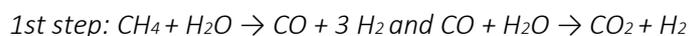


Source: Fuel Cells and Hydrogen Observatory

1.2.3. Other captive hydrogen production plants

The captive hydrogen production sites located in refineries or ammonia plants comprise around 91% of total captive hydrogen production. Other than these processes, hydrogen is produced at scale also for the production of a number of other chemicals, including methanol and hydrogen peroxide.

The most common methanol production method is steam reforming of methane and subsequent synthesis, and follows the following process:



This production consumes about 1,400 Nm³ H₂/t of methanol [1]. Methanol is an important chemical raw material used for the production of formaldehyde, acetic acid and MTBE or fatty acid methyl esters (FAME), adhesives and solvents.

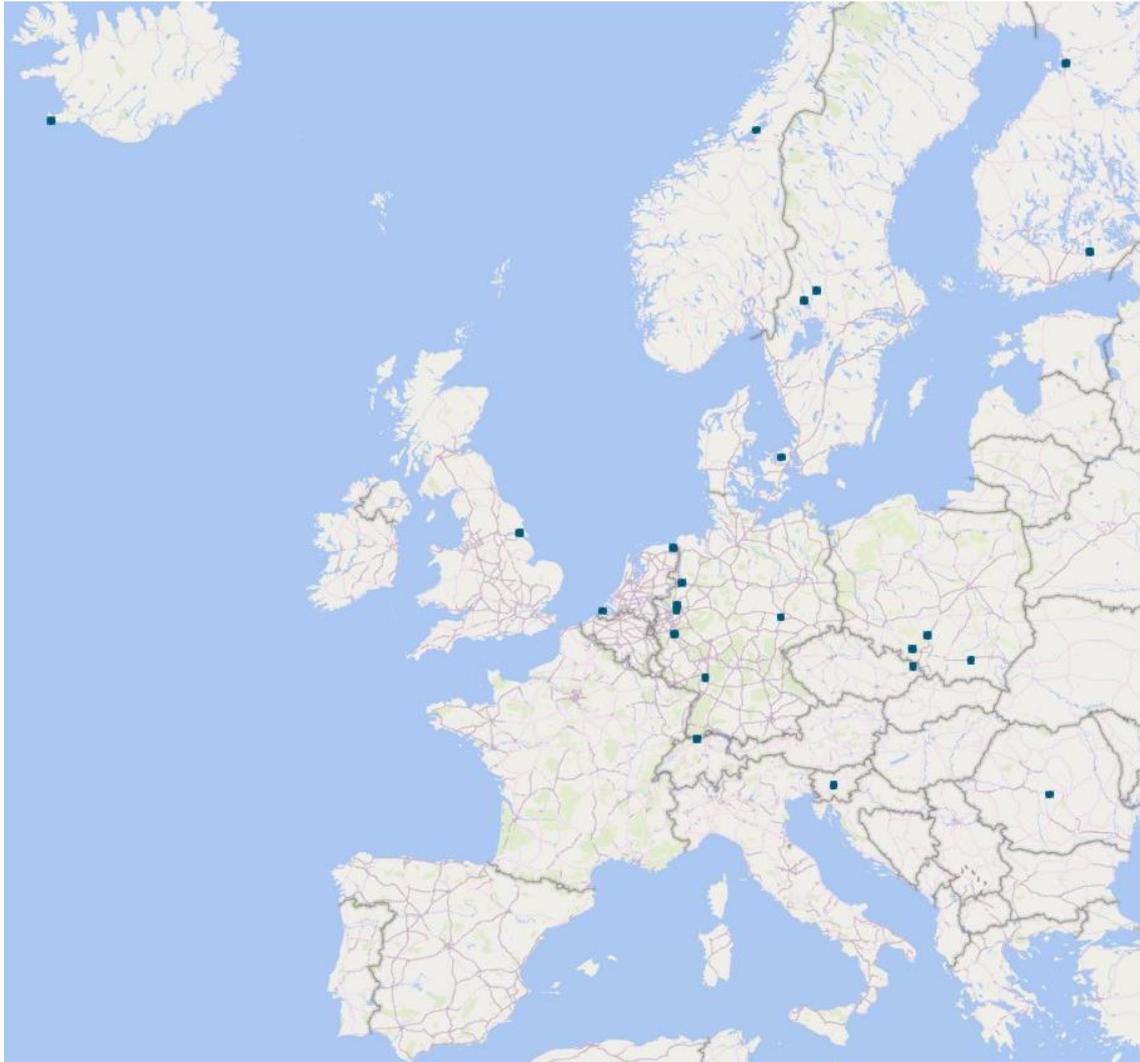
Other uses of hydrogen in the chemical industry include the production of such high-volume chemical products as hydrogen peroxide, for which hydrogen consumption is approx. 735 Nm³ H₂/t [1], hydrogen chloride, aniline, cyclohexane, TDI and oxo-alcohols. In most cases, production of those chemicals takes place at large integrated chemical or petrochemical plants.

As is the case with hydrogen produced for the oil refining or fertilizer industry, the overwhelming number of installations today use fossil fuels as feedstock for production of hydrogen.

One notable exception is Carbon Recycling International's George Olah Renewable Methanol Plant in Svartsengi (Iceland). The plant is able to produce 5 million litres of methanol per year and uses hydro and geothermal energy for producing hydrogen from water electrolysis, which is then reacted with CO₂ from flue gases to produce methanol [3].

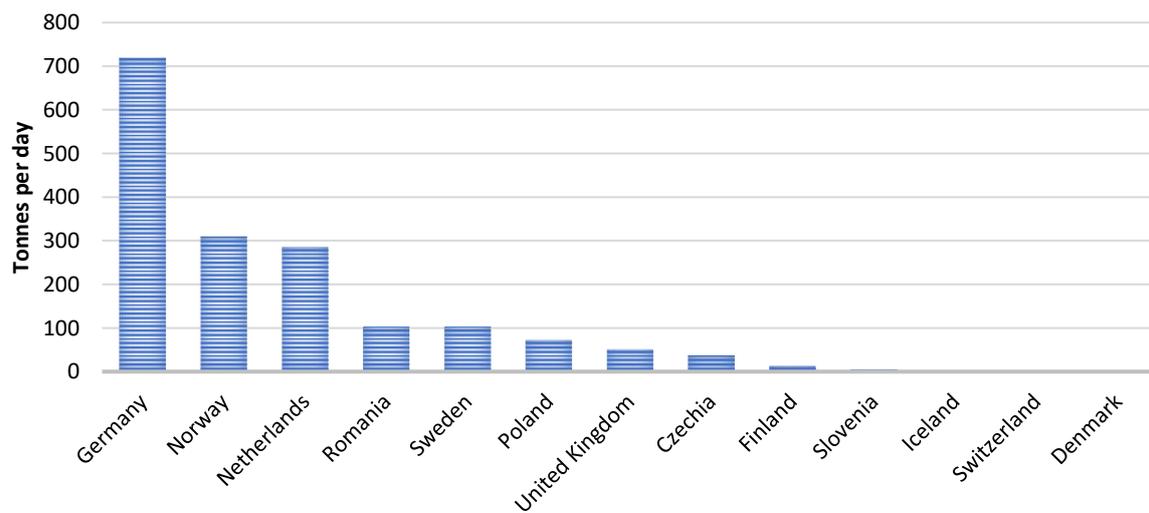
Total captive hydrogen production capacity in Europe dedicated to methanol and other chemicals is approximately **1,707 t per day** split between **23 facilities**.

Figure 9. Captive hydrogen production units installed for methanol and other chemicals



Source: Fuel Cells and Hydrogen Observatory

Figure 10. Captive hydrogen production capacity for methanol or other chemical plants, excluding ammonia.



Source: Fuel Cells and Hydrogen Observatory

1.3. Merchant hydrogen production

The merchant hydrogen plants can be divided into two main categories:

- plants dedicated to supply a single large-scale consumer with only excess capacity available to supply the retail hydrogen market; and
- small and medium scale hydrogen production sites designed for the purpose of supplying mostly retail customers.

While the first type can be comparable in scale to the largest captive hydrogen production facilities, the installations designed with the hydrogen retail market in mind are an order of magnitude smaller in terms of their maximum capacity.

The report identified 108 merchant hydrogen plants operational in Europe in 2019. **Total capacity of those plants has been estimated at 3,865 t per day.**

Figure 11. Identified merchant hydrogen plants

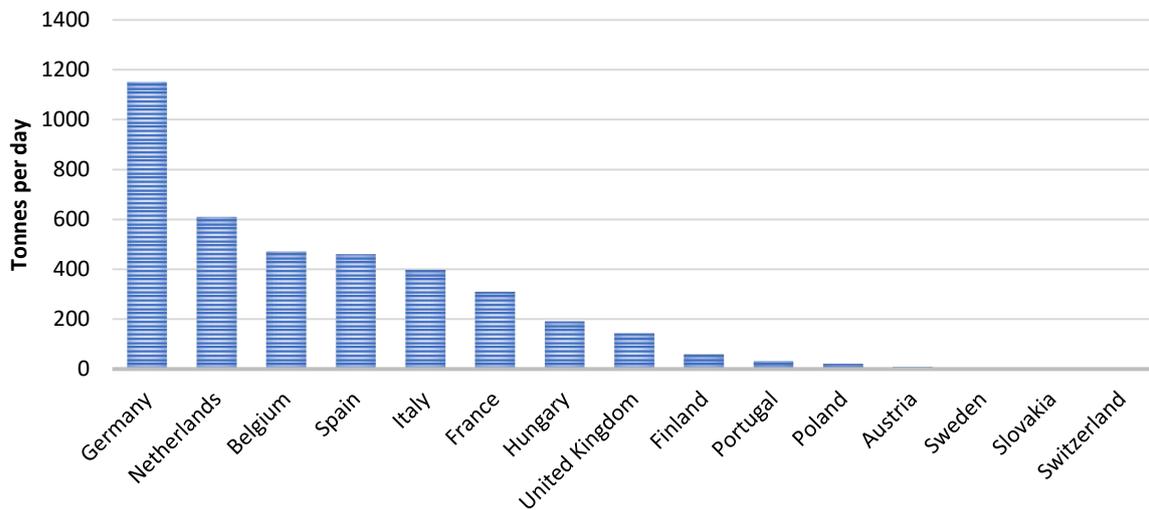


Source: Fuel Cells and Hydrogen Observatory

The merchant hydrogen market in Europe is dominated by 4 groups: Linde Gas, Air Liquide, Air Products and Messer, that own a combined 81% of plants and 90% of total merchant hydrogen production capacity.

As was the case with captive hydrogen production, most merchant hydrogen production capacity is located in Germany (29%), the Netherlands (15%), Belgium (12%), Spain (11%), Italy (10%), and France (8%).

Figure 12. Merchant hydrogen production capacity.



Source: Fuel Cells and Hydrogen Observatory

From a technology perspective, while most production capacity is still fossil fuel based, 11% of the merchant hydrogen production capacity also comes from by-product production from the chlor-alkali and sodium chlorate processes.

1.4. By-product hydrogen production

By-product hydrogen production capacity, by which we mean hydrogen produced as a by-product of other processes, has been estimated at **8,523 t per day**, including:

- 4,541 t per day of hydrogen mixed in coke oven gas,
- 1,777 t per day of hydrogen as by-product from refining operations⁷,
- 581 t per day of hydrogen produced by the chlor-alkali process,
- 108 t per day of hydrogen produced by the sodium chlorate process,
- 1,105 t per day of hydrogen produced during ethylene production,
- 412 t per day of hydrogen produced during styrene production.

The hydrogen production rate for ethylene and styrene production processes is around 190 Nm³ H₂/t ethylene and 220 Nm³ H₂/t of styrene [1]. By-product hydrogen from those industries is almost universally used on site as a feedstock for other chemical or petrochemical processes further downstream.

The by-product production rate from the chlor-alkali industry is around 300 to 270 Nm³ H₂/t chlorine [1]. On average, the industry vents around 15% of produced hydrogen into the atmosphere with the

⁷ This number is significantly higher in real life and the authors continue to improve the data quality between captive hydrogen production capacity at refineries from dedicated HGUs and its by-product production at refineries

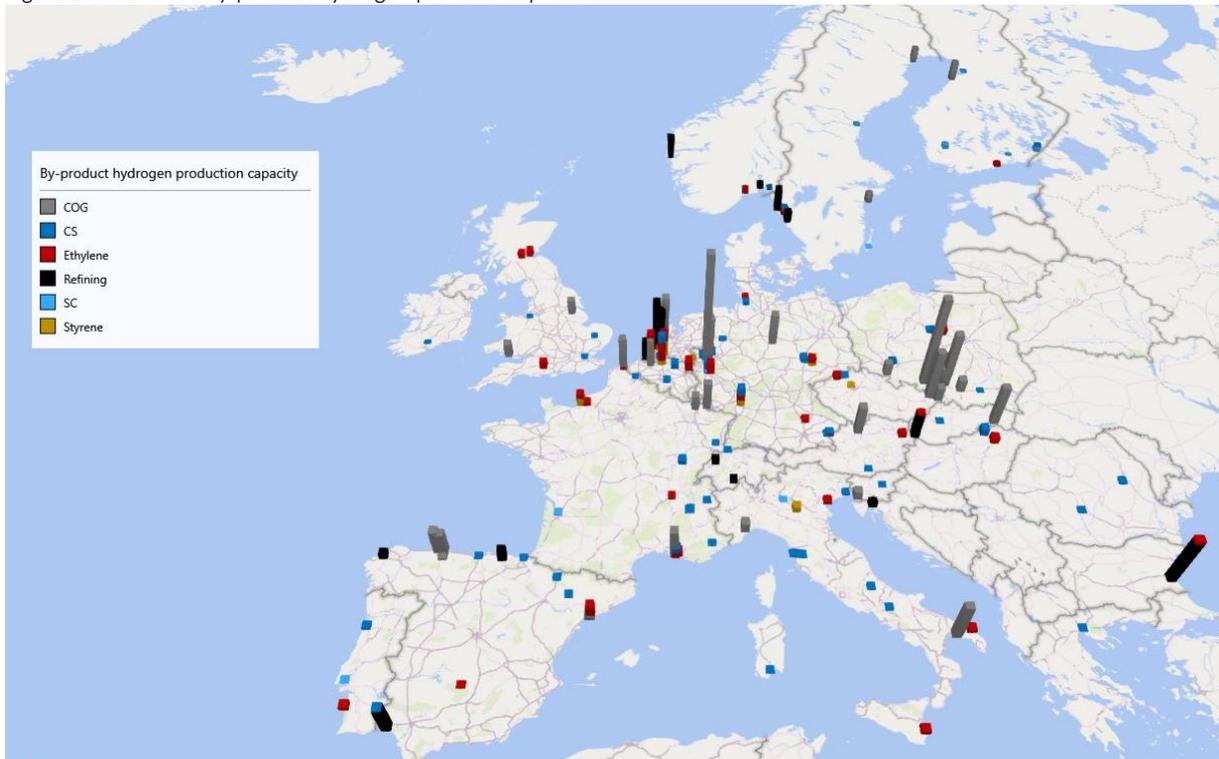
remaining 85% usually burned for heat or used in a CHP unit to generate both heat and power. Because by-product hydrogen from the chlor-alkali industry has high purity, if a pipeline network is available, by-product hydrogen can also be sold to other industrial users or sold to hydrogen merchants. In the case of the chlor-alkali plant in Cologne, Germany, some by-product hydrogen is also used as a fuel for FCEV buses.

The biggest potential source of by-product hydrogen is coke oven gas (COG), where the hydrogen production rate is about 450 Nm³ H₂/t of product. In this case though, the output gas is not pure hydrogen but rather a mixture of hydrogen (55%-65%) and methane, carbon monoxide, CO₂ and nitrogen. Coke oven gas is used to enrich the calorific value of the other process gases for use in blast furnace stoves, the reheating furnaces of hot strip mills, for other high temperature processes, or for the under-firing of coke ovens. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and is also used in power plants [4].

Other, smaller by-product hydrogen sources include:

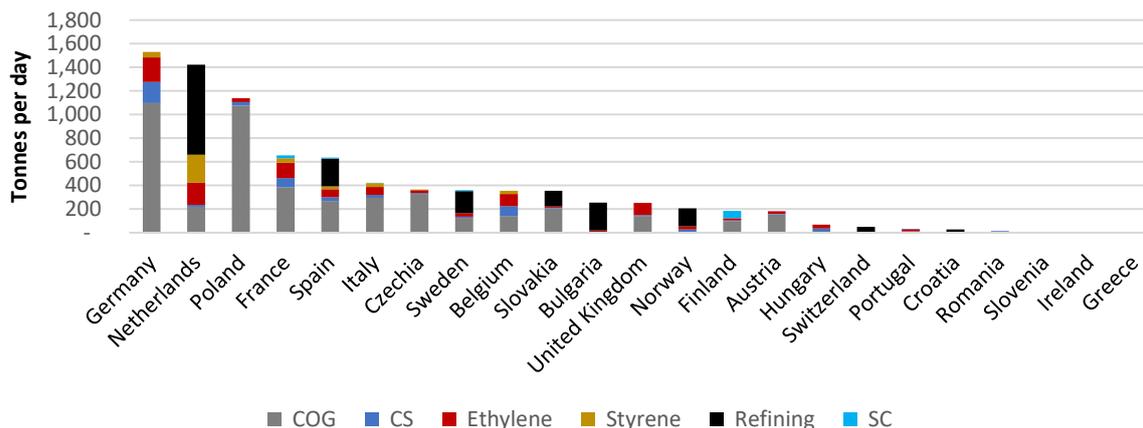
- Acetylene production: 3,400 – 3,740 Nm³ H₂/t product
- Cyanide production: 2,470 Nm³ H₂/t of product (Degussa’s BMA process) [1].

Figure 13. Identified by-product hydrogen production plants



Source: Fuel Cells and Hydrogen Observatory

Figure 14. By-product hydrogen production capacity⁸



Source: Fuel Cells and Hydrogen Observatory

1.5. Clean hydrogen production capacity

The most common method of producing hydrogen is steam reforming of natural gas (SMR). Less common are partial oxidation (POX) and autothermal reforming (ATR). SMR and natural gas is widely used for all applications including oil refining, ammonia synthesis, or any other bulk hydrogen production. Even though natural gas is the most common feedstock, steam reforming is also used with other feedstocks, which include also liquid hydrocarbons like LPG or naphtha.

Out of the 326 identified hydrogen production plants which were using fossil fuels as feedstock, only three were using carbon capture technologies:

- Grupo Sappio hydrogen production unit in Mantova, Italy with a capacity of around 1,500 Nm³/h that started operating in 2016.
- Air Liquide Cryocap installation in Port Jerome, France, capturing CO₂ from hydrogen supplied to an Exxon refinery, with a capacity of around 50,000 Nm³/h that started operating in 2015.
- Shell refinery in Rotterdam, Netherlands where CO₂ from hydrogen production is captured and sold for agricultural use as part of the OCAP project since 2004.

The total share of hydrogen production capacity from fossil fuels with CCS/CCU is ~0.5% equating to 131 tonnes per day.

Hydrogen can, of course, also be produced with electricity by splitting water via **water electrolysis**. There is a significant number of electrolyzers installed in Europe. In the past, electrolyzers have been employed whenever the volume of hydrogen demand is high enough to warrant building a dedicated installation onsite, instead of external supplies in cylinders or tube trailers, but not high enough to invest in an SMR + PSA unit, especially whenever high purity grade hydrogen is required. This includes for example electrolyzers installed for captive hydrogen production at food processing facilities (fat hardening) or power plants where hydrogen is used for cooling purposes. According to the JRC [5] the total installed capacity of electrolyzers in Europe is around 1 GW, which would amount to around 1.4% of total hydrogen production capacity. But since those electrolyzers are quite numerous and relatively

⁸ The lack of by-product hydrogen production capacity from refining processes in some countries stems from limited data availability. For countries where refining is not included in this by-product chart, this by-product capacity is captured as part of the captive production capacity.

small scale (rarely exceeding the tens or hundreds of kW range), they are extremely hard to track and have been excluded from detailed analysis.

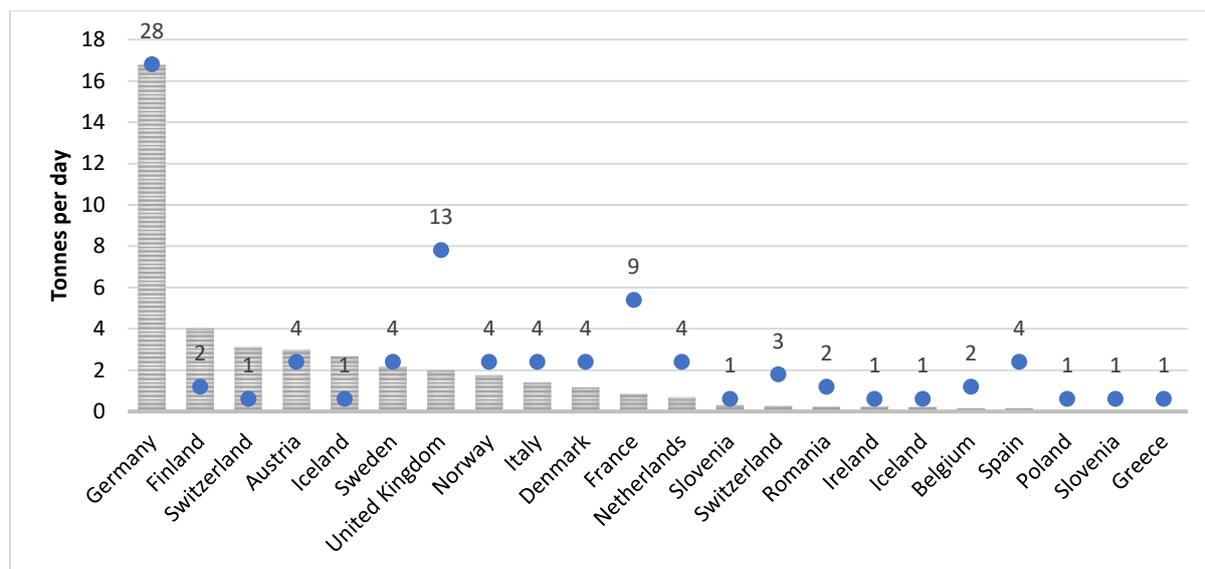
Beyond the established hydrogen use cases mentioned above, there is increased activity in development of power-to-hydrogen projects, where electricity is used to produce hydrogen via water electrolysis. By the end of 2019, the authors identified **95 operational power-to-gas** (water electrolytic) projects. Total power of those electrolyzers was around **92 MW** equalling a hydrogen generation capacity of ~41 t of electrolytic hydrogen per day (**0.14% of total production capacity**).⁹ Compared to 69 MW in 2018, this represents a 33% increase in operational power-to-hydrogen capacity between 2018 and 2019.

While some are commercial plants, others were built as part of R&D or demonstration plants destined to be decommissioned after only a few years of operations.

Most of them produce electrolytic hydrogen for merchant sales, on-site industrial consumption, mobility applications, or energy storage for renewable energy grid balancing.

Countries with the largest number of installations are Germany (28), United Kingdom (13), France (9). Countries with the largest installed water electrolytic production capacity are Germany with 17, Finland with 4, Switzerland with 3, Austria with 3, and Iceland with 3 t per day.

Figure 15. Hydrogen production capacity and number of projects using water electrolysis in 2019



Source: Fuel Cells and Hydrogen Observatory

⁹ The production numbers from electrolysis reflect maximum technical production capacity. Actual production numbers are significantly lower due to the various operating conditions of the individual electrolyzers.

2. Demand for hydrogen

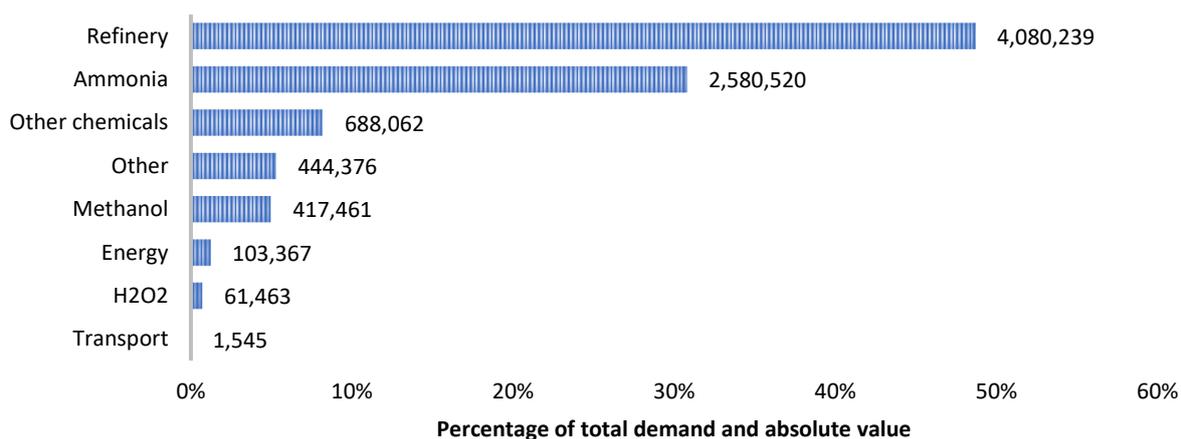
2.1. Summary

Hydrogen consumption data in this report has been collected and estimated based on available information gathered from a number of sources as well as calculations based on hydrogen production capacity at different hydrogen production plants. The external sources include EUROSTAT supplemented by information published or received from a number of trade associations (Eurochlor, Fertilizers EUROPE, Fuels Europe, CONCAWE, Petrochemicals Europe, Cefic).

Total demand for hydrogen in the analysed countries in 2019 has been estimated at **8.4 Mt**. The biggest share of hydrogen demand comes from refineries, which were responsible for 49% of total hydrogen use, followed by the ammonia industry with 31%. Together these two sectors consumed 80% of total hydrogen consumption in the EU, EFTA, and UK. About 13% is consumed by the chemical industry, with methanol production accounting for 5% of that.

Emerging hydrogen applications, like the transportation sector, comprised a very small portion of the market (0.02% in 2019).

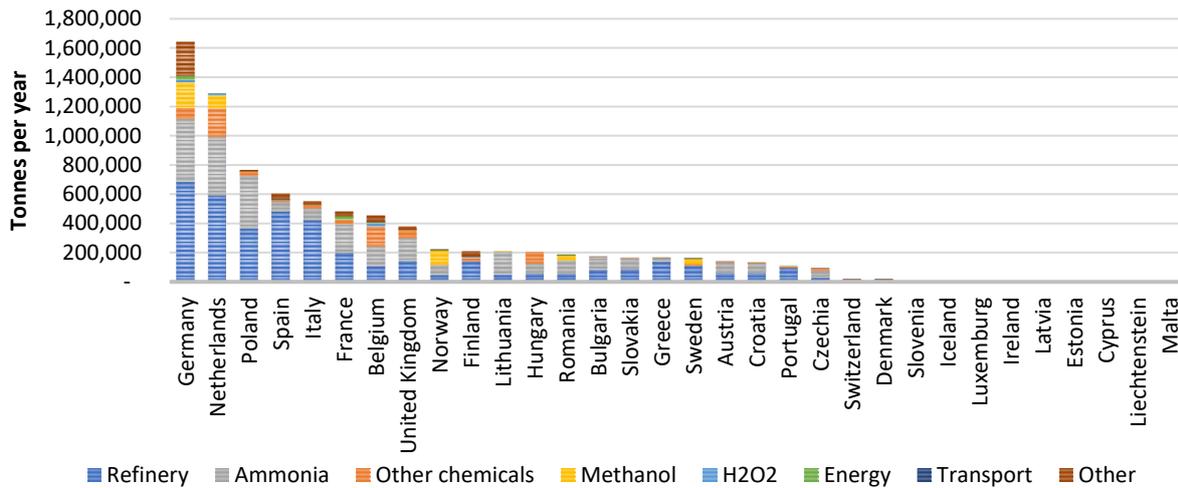
Figure 16. Total demand for hydrogen in 2019 by application



Source: Fuel Cells and Hydrogen Observatory

More than half of total hydrogen consumption takes place in just four countries: Germany (20%), the Netherlands (15%), Poland (9%), and Spain (7%).

Figure 17. Total demand for hydrogen in 2019 by country



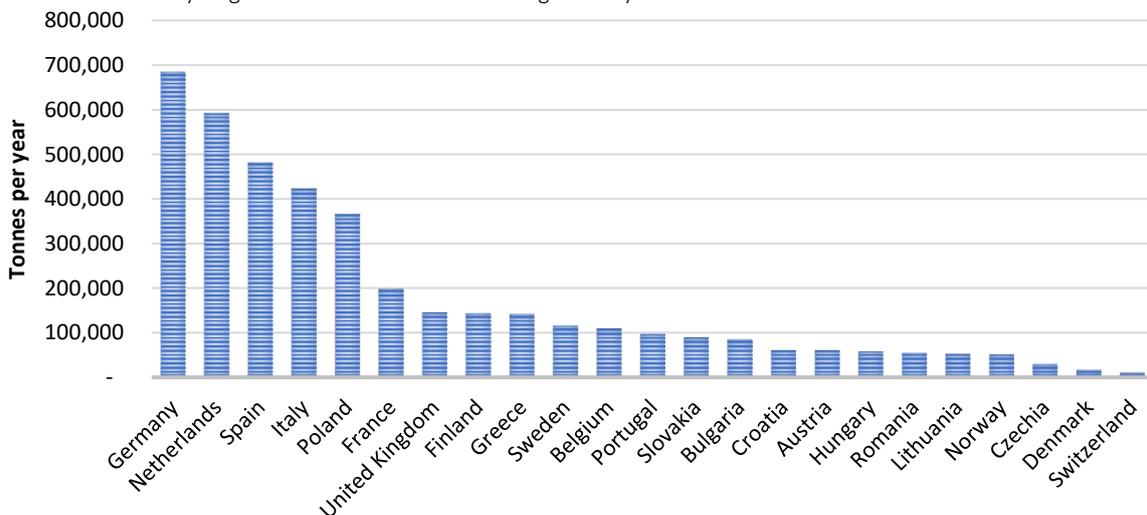
Source: Fuel Cells and Hydrogen Observatory

2.2. Refining industry

As mentioned in Section 1.2.1, refineries use hydrogen mostly for hydrocracking and hydrotreating processes, including hydrodesulphurisation. As legislative requirements require ever lower sulphur content in fuels, more desulphurisation is needed to achieve these targets, driving up hydrogen consumption in the sector [2]. Similarly, as demand for distillates such as jet fuel, kerosene, high-quality lubricating oils and diesel increases worldwide, so does the importance of hydrocracking. As a result, even though some refining processes generate hydrogen, most refineries are net consumers of it. Yet, because the net hydrogen balance of a refinery depends strongly on the specific processes involved and the mix of output products, it is extremely challenging to precisely estimate the actual demand for hydrogen, which cannot be simply calculated based on production volumes alone.

Nevertheless, based on gathered information about hydrogen production capacities at refineries, together with information about their capacity utilization, we estimate that the total hydrogen demand from the oil refining and petrochemical industry, in 2019, was **4.1 Mt**.

Figure 18. Estimated hydrogen demand from the oil refining industry



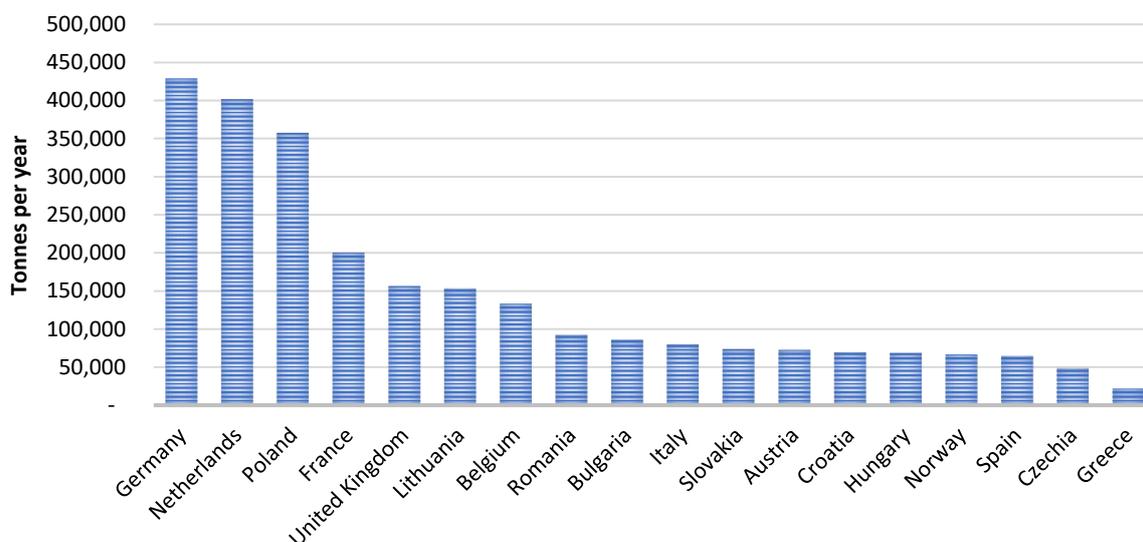
Source: Fuel Cells and Hydrogen Observatory

2.3. The chemical industry

In the chemical industry, the largest consumers of hydrogen are the ammonia manufacturers. Ammonia is used for the production of fertilizers and nitric oxide, which is an intermediate product for the production of nitric acid. In addition, ammonia is used for the production of sodium carbonate (soda ash), explosives, hydrogen cyanide, synthetic fabrics, and other products.

Total demand for hydrogen by the ammonia industry in 2019, based on Eurostat data, can be estimated at **2.6 Mt**. Due to confidentiality issues, detailed statistics about ammonia production are not available for some EU Member States. In those cases, hydrogen production capacity in the ammonia industry in those countries and utilization rates were used instead.

Figure 19. Estimated hydrogen demand from the ammonia industry

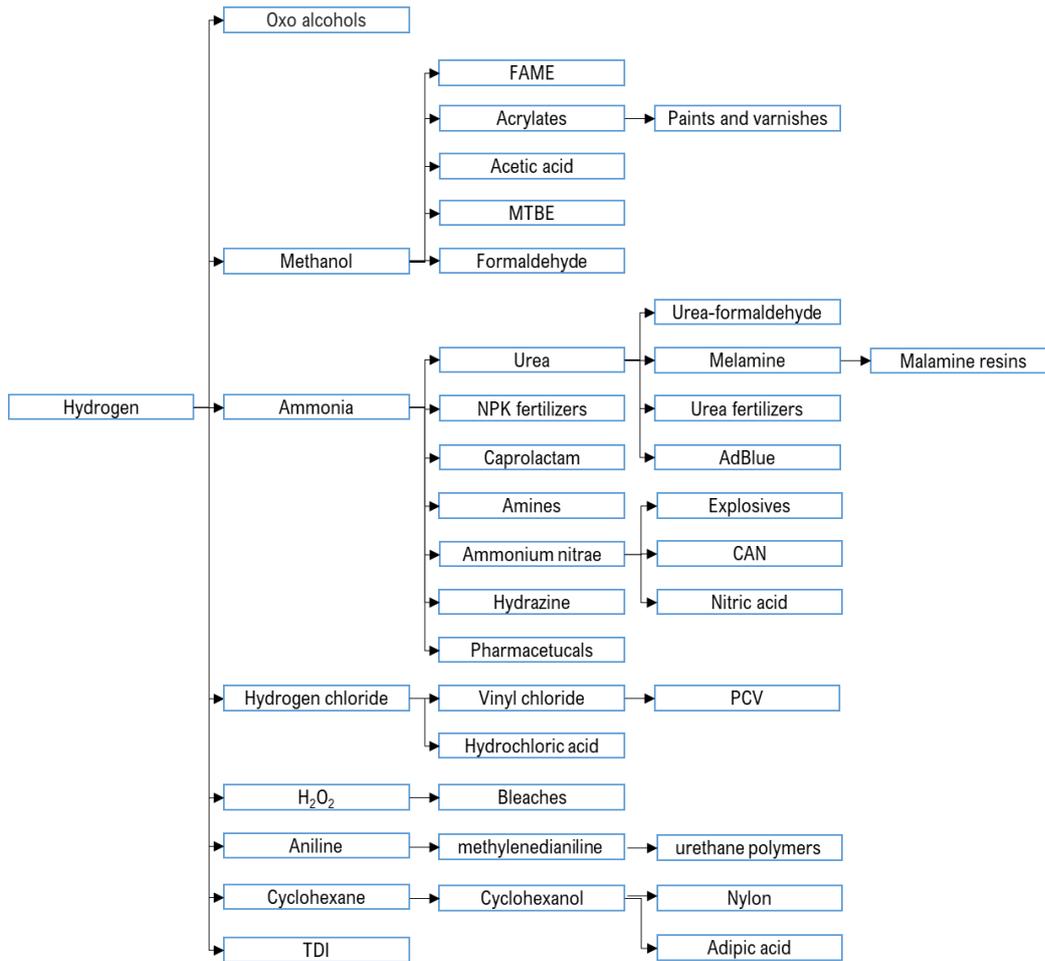


Source: Fuel Cells and Hydrogen Observatory

Even though the ammonia industry dwarfs other applications, it is by no means the only source of demand for hydrogen from the chemical industry. Other chemicals that require hydrogen input in their production process are (among others):

- Methanol
- Cyclohexane
- Aniline
- Caprolactam
- Hydrogen Peroxide
- Oxo Alcohols C8
- Oxo Alcohols C4
- Toluene Diisocyanate (TDI)
- Hexamethylenediamine
- Adipic acid
- Hydrochloric acid
- Tetrahydrofuran

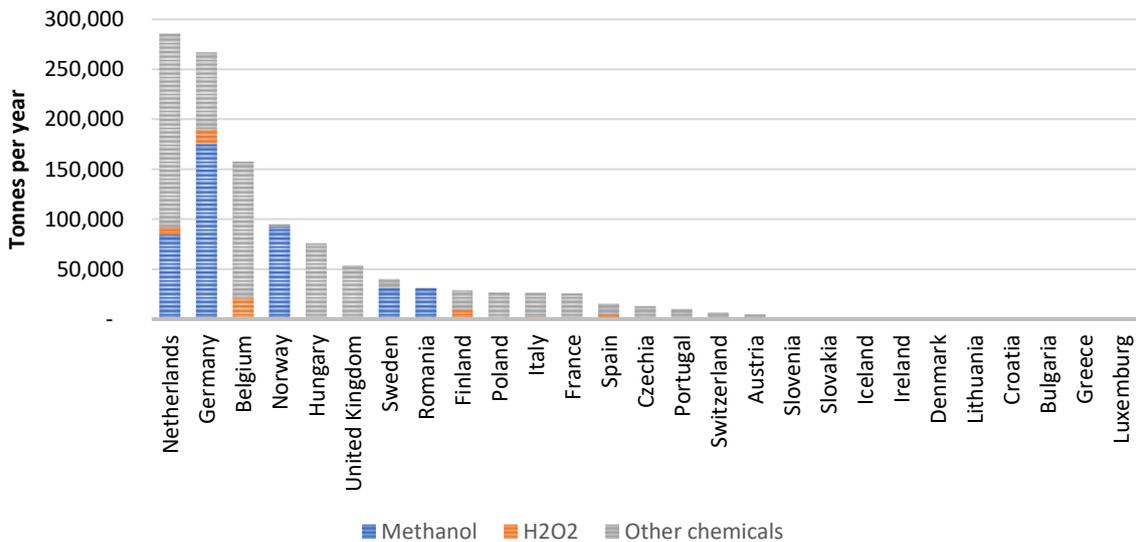
Figure 20. Chemical industry value chain dependant on hydrogen supply



Source: own elaboration.

Total demand for hydrogen, in 2019, from the chemical industry (other than ammonia production) has been estimated at around **1.2 Mt**, with almost half coming from Germany and the Netherlands.

Figure 21. Estimated hydrogen demand from the chemical industry other than ammonia manufacturing



Source: Fuel Cells and Hydrogen Observatory

2.4. Other industries

The oil refining and chemical industries are responsible for over 93% of total demand for hydrogen. The remaining demand comes from the following applications:

Steel manufacturing and metals processing

Mixture of hydrogen and nitrogen (5% to 7% hydrogen) is used commonly as an inert protective atmosphere in conventional batch annealing in annealing furnaces. Batch annealing with 100% hydrogen is also possible and results in better productivity, improved mechanical properties, surface, and product quality.

Manufacture of Glass

In the glass industry, hydrogen is an inerting or protective gas in flat glass production. It is also used in the flame polishing process of glass products.

Food processing

By hydrogenating unsaturated fatty acids in vegetable oils, hydrogen is used in the production of margarine. Hydrogenation is usually carried out by dispersing hydrogen gas in the oil, in the presence of a finely divided nickel catalyst supported on diatomaceous earth.

Energy sector

While hydrogen can be used in a fuel cell to generate heat and energy with high efficiency, currently hydrogen use in the energy sector mostly consists of:

- Burning hydrogen in boilers or CHP units for heat or heat and power generation – mostly done onsite where hydrogen is generated as a by-product of other processes (chlor-alkali).
- Using hydrogen for generator cooling. The amount of hydrogen demand depends on the installed power of turbines, their age and technical condition – especially the condition of the generator's hydrogen seals. Depending on those factors, and resulting hydrogen demand, some power plants have their own HGU's and only use external suppliers to cover additional needs, while other supply all of the required hydrogen from external sources.

Transportation

Hydrogen can also be used as a fuel – both directly in fuel cells or in an internal combustion engine, or indirectly when renewable hydrogen is used to synthesise other more complex synthetic fuels. While this application currently forms an insignificant part of hydrogen consumption (below 0.1%), it is expected to grow in the future.

Appendix 1: List of acronyms

ATR	<i>Autothermal reforming</i>
BMA	<i>Blausäure (hydrogen cyanide) from Methan (methane) and Ammoniak (ammonia)</i>
CCS	<i>Carbon capture and storage</i>
CCU	<i>Carbon capture and utilisation</i>
CHP	<i>Combined heat and power</i>
COG	<i>Coke oven gas</i>
CS	<i>Chloralkali</i>
EEA	<i>European Economic Area</i>
EFTA	<i>European Free Trade Association</i>
EU	<i>European Union</i>
FAME	<i>Fatty acid methyl esters</i>
FCEV	<i>Fuel cell electric vehicle</i>
HGU	<i>Hydrogen Generation Unit</i>
HyARC	<i>Hydrogen Analysis Resource Centre</i>
JRC	<i>Joint Research Centre</i>
LPG	<i>Liquefied petroleum gas</i>
Mt	<i>Million tonnes</i>
MTBE	<i>Methyl tert-butyl ether</i>
POX	<i>Partial oxidation</i>
PSA	<i>Pressure swing adsorption</i>
SC	<i>Sodium chlorate</i>
SMR	<i>Steam methane reforming</i>
TDI	<i>Toluene diisocyanate</i>

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Chapter 1

2021 Technology & Market Report

July 2021



Disclaimer

This report is based on data gathered as part of the Fuel Cells and Hydrogen Observatory as at 31 December 2020. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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This report was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from <https://www.fchobservatory.eu/>

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Executive Summary

The Fuel Cells and Hydrogen Observatory is an ambitious project to collect available valuable sector information in a single go-to source and make it open to all interested stakeholders. The technology and market module of the FCHO presents a range of statistical data as an indicator of the health of the sector and the progress in market development over time.

This module currently focusses on global fuel cell system shipments and on European FCH actors, vehicle registrations, refuelling stations and the hydrogen market. The ambition over time is to broaden the scope of companies, technologies and markets and to widen the reach of geographies covered by the FCHO as the market itself evolves. This will enable the annual report to make year on year comparisons assessing market progress and identify strengths and trends. This is the second annual report on the FCHO and provides a snapshot of technology and market data in the period January 2020 – December 2020.

Purpose:	The technology and market module of the FCHO presents a range of statistical data as an indicator of the health of the sector and the progress in market development over time. https://www.fchobservatory.eu/observatory/technology-and-market
Scope:	Fuel cell shipment data is presented on a global basis. Other sections of the technology and market chapter (HRS data and FCEV data) are presented on a European basis. The report spans January 2020 – December 2020.
Key Findings:	COVID-19 has without doubt impacted the deployment of fuel cells and hydrogen in 2020 compared to industry expectations: Global Fuel Cell shipments > 1.3 GW Europe Fuel Cell shipments up to 148.6 MW Europe HRS in operation or under construction 162 FCEVs up 41% to 2,774

In 2020, the fuel cell and hydrogen industry, similar to all industries around the globe had experienced unprecedented supply chain challenges as a result of COVID-19. This has significantly slowed down the deployment of hydrogen fuel cells and the relevant applications compared with expected levels, but as a testimony to the continuing belief in the sector, modest growth was observed nevertheless. Global fuel cell system shipments saw a 10% increase in 2020, totalling at 1.3GW. Asia continues to lead in shipment volumes, accounting for almost 70% of the total MW shipped worldwide, whilst the US experienced yet again another decline, continuing the trend from 2019. Europe represents 10% of the total shipment in MW, growing from 113MW in 2019 to 149 MW in 2020.

Amongst fuel cell applications, the transport sector continues to lead with a growth of 25% on number of units shipped globally. This is driven by the deployment of more than 20,000 FCEVs of all types, of which 50% were in the material handling sector to support the demand of essential industries in 2020. Similarly, shipments of stationary applications surged despite a slowdown of deployment elsewhere with a growth of 10%, totalling at 57,800 units shipped.

HRS deployment in Europe was hard-hit by the pandemic in 2020. Supply chain challenges have caused significant delays in constructions versus announced deployments. A small growth prevailed bringing the total number of HRS operating or in construction to 162 at the end of 2020, with many more in the

planning stage at year end. Japan remains the leader with their network of 133 HRS but have also experienced similar delays like the rest of the world. New registration of fuel cell passenger cars in Europe were up by 41%, hitting a total number of 2,774 vehicles in 2020. South Korea surpassed California to become the global leader in FCEV deployment after seeing a 38% increase in domestic shipments in 2020. It now has over 10,000 FCEV on the road.

The global pandemic has undoubtedly derailed the fuel cell and hydrogen industry from its anticipated growth trajectory. While the long-term impact of the COVID-19 pandemic on the global economies remains unclear, with nations pushing for green economic recovery plans, there is belief that this slowdown is temporary, and the rate of deployments will resume to pre-COVID levels in 2021 as economies look to recover in a green and sustainable way.

The Commission's economic recovery plan 'Next Generation EU' highlights hydrogen as an investment priority to boost economic growth and resilience, create local jobs and consolidate the EU's global leadership. Asia continues to show strong momentums with ambitious national targets and policy drivers to accelerate deployments of fuel cell technologies in China, Japan and Korea. As the US re-joins the Paris Agreement, growth is also expected to resume in the fuel cell and hydrogen industry in North America, signs of which are already emerging from the new administration.

July 2020 saw the publication of the EU Hydrogen Strategy, laying out the ambition to decarbonise hydrogen production and to expand its use in sectors where it can replace fossil fuels. The European Clean Hydrogen Alliance was formed at the same time and will help to deliver on this strategy. In the EU, national hydrogen strategies (Germany, France, Netherlands, Spain, Norway and Austria) were also published, indicating the potential for successful development of a clean and globally competitive hydrogen industry in Europe has never been more achievable.

1. Introduction

The information in this report covers the period **January 2020 – December 2020**. The technology and market module of the FCHO presents a range of statistical data as an indicator of the health of the sector and the progress in market development over time.

This includes statistical information on the size of the global fuel cell market including number and capacity of fuel cell systems shipped in a calendar year. For this first edition, data to the end of 2020 is presented where possible, alongside analysis of key sector developments. Fuel cell system shipments for each calendar year are presented both as numbers of units and total system megawatts. The data are further divided and subdivided by:

- **Application:** Total system shipments are divided into Transport, Stationary and Portable applications
- **Fuel cell type:** Numbers are provided for each of the different fuel cell chemistry types
- **Region of integration:** Region where the final manufacturer – usually the system integrator – integrates the fuel cell into the final product
- **Region of deployment:** Region where the final product was shipped to for deployment

The data is sourced directly from industry players as well as other relevant sources including press releases, associations, and other industry bodies. The aspiration is to include data related to other parts of the supply chain including electrolysers and component suppliers, as well as employment statistics for the sector when this information becomes available.

Information is presented on the number of hydrogen refuelling stations (HRS) deployed since 2014 with detailed information on HRS in operation including pressure, capacity etc. In parallel, the observatory provides data on the registered fuel cell electric vehicles (FCEVs) on European roads, providing an indication of the speed of adoption of hydrogen in the transport sector. This annual report is an enrichment analysis of the data available on the FCHO, providing global context and insights on trends observed year-over-year.

All sections in the Technology & Market module are updated following an annual data collection and validation cycle and the annual report is published the following Spring.

2. 2020 Snapshot

2.1. Data Collection Methodology

The fuel cell shipment data at the end of 2020 as presented in the Technology & Market module of the Observatory is derived from E4tech's Fuel Cell Industry Review 2020¹. This data presents a snapshot of the size of the global fuel cell market and is a consolidated view of data collected by confidential survey with over 100 participants in the fuel cell and hydrogen supply chain. The survey was conducted through to the end of September 2020 and includes a forecast for the last quarter of the year, 2020².

The industry survey was again conducted this year by E4tech as part of its scope for the Observatory.

Hydrogen Refuelling Station (HRS) data is derived from the European HRS Availability System³. The data is extracted and analysed to derive the number of HRS deployed in European member states at the end of 2020. Additional information on non-EU countries is sourced through desk research.

Information on Fuel Cell vehicle deployments in Europe is sourced from the European Alternative Fuels Observatory (EAFO⁴) which monitors vehicle deployments across a broad range of alternative fuels including hydrogen. This data is supplemented with desk research for non-EU markets.

2.2. Fuel Cell Shipments

The FCHO provides detailed statistics on a number of indicators for the market development of the fuel cell space. Annual data is presented on system shipments and the total of those systems in megawatts, categorised by application, region and fuel cell type as described below. Shipment numbers are rounded to the nearest 100 units and megawatt data to the nearest 0.1 MW. Where power ratings are quoted, these refer to the electrical output unless stated otherwise. In general, the nominal, not peak, power of the system is used, with the exception of transport. Because continuous power depends heavily on system design and how it is used, peak power is reported for transport units.

The reported figures refer to shipments by the final manufacturer, usually the system integrator. In transport the vehicle is counted when shipped from the factory. This is because the shipments of stacks or modules in a given year can be significantly different from the shipment of final units (e.g. vehicles) in the same timeframe. We use stack and module shipment data to enable correlation of numbers between years. The regional split in the data is provided both in terms of where the systems have been integrated and where they are shipped to. Where possible, we do not include shipments for toys and educational kits.

The data is presented using the following definitions:

- Shipments by region of deployment, depicting where systems are shipped to for final deployment,
- Shipments by region of system integration, depicting where stacks are integrated into final system such as a vehicle or CHP system, and

¹ E4tech Fuel Cell Industry Review, fuelcellindustryreview.com

² 2020f is the data at end of 2020 using the forecasted numbers for the last quarter

³ HRS Availability System, h2-map.eu

⁴ European Alternative Fuels Observatory, eafo.eu

- Shipments by application, depicting the number of systems by application area (transport, stationary etc)

2.2.1. Shipments by Region of Deployment

2020 was a difficult year for the fuel cell sector due to the impact of the COVID-19 pandemic. Supply chain delays and economic declines on a global scale had a significant impact on fuel cell deployment. While the overall trend continues to follow a positive trajectory, 2020 was unable to continue the strong momentums experienced in 2019 and as a consequence, this year saw the lowest growth levels in the past 5 years. In terms of overall capacity, growth in Europe’s annual deployments increased **35.6 MW or 32%** in 2020. This is significantly lower than the growth experienced in 2019 at 71.8 MW, reflecting deployment slowdowns and challenges experience throughout 2020.

The same can be said of Asia, where the recorded growth in Megawatts for 2020 at **168.5 MW** was about half compared to the one for 2019. However, Asia remains the global leader in terms of capacity as it inches closer to the 1 GW milestone. Continuing the trend from 2019, a shift to larger systems is once again observed in the 2020 deployment capacity in both Europe and Asia. In Europe, the average system size increased from 5.35 kW/unit in 2018 to 10.6 kW/unit and 11.7 kW/unit in 2019 and 2020 respectively. FC systems are slightly larger in Asia, where the average sizes increased from 6.64 kW/unit in 2018 to 13.9 kW/unit and 15.5 kW/unit in 2019 and 2020 respectively.

In North America, the total MW of fuel cell deployments declined for the second time in a row since 2019 due to the drop in Mirai shipments. However, the total number of units deployed saw an increase of **32%** driven by smaller capacity applications such as material handling, which continues to experience success in the US market.

Table 1. Units by Region of Deployment

1,000s units	2015	2016	2017	2018	2019	2020f*
Europe	8.4	4.4	5.1	7.7	10.7	12.7
N America	6.9	7.7	9.4	9.3	8.1	10.7
Asia	44.6	50.6	55.3	50.9	53.5	58.8
RoW	1	0.5	0.8	0.6	0.2	0.2
Total	60.9	63.2	70.5	68.5	72.50	82.40

* 2020f is the data at end of 2020 using forecasted numbers for the last quarter

Table 2. Megawatts by Region of Deployment

MW	2016	2017	2018	2019	2020f*
Europe	27.4	38.9	41.2	113.0	148.6
N America	213.6	331.8	425.3	339.2	252.7
Asia	273.8	285.8	337.9	743.9	912.4
RoW	1.7	2.1	1.2	0.2	5.0
Total	516.5	658.6	805.8	1,196.3	1,318.7

2.2.2. Shipments by Application

2020 saw a 14% increase in the total number of units shipped over 2019 with over 80,000 units or 1.3 GW shipped. Echoing the overall trend, the average capacity has also increased steadily over the years across all applications. In 2020, the average capacity sits at 16 kW/unit, doubling the capacity seen in 2016.

Table 3: Global Shipments by Application

1,000s units	2016	2017	2018	2019	2020f
Portable	4.2	5.0	5.7	3.9	4.1
Stationary	51.8	54.9	51.9	52.2	57.8
Transport	7.2	10.6	10.9	16.4	20.5
Total	63.2	70.5	68.5	72.5	82.4

COVID-19 resulted in significant slowdowns in the deployment of transport applications. This can be seen the decrease in growth compared to previous years, from 50% in 2019 to **25% in terms of number of units** and from 58% to **8% in capacity**, but overall growth in stationary fuel cells was largely unaffected.

Table 4: Global MWs shipped by Application

MW	2016	2017	2018	2019	2020f
Portable	0.3	0.6	0.7	0.4	0.4
Stationary	209.0	222.3	220.6	274.8	324.8
Transport	307.2	435.7	584.5	921.1	993.5
Total	516.5	658.6	805.8	1,196.3	1,318.7

Despite this reduction in growth, fuel cell vehicles remain as the primary application in terms of capacity, with shipments of more than **20,000 vehicles of all types**, making up approximately **75% of the total MW** of expected shipments by year end. Among this, material handling applications account for 50% of total transport shipments, almost doubling the number of deployment from 2019 as the forecast approaches 10,000 units towards the end of 2020 to support the demand of essential industries amidst the pandemic. In the passenger car market, Hyundai and Toyota remain dominant and collectively account for two thirds of this supply. Other noticeable factors were the number of fuel cell trucks and buses in China, who continues to lead the deployment in this sector with an estimate of 1,400 units shipped in 2020, equivalent of 87 MW capacity.

Growth in stationary applications from 2019 continued into 2020 after being stagnant for many years with a total shipment of more than **57,000 units** and a capacity of **320 MW**. 85% of this comes from large CHP and prime power above 100 kW, but still only accounts for around 400 units globally. The Japanese En-farm and the KfW 433 initiative in German programme continue to have major impacts with a forecasted deployment of over 47,000 units and 5,000 units of micro-CHP respectively.

The number of shipped portable units remain unchanged with a slight increase in capacity, once again suggesting a shift to larger systems but the overall MW shipments remains low.

2.2.3. Shipments by Region of System Integration

Table 5: Global units shipped by region of system integration

1,000s units	2016	2017	2018	2019	2020f*
Europe	4.2	6.6	8.7	10.0	16.8
N America	6.3	8.4	6.6	6.7	11
Asia	52.5	55.3	53.1	55.7	54.6
RoW	0.2	0.0	0.0	0.0	0.0
Total	63.2	70.4	68.5	72.5	82.4

The numbers for shipments by region of system integration, depicting where stacks are integrated into final system, reveal that Asia is not only leading deployment of fuel cells (ca. **69% of total megawatts**) but is also home to nearly **85%** of fuel cell system megawatts manufactured in 2020. Again a large part this is due to Toyota’s and Hyundai’s fuel cell passenger car manufacturing, where the deployment of NEXO represents close to 50% of the global fuel cell shipments by MW of all kinds. While the total MW of system integration grew by 11% from 2019, the overall units saw a slight decline of 2% in Asia. Once again, this could be another reflection of the trend that systems are growing in capacity.

Outside Asia, notable fuel cell manufacturing activity is found in the US with a focus on stationary fuel cells and material handling applications. As there is no fuel cell car model available from US OEMs, the US remains a net importer of fuel cell systems, despite strong players in stationary fuel cell systems and in PEMFC stacks and components.

Table 6: Global units shipped by region of system integration

MW	2016	2017	2018	2019	2020f
Europe	6.7	8.2	11.0	13.8	22.8
N America	188.3	215.1	179.4	167.3	176.8
Asia	320.8	434.6	615.4	1010.2	1119.1
RoW	0.8	0.1	0.0	0.0	0.0
Total	516.5	658.0	805.8	1191.3	1318.7

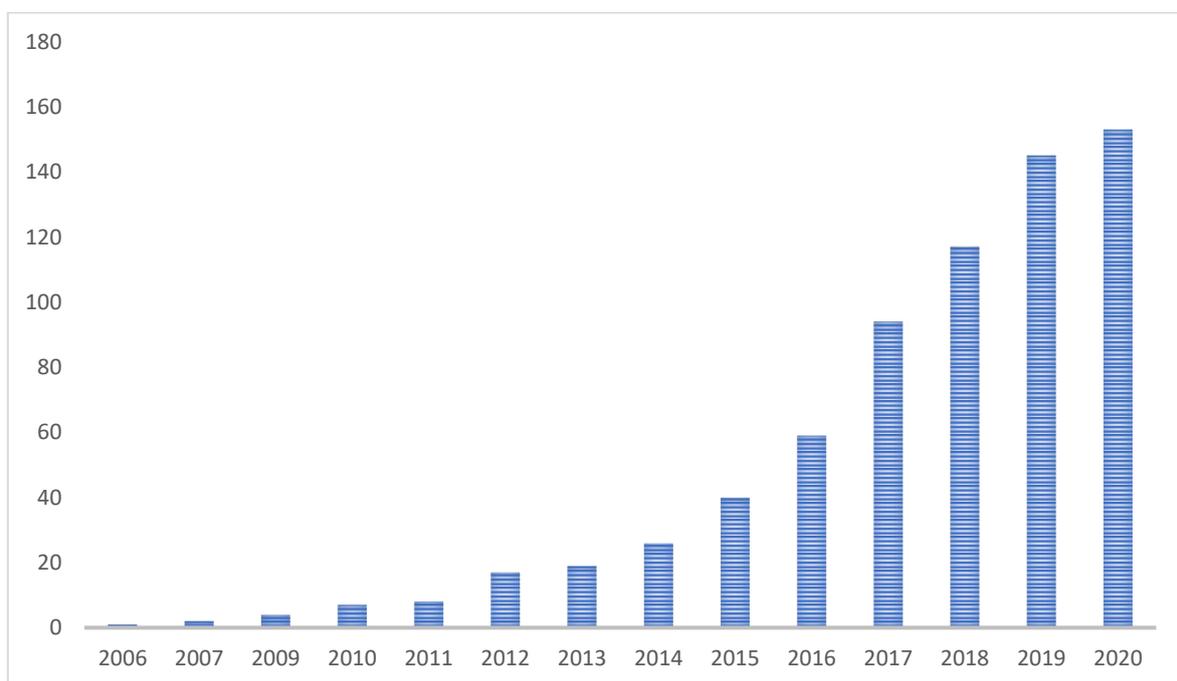
In Europe, fuel cell system manufacturing remains low in comparison to other regions and the activity is spread across a pool of companies active in different fuel cell technologies and applications, often driven by demonstration projects or early commercialization such as micro-CHP in Germany. However, several globally leading fuel cell technology suppliers such as Bosch, Ceres, Elcogen and many more are based in Europe and participate in the market growth elsewhere.

3. Hydrogen Refuelling Stations

The HRS module within the FCHO provides a range of information on technical characteristics including for example, station opening times, station operator, refuelling options (pressure) available as well as a live station availability update. This information is displayed on the portal and is derived from the HRS Availability System (HRS-AS) in real time.

This analysis provided here draws upon the supporting database compiled for the HRS-AS, supplemented by additional desk research to provide a picture of hydrogen refuelling station deployments in Europe⁵. The HRS-AS database tracks the onstream availability of public HRS stations in Europe. It does not include private HRSs.

Figure 1: Cumulative number of HRS operational at end 2020
Source: HRS-AS



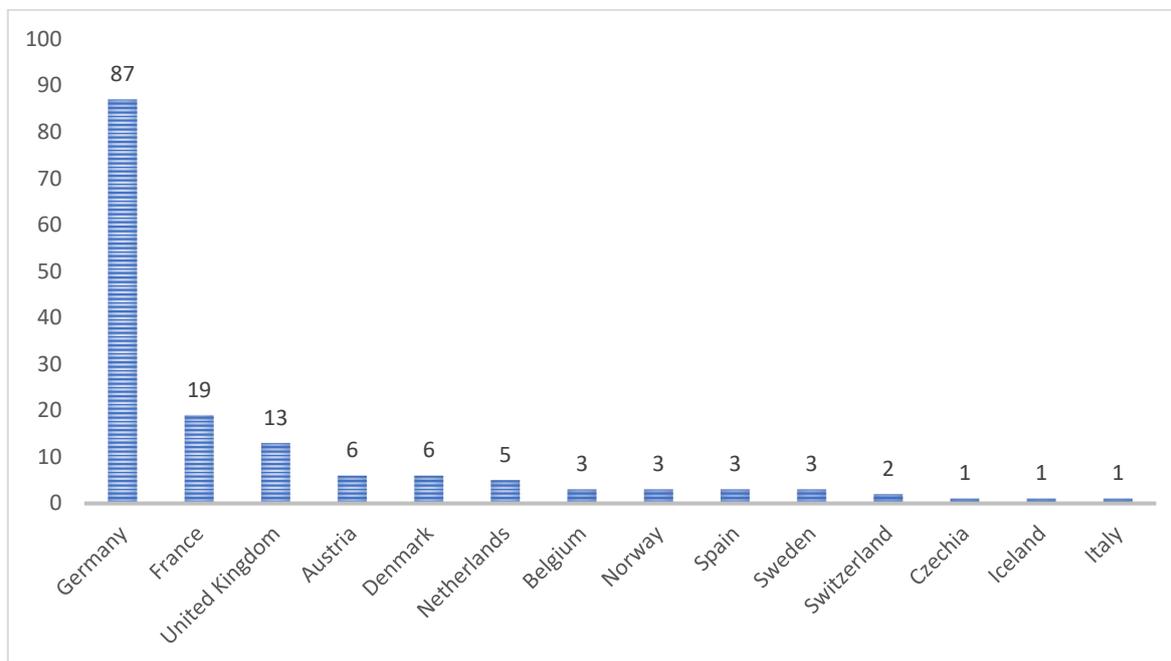
Growth in the hydrogen refuelling infrastructure has slowed down significantly in 2020 due to the impacts of COVID-19. Deployments in most European countries were paused with only a small number of new stations added in Germany, France and Denmark. The total European stations in operation or under construction at the end of 2020 stood at **162** with many more in the planning stage, including those delayed from 2019.

In Europe, Germany continues to lead the way with **93 stations** operating or under construction, including **8 new stations** becoming operational in 2020.

⁵ The database used to complete the analysis is not an exhaustive list of HRS in the Europe, but rather was used to show a representative view of HRS roll out progress.

Figure 2: Number of HRS operational by Country at end 2020

Source: HRS-AS



Supply chain challenges in 2020 resulted in significant delays in the deployment of planned HRS in France and Netherlands. Similar impacts were experienced in Germany, delaying its 2020 goal of **100 HRS** to be now fulfilled in early 2021. Despite the temporary slowdown, a sharp ramp up in deployment is expected in France and Netherlands, accounting for over 50% of the total growth planned in the continent. As the world recovers COVID-19, it is essential that the momentum seen in previous years is recreated, alongside suitable levels of vehicle deployment, if individual country targets are to be reached for example, Germany’s target of 400 HRS by 2025.

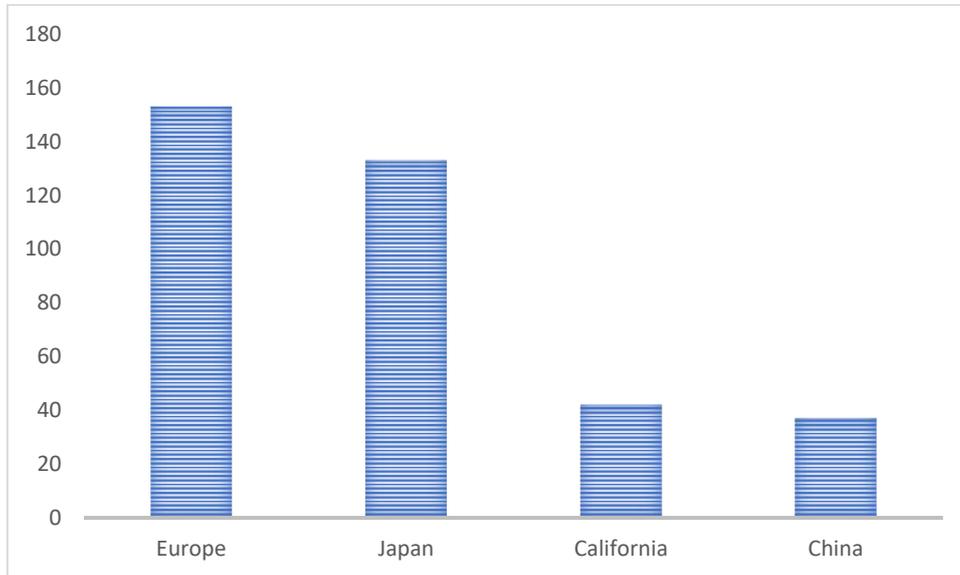
HRS deployment status can be seen in Figure 3 where Japan remains the leader with a total of **133** stations operational at the end of 2020, despite adding only **3 new HRS** and falling short of its 2020 target of 160 stations due to COVID-19 induced supply chain delays. With support from ongoing regulatory reforms, Japan aims to accelerate the deployment of 320 HRS by 2025. In Korea, approximately **13 new stations** were added in 2020, bringing the total to **43** operating HRS which is now far short of its national target of 310 stations by 2022.

In California, a total of **42 stations** were operational with an addition 15 in development, coming just under the goal of 64 HRS by 2020. While the deployment rate has been fairly slow since 2018, the goal to have 200 stations by 2025 is still attainable and the next two years will be critical in meeting that ambition.

37 Hydrogen refuelling stations were in operation in China, with the addition of 9 new stations since 2019, putting them far behind their goal of 100 HRS by 2020. However, recent partnerships show promising signs of future growth in deployment to support trucks and buses used for the 2022 Beijing Winter Olympics.

Figure 3: Number of HRS operational by Country at end 2020

Source: HRS-AS, The Fuel Cell Industry Review 2020



4. Fuel Cell Vehicles

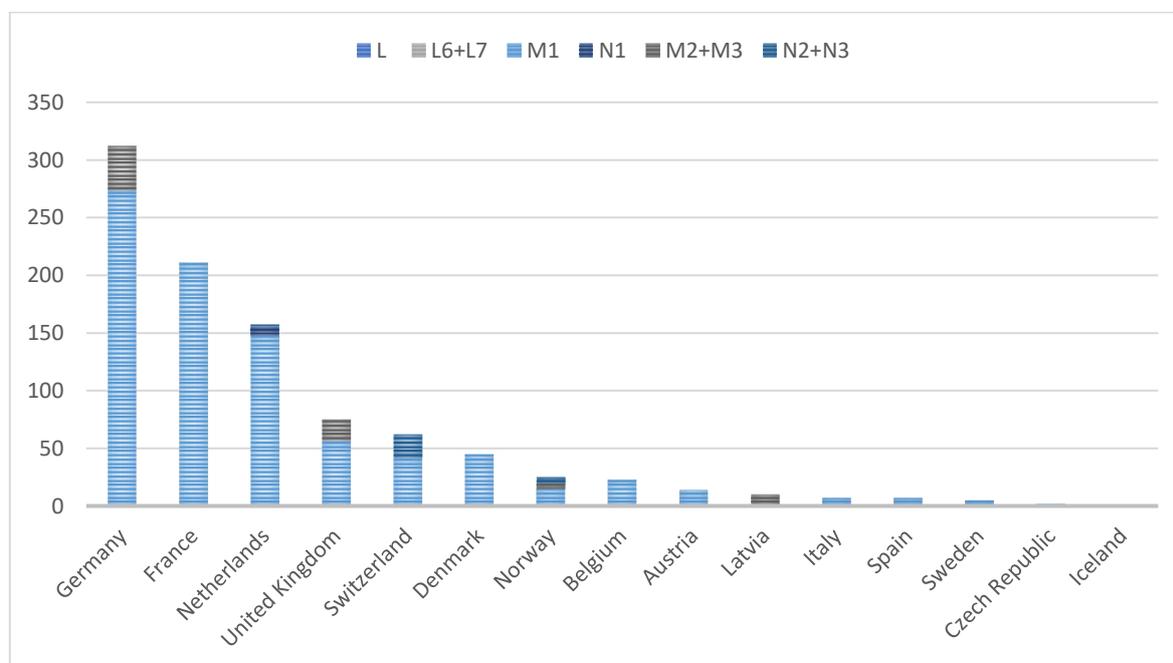
The fuel cell vehicle data is sourced from EAFO who use national (usually governmental) registration bodies, where they exist, to collate the data. Where no recognised national organisation exists to collect this data, desk research supplements the efforts. In this analysis ‘net new registrations’ excludes vehicles that have been exported or that have been decommissioned from service. The full list of relevant EAFO sources for country can be found at eafo.eu.

Despite COVID-19 challenges, Europe still saw a **41% growth** in new registrations of fuel cell passenger cars in 2020 up to **2,750 vehicles**, from a base of 1,959. **German, France and the Netherlands** experience the largest growth of **274, 211 and 148 vehicles** respectively. Notably, the Netherlands has surpassed the UK in the number of total fuel cell vehicles due and took its place for having the third largest fuel cell fleet in Europe as seen in Figure 3.

Looking at trends within fuel cell vehicle manufactures, Hyundai and Toyota remain dominant, with the sales of NEXO, released by Hyundai at the end of 2018, outperforming the more established Mirai. The new model 2021 Mirai was released at the end of 2020, in line with Toyota’s announcements on increasing production capacity. New European registrations of Mercedes’ GLC F-Cell (Daimler’s fuel cell/electric hybrid) fell to 24 and though a long way behind the top two, Mercedes replaced Honda as the third largest FCEV OEM while Clarity’s sale fell to 0 in 2020. BMW confirmed that starting in 2022, it will be piloting a small series of ‘i Hydrogen Next’, developed in cooperation with Toyota, and this model is expected to become available to consumers after 2025. BMW has also announced their plans to release a consistent line up of FCEV by 2030. Light duty vehicles are combined with passenger vehicle in this analysis with new registration seen under both Mercedes’ Crafter and Volkswagen’s Transporter.

Figure 4: Net number of FCEVs registered by country at end 2020

Source: EAFO



The story is similar elsewhere, particularly in Asia. South Korea surpassed California to become the global leader in FCEV deployment after seeing a **38% increase** in domestic shipments in 2020. This brings the total of Hyundai NEXOs on the road to 10,000. In Japan, domestic sales of Mirai grew from 2019 despite a decline in the international market. In California, however, FCEVs have been hard-hit by

COVID, dropping to fewer than **1,000 passenger vehicles** sold or leased in 2020 – the lowest number recorded since 2015.

A similar trend is observed with fuel cell bus registrations in Europe and countries with the most activities in 2020 includes Germany, United Kingdom and Latvia. Germany added **38 new buses** in December of 2020, bringing the total number to 54 buses whilst **21 new buses** were added to the UK fleet in 2020. Latvia witnessed the third largest growth in Europe with the addition of **10 fuel cell buses** for the first time. Norway doubled the size of their fleet, adding another **5 new buses** in 2020. Finally, Luxembourg also became fuel cell bus operators in 2020 with the first ever addition of **5 buses**. While falling short of JIVE's target to deploy 300 buses across Europe in 2020, these new registrations doubled the total number of fuel cell buses in Europe from 192 in 2019 to **390**.

Fuel cell bus fleets are expanding at a much slower rate in the USA, with California leading the growth with **47 operating vehicles** by 2020. The total number of buses in the country increase by 22 to a total of **64 buses**.

In Asia, China leads with the largest fuel cell bus fleet with a total of **3,600 new vehicles** by the end of 2020 and this level of growth is expected to continue in the coming years with ongoing support from the government. Elsewhere, South Korea expanded their fleet of 5 with **15 new buses** and Japan is recorded to have a total of 91 fuel cell buses in service by the end of 2020.

Heavy goods vehicles have also started to growth with the delivery of the first 10 Hyundai Xicent fuel cell truck in Switzerland in July of 2020. A further 10 heavy-duty vehicles were registered by the end of 2020, making Switzerland the largest fuel cell truck fleet operator in Europe. Hyundai's ambition is to put 1,600 hydrogen trucks on Swiss roads by 2025. Norway also added 5 of their first heavy-duty fuel cell trucks and the Netherlands added a further 2 new fuel cell trucks to their fleets. Heavy duty trucks are widely recognised as a 'sweet spot' for hydrogen and growth in this sector is expected to ramp in the coming years.

Outside of road transport, fuel cell technologies have also made progress in other transportation mediums in Europe, predominantly as demonstrator projects. September 2020, in the aviation industry, ZeroAvia flew a Piper M class six-seater plane for 20 minutes powered by a 100kW Powercell stack. On water, Ballard's Marine Centre at Hobro, Denmark launched the industry's first module designed for primary propulsion power in ships. Back to the ground, two units of fuel cell powered Coradia iLint trains finished their 18-month passenger service trial, completing 180,000 km of service and 95% reliability on the Eisenbahnen Verkehrsbetrieb Elbe-Weser line in Lower Saxony in spring 2020. Their success paved the road for 14 Coradia iLints units that will begin commercial service in 2021/2022. In total, at least 41 train units were ordered to be produced in Salzgitter, Germany.

Chapter 3
2021 EU and National Policies Report
July 2021



Disclaimer

This report is based on data gathered as part of the Fuel Cells and Hydrogen Observatory as at 31 May 2021. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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Executive Summary

Material and Geographical Scope

Purpose:	The policy module of the FCHO presents an overview of EU and national policies across various hydrogen and fuel cell related sectors. It provides a snapshot of the current state of hydrogen legislation and policy. https://www.fchobservatory.eu/observatory/policy-and-rcs/eu-policies https://www.fchobservatory.eu/index.php/observatory/policy-and-rcs/national-policies
Scope:	While FCHO covers 38 entities around the world, due to the unavailability of some data at the time of writing, this report covers 34 entities. The report reflects data collected January 2021 – May 2021.
Key Findings:	Hydrogen policies are relatively commonplace among European countries, but with large differences between Member States. EU hydrogen leaders do not lag behind global outliers such as South Korea or Japan.

The section of the Fuel Cells and Hydrogen Observatory (FCHO) on “Policy, Regulation, Codes” provides users with a comprehensive overview of **the most relevant policies at EU, national or regional level that directly or indirectly affect the development and deployment of the hydrogen technologies** under the scope of the Observatory.

While many legislative and non-legislative acts have a certain relevance for hydrogen technologies, the FCHO has chosen to focus on those policies that impact the business case for FCH technologies, meaning that they are **relevant to decision makers** when deciding whether to apply (or not) an FCH solution in a particular field. Legal and administrative requirements which have to be complied with by project developers when implementing hydrogen solutions are already covered comprehensively by other sources¹ and are not covered by the FCHO.

¹ www.hylaw.eu

Figure 1: Material scope of the FCHO Policy Module

1. Administrative and Legal Requirements (e.g. permitting, safety, etc.)
 - ➔ Required for implementation and compliance
 - www.hylaw.eu
2. Legislation and policies which acknowledge and support the role of hydrogen for policy objectives (climate, energy, transport, etc.)
 - ➔ Important for strategic decisions
 - www.fchobservatory.eu
3. Relevant non hydrogen specific policies (e.g. mandates, obligations, taxes on fossil fuels, decarbonisation targets)
 - ➔ An additional reason to act
 - www.fchobservatory.eu

At EU level, the FCHO covers all relevant legislative (Regulations and Directives) and non-legislative (Institutional Communications) policies pursued by the EU with a strong impact on hydrogen technologies (through May 2021).

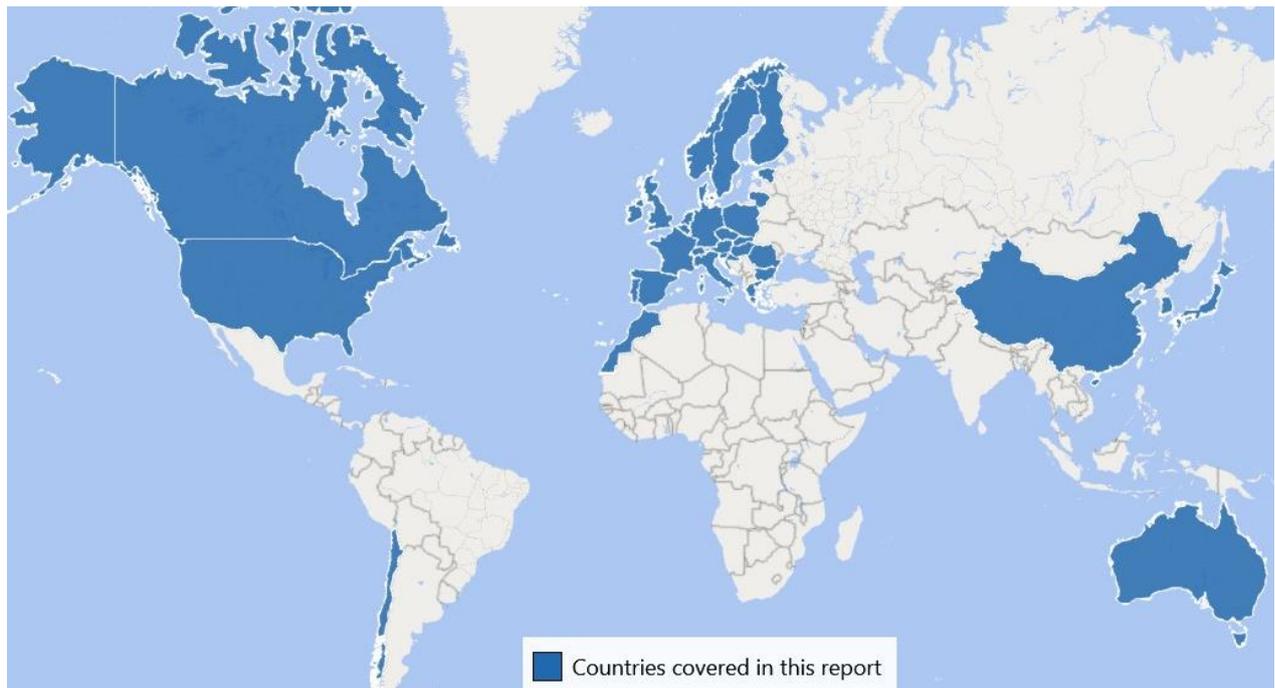
Table 1: EU policies covered by the FCHO

Legislative measures (in force)	Non-legislative policies (or planned legislative measures)
Renewable Energy Directive	EU Green Deal
Energy Efficiency Directive	European Climate Law
CO2 emission performance standards for new passenger cars and light-duty vehicles	Industrial Policy and State Aid
CO2 emission performance standards for new heavy-duty vehicles	ETS Innovation Fund
Alternative Fuel Infrastructure Directive	Sustainable Finance (including R&D) under the EU Green Deal
EU Emission Trading System (ETS)	The EU Hydrogen Strategy under the EU Green Deal
Public Procurement rules for clean vehicles	The EU Energy System Integration Strategy under the EU Green Deal
	The Offshore Renewable Strategy
	The Renovation Wave
	The Sustainable and Smart Mobility Strategy
	The Effort Sharing Regulation
	The TEN-E Regulation

At national and regional level, the FCHO covers 38 entities comprised of 37 countries and one sub-national unit, the State of California. The entities have been chosen to cover the EU, EEA, as well as other hydrogen outliers such as South Korea, Japan, China, and others. As of writing of this report in June 2021, the FCH Observatory contained updated information from 34 out of the 38 entities.² As a result, the data included in this report covers these 34 countries, 26 of which are members of the EU/EEA/UK. The FCH Observatory team will seek to complete its database to cover all 38 entities. The geographical coverage of this report is available in Figure 2, below.

² The entities for which data is only available from April 2020 and have not been updated as of the writing of this report are Australia, China, Japan, Morocco.

Figure 2: Geographical coverage of this report for national policies



National policies have been organized in the following categories: (i) fuel cell electric vehicles, (ii) stationary power, (iii) hydrogen as a fuel and hydrogen refuelling infrastructure, (iv) hydrogen production, transmission, and distribution, (v) hydrogen in industry, and (vi) general questions.

EU policies have been structured around 3 main areas of impact:

- Hydrogen production
- Hydrogen distribution³
- End-use sectors⁴

Main findings

At EU level, a year and half after the announcement of the EU Green Deal in December 2019, the framework of policies tackling the hydrogen industry is still profoundly changing. Understood as the EU’s ‘new growth strategy’, the Green Deal is a high-level political strategy which aims at carbon neutrality in the EU by 2050, a target now enshrined in the European Climate Law, which it is to be formally approved shortly. The Green Deal, which encompasses all sectors of the economy, includes a broad legislative reviewing process of already-existing policies and a series of new legislative and non-legislative acts.

Essentially, 2020 has seen the announcement of several strategies, which complement the Green Deal by setting a vision in specific sectors or dimensions of the energy system. The Energy System Integration Strategy, the Hydrogen Strategy, or the Smart and Sustainable Mobility are some of the main ones.

The unprecedented uncertainties brought about by the COVID-19 crisis (and subsequent economic recovery package) will, no doubt, fundamentally change the policy landscape in the years to come. However, clear political messages have confirmed that the EU Green Deal will remain the path forward

³ Further broken down into (i) ‘large scale storage’, (ii) ‘hydrogen in the gas grid’, (iii) ‘transport and storage in liquid carriers’, (iv) ‘transport by road, ship, etc.’, and (iv) ‘HRS for multiple applications’.

⁴ Further broken down into (i) ‘transport’ (‘road transport’, ‘maritime’, ‘aviation’, and ‘trains’), ‘heat and power’ (‘stationary fuel cells’ and ‘hydrogen burners and turbines’), and ‘energy intensive industry’.

and will represent the backbone of the industrial and economic policies pursued by the EU. The Commission plans on releasing concrete legislative proposals aimed at implementing the Green Deal into law, that is aligning the regulatory framework with the increased ambition of 55% greenhouse gas reduction by 2030 and climate neutrality by 2050. In that respect, the upcoming Fit for 55 Package (which encompasses no less than 12 legislative proposals, including the RED II review) for July 14th and the Hydrogen and Decarbonised Gas Market Package for Q4 2021 will be crucial.

This report briefly presents the main policies which are relevant at EU level, while the FCHO website itself goes deeper into how each policy impacts hydrogen in the different areas of the value chain.

At national level, given the stage of the clean hydrogen industry, there are large discrepancies between the adoption rates of various policies among different countries. The outliers in having adopted the most hydrogen friendly policies in Europe are Austria, France, Germany, Italy, Sweden, United Kingdom, while, in the rest of the world, the countries with most hydrogen policies are South Korea, and the USA.

Policies supporting utilization of hydrogen in transport through fuel cell electric vehicles (FCEVs) are the most common from all sectors. The most common types of policies enacted in this field are purchase subsidies, registration tax benefits and ownership tax benefits. 31 out of the 34 countries included in this year's report have at least one policy supporting FCEVs with 25 of them having three or more policies in place.⁵ 24 out of the 26 EU/EEA/UK countries have at least one FCEV supporting policy in place. Austria, France, and Norway have the largest number of subsidy policies supporting FCEVs with six financial and non-economic incentives in place while Portugal, Lithuania, and Morocco are the only countries with no FCEV supporting policies.

Policies supporting hydrogen as a fuel and hydrogen refuelling infrastructure are also quite common. This type of policies include CAPEX⁶ support, mandates, permitting rules, and other policies. 27 out of 34 countries have at least one policy in place and 14 countries have three or more policies. Among EU/EEA/UK, 21 out of 26 countries have at least one policy with Czech Republic, Germany, Italy, and United Kingdom having adopted four different policies. The most common refuelling infrastructure policies include permitting guidelines and other policies in 17 countries and CAPEX support in 14 countries..

Policies supporting stationary fuel cell power such as CAPEX support and tax incentives are less common with only 15 out of the 34 countries having at least one policy in place. Among EU/EEA/UK, 12 out of 26 countries have at least one policy. The leaders are Germany with four different policies, followed by Bulgaria, Finland, Italy, Netherlands, Slovenia, and United Kingdom with two policies in place each. CAPEX support for stationary applications is available in ten countries while tax incentives are enacted in five countries.

The most common policies supporting **hydrogen production** are CAPEX subsidies with 13 countries providing CAPEX subsidies in some form for renewable or low-carbon hydrogen production plants.⁷ These funding sources are implemented through different instruments. In Germany, electrolyzers built for hydrogen production for the transport sector are eligible for support at 45% funding rate. In Flanders, Belgium, support of renewable or low-carbon hydrogen production is eligible for funding at a rate between 20% to 40% of the required CAPEX through its "Strategische ecologiesteun". The second most common hydrogen production policies are exemptions from or reductions of electricity price components when producing hydrogen. Such types of incentives are available in five countries. In Sweden and Denmark, electricity for hydrogen production is exempt from the electricity tax. In Germany, under the German Renewable Energy Sources Act (EEG) 2021, the EEG levy for electricity for

⁵ The full list of the 34 covered countries is in the Annex.

⁶ CAPEX: capital expenditure to acquire, maintain or improve a fixed asset

⁷ Eight of those are in EU/EEA/UK.

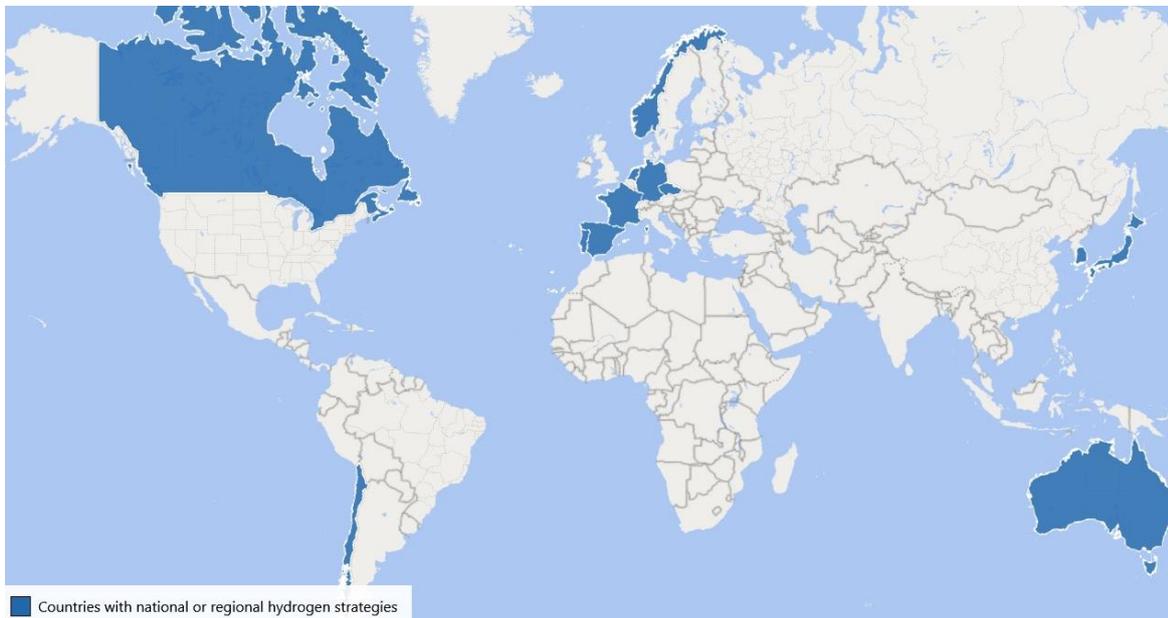
renewable hydrogen production is zero. In addition, in case of use of grid electricity with guarantees of origin, electrolyzers are exempt from grid charges under the Energy Industry Act.

In regards to **hydrogen transmission**, out of the 34 countries covered in this report, Denmark and Germany are the only two countries with a specific policy in the area. The policies enacted in the two countries applies to the allocation of gas grid connection costs between network operator and hydrogen production plant operator.

While hydrogen is widely used in **industrial applications**, policies supporting the introduction of renewable or low-carbon hydrogen in industry are less common. Low-carbon hydrogen demonstration subsidies are the most common form of support, being available in 14 countries. (12 in EU/EEA/UK). Some form of CAPEX support for renewable/low carbon hydrogen production used in industry for non-demonstration projects are in effect in Austria, Belgium, Bulgaria, Finland, Germany, and Netherlands.

Hydrogen roadmaps and strategies are relatively commonplace. Among the surveyed countries, 12 out of 34 have national or regional hydrogen strategy. Figure 3 visualizes hydrogen strategy adoption in the covered countries.

Figure 3: Countries with national or regional strategies in place as of June 2021



1. EU Policies and Regulations

This report provides users with a comprehensive overview of the **most relevant policies at EU level that directly or indirectly affect the development and deployment of the hydrogen technologies** covered by the Fuel Cells and Hydrogen Observatory (FCHO). This report presents an overview of those EU policies.

This report analyses a total of 18 policies, both of legislative and non-legislative content and enacted at EU level. Legislative content typically involves a Directive (e.g. Renewable Energy Directive) or a Regulation (e.g. Regulation setting CO2 emission performance standards for new passenger cars and light-duty vehicles). In contrast, non-legislative content typically involves a high-level political strategy, roadmap or communication (e.g. EU Green Deal communication or the Hydrogen Strategy).

The policies covered are presented in the table below.

Table 2: EU Policies covered by the FCHO

Legislative measures (in force)	Non-legislative policies (or planned legislative measures)
Renewable Energy Directive	EU Green Deal
Energy Efficiency Directive	European Climate Law
CO2 emission performance standards for new passenger cars and light-duty vehicles	Industrial Policy and State Aid
CO2 emission performance standards for new heavy-duty vehicles	ETS Innovation Fund
Alternative Fuel Infrastructure Directive	Sustainable Finance (including R&D) under the EU Green Deal
EU Emission Trading System (ETS)	The EU Hydrogen Strategy under the EU Green Deal
Public Procurement rules for clean vehicles	The EU Energy System Integration Strategy under the EU Green Deal
	The Offshore Renewable Strategy
	The Renovation Wave
	The Sustainable and Smart Mobility Strategy
	The Effort Sharing Regulation
	The TEN-E Regulation

The FCHO website links these policies based on their relevance and impact across various value chain levels and applications of the hydrogen and fuel cell industry. Those are broken down into three main categories.

Table 3: Policy dimensions covered by the FCHO EU policies section

1. Hydrogen Production	2. Hydrogen Distribution	3. Hydrogen End-Uses
	Large scale storage	Transport <ul style="list-style-type: none"> • Road transport • Maritime • Aviation • Trains
	Hydrogen in the gas grid	Heat and Power <ul style="list-style-type: none"> • Stationary fuel cells • Hydrogen burners and turbines
	Transport and storage in liquid carriers	Energy Intensive Industry
	Transport by road, ship, etc.	
	HRS for multiple applications	

1.1. Overview

The **European energy policy landscape** has gone through many changes in 2020, with the objectives of increasing the ambition to establish a regulatory framework conducive to the transition towards a climate neutral economy, accelerate greenhouse gas reduction, and foster the emergence of clean technologies, such as hydrogen. In late 2019, the newly elected European Commission presented its proposal for a European Green Deal. This policy roadmap is meant to be ‘the EU’s new growth strategy’. This announcement builds on political momentum where climate issues gained significant importance across the EU, and marks a strong shift in EU energy policies, now giving significantly stronger emphasis to the decarbonisation dimension of the Energy Union. The Green Deal indeed is now materialising in many legislative and non-legislative initiatives, aimed at implementing the increased level of ambition. Most importantly, the European Climate Law, is on the verge of being formally adopted by EU institutions following their provisional agreement in April 2021, sets into EU law the binding target of net zero greenhouse gas emissions by 2050 (so-called ‘carbon neutrality’ or sometimes ‘climate-neutrality’), as well as a 55% greenhouse gas reduction EU target by 2030. The initiatives meant to enable this transition include the Energy System Integration Strategy and the European Hydrogen Strategy. Both strategies, released in the form of Communications from the European Commission, clearly show the importance hydrogen is given in helping decarbonise the economy, not least ‘hard-to-abate’ sectors, that are harder to electrify, such as high temperature industry (steelmaking, cement...), fertilisers, and heavy and long-haul transport (maritime, aviation, heavy duty vehicles, etc.). In these two strategies, hydrogen is seen as a key technology to link the components of the energy system (thanks to its versatility and its potential for energy storage and for decarbonisation means in hard-to-abate sectors either as fuel or feedstock). The Commission, in the context of the European Hydrogen strategy sets clean hydrogen production targets: it will aim for at least 6 GW of renewable hydrogen production capacity (i.e. electrolyzers) by 2024 in the EU (resulting in the production of 1 million tonnes of renewable hydrogen) and for 40 GW by 2030 with an additional 40 GW installed in the EU’s neighbourhood. (resulting in the production of 10 million tonnes of renewable hydrogen).

The legislative agenda of 2021 is shaping up to be as important as 2020 for the EU’s energy and hydrogen sectors. **The “Fit for 55” Package, meant to help achieving the 55% target, and the “Hydrogen and decarbonised gas market” package will be the two major bundles of legislation that will aim to**

enable the achievements of EU’s climate targets. They should set a regulatory framework conducive to the clean energy transition aligned with 55% GHG reduction by 2030 and climate neutrality by 2050 and, among others, to the development of a hydrogen economy. **The former package is expected on July 14th, 2021, and the latter in Q4 2021.** The analysis provided by this report is therefore strictly based on the versions of legislations prior to the release of the Fit for 55 Package, which will aim to extensively review 8 already-existing legislations and propose 4 new ones, as outlined in Table 3 below.

Table 4: Policy items planned under the Fit for 55 Package

Revision of already-existing legislation	Proposals for new legislation
Revision of the EU Emission Trading System, including revision of the EU ETS Directive concerning aviation, maritime and CORSIA	ReFuelEU Aviation – sustainable aviation fuels
Revision of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF)	FuelEU Maritime – green European maritime space
Effort Sharing Regulation	Carbon border adjustment mechanism
Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target	Climate Action Social Facility
Amendment of the Energy Efficiency Directive to implement the ambition of the new 2030 climate target	
Revision of the Directive on deployment of the alternative fuels infrastructure	
Amendment of the Regulation setting CO2 emission standards for cars and vans	
Revision of the Energy Tax Directive	

(Source: European Commission)

1.2. Energy

In the **energy** sector, most policies covered by the analysis will have an impact on hydrogen deployment and could also support its scale up. The current version of the **Renewable Energy Directive** sets a 32% target share of renewable energy in the EU’s gross final energy consumption by 2030. The legislation is set to be reviewed under the Fit for 55 Package: the target for renewables share will be revised upwards to align with the new 2030 objective of 55% reduction of greenhouse gas reduction in the EU. National contributions towards this target are determined by Member States, within integrated national energy and climate plans (NECPs) in accordance with Regulation (EU) 2018/1999 (The Governance Regulation) and other acts (e.g. Effort Sharing Regulation, which is also being revised under the upcoming package). Hydrogen can support Member States in the achievement of their respective targets by reducing average emissions from the gas system, by helping to integrate more renewable energy in transport and industrial sectors, and by acting as a grid balancing instrument through energy storage (increasingly needed with renewables deployment). Indeed, the Commission repeatedly mentioned hydrogen as one of the most popular forms of energy storage (not least for seasonal large-scale storage) and which is to play a “nodal role” to foster energy system integration. This was specifically acknowledged for the offshore context, for instance, in the **Offshore Renewable Strategy**, which highlights the potential of offshore hydrogen production to reap offshore and intermittent power production and of hydrogen pipelines to transport the energy back to shore in a cost-efficient manner. While the Strategy was

published in November 2020, the European Parliament is now drafting its position on the topic by means of an own-initiative (INI) report.

The **EU's Emission Trading System** (EU ETS) is another major legislation that is up for revision under the upcoming package. The current ETS covers around 45% of the EU's greenhouse gas emissions, which are not subject to the **Effort Sharing Regulation** (ESR). While the ESR provides binding targets for Member States per sector, ranging from 0% to -40% compared to 2005 emission levels, the ETS Directive (2003/87/EC) has the objective to contribute to reducing overall CO₂ emissions by 40% by 2030 compared to 1990 levels (i.e. a 43% reduction by 2030 compared to 2005 levels), based on its last revision in 2018. Considering the upwards review of EU-level CO₂ emission reduction targets, both emission reduction targets covered by the ESR and the ETS are expected to be revised upwards under the upcoming Fit for 55 Package.

More specifically, regarding the Commission's plans for ETS reform, both the emission (sectoral) coverage and the contribution of the ETS to emission reduction objectives (via reduced available allowances, etc.) could be expanded and boosted respectively under the upcoming revision proposal in July. This could especially help accelerate the deployment of hydrogen in the activities whose emissions are already covered by the cap-and-trade system, such as energy-intensive industries (e.g. steel, cement, etc.) or aviation, as well as in sectors that may be added with this review (e.g. maritime and road transport e.g.). Besides, allowances allocated for free to a number of industries so far could be progressively phased out, as a new **Carbon Border Adjustment Mechanism** (CBAM) would be phased in. This CBAM will be another proposal under the Fit for 55 Package and could put a carbon price on imported products by mirroring price levels in the EU ETS. It would aim at further encouraging third countries to reduce their emissions while protecting EU industry against carbon leakage. The CBAM could cover a limited amount of sectors at first, and then be gradually expanded to others. It would also provide 'own resources' (revenues) to the EU. **The Innovation Fund**, which is funded by ETS auction revenues, should, be a useful support tool to finance innovative projects in low-carbon technologies, including hydrogen.

The highly expected fourth Gas Package, or "**Hydrogen and decarbonised gas market**" package, will, as its prospective name reveals, shape new opportunities for hydrogen deployment. Building on the Energy System Integration and Hydrogen Strategies, the new framework will aim at establishing the regulatory framework for the development of hydrogen in Europe, as well as that of other clean alternative gas technologies, and at enabling sector integration. Hydrogen will also have a role to play in the futureproofing of already-existing natural gas infrastructure, in the context of the current revision of the **TEN-E regulation**, which includes two new energy infrastructure categories: hydrogen and electrolyzers.

1.3. Transport

In the **transport** sector, 2020 was marked by the publication of the European Commission's **Sustainable and Smart Mobility Strategy** at the end of the year. It presented the Commission's vision on transport, specifically under the light of the sector's decarbonisation challenge, entailing the required clean fuel supply ramp up, clean fuel infrastructure deployment, fleet renewals, and demand stimulation, to cite a few key aspects. The Strategy highlights the role that hydrogen and hydrogen-based fuels are expected to play.

Both regulations setting **CO₂ emission performance standards** for new passenger cars and light-duty vehicles and for new heavy-duty vehicles contribute to promoting low-carbon mobility, by making standards stricter, emission reduction targets more ambitious, and by including a precise timeframe for

this decade. The former regulation, for cars and vans, will be revised under the Fit for 55 Package in July and the latter, for heavy-duty vehicles, in 2022. **The Clean Vehicle Directive**, which sets public procurement rules for clean vehicles, and the **Alternative Fuel Infrastructure Directive (AFID)**, which establishes a common framework for alternative fuels deployment, are also expected to boost demand in clean vehicles (including FCEVs) in public procurement and to bolster the deployment of infrastructure for the distribution of clean transport fuels, like hydrogen, such as via HRS and in ports, among others. The AFID will be revised under the Fit for 55 Package.

In **maritime transport**, the European Commission plans to extend the scope of the EU ETS to maritime in order to control and help reduce greenhouse gas emission from the sector. Besides, the Commission is considering the inclusion of **road transport** under the EU ETS, possibly under a separate system. The ETS Innovation Fund is intended to redirect revenues from ETS allowance auctioning into industry demonstration projects for innovative low-carbon technologies. In the aviation sector, the ETS is already implemented and plans are to reduce the number of free allowances allocated to airlines. The Renewable Energy Directive, which sets a 14% renewables target for transport, is expected to affect all levels of the transport sector. As mentioned, the Directive will be revised in July and the target for renewables in transport is expected to be increased accordingly. Moreover, two other upcoming policy initiatives under the Fit for 55 package, ReFuelEU Aviation and FuelEU Maritime, should promote the ramping up of decarbonised fuels in maritime and air transport sectors, including hydrogen. Overall, these policies will impact mobility and transport, with the main objective of reducing greenhouse gas emissions. Hydrogen and fuel cell technologies have a major opportunity to benefit from this change, thanks to the potential of their applications at many levels of the transport sector.

1.4. Industrial and financial policies

Industrial and financial policies are expected to have cross-cutting impacts on the hydrogen industry too and the deployment of H₂. These include the Commission's Industrial Strategy (March 2020). It launched the **European Clean Hydrogen Alliance** and it planned the revision of state aid rules, notably for **Important Projects of Common European Interest (IPCEI)** and the **Environmental Protection and Energy State Aid Guidelines (EEAG)**, three key landmarks to foster the uptake in the production and deployment of clean hydrogen technologies. In the meantime, the Clean Hydrogen Alliance was kickstarted second half 2020, along with the work of its six round tables (Production, Transmission and Distribution, Industrial applications, Mobility, Energy sector, Residential applications), aimed at representing the whole hydrogen value chain, in early 2021. While the collection of hydrogen projects came to an end in May, a first overview was presented at the [Hydrogen Forum](#) in June and the pipeline of scale up investment projects will be provided by the Commission at the November Hydrogen Forum. In the meantime, the Alliance Roundtables are preparing a report highlighting barriers and mitigation measures for hydrogen development, which will be presented in November too.

Regarding **State Aid**, the Commission is currently reviewing its Guidelines on State aid for environmental protection and energy in order to align with new energy and environment targets and initiatives and to deliver on the Green Deal. Hydrogen technologies should be able to reap some benefits from the flexibilisation foreseen to be provided by the revision.

Moreover, the **Energy Taxation Directive**, which is under review under the Fit for 55 Package too, aims to shift the tax burden from labour to pollution. Clean hydrogen should be positively impacted from the change, as low-carbon technologies could benefit from financial incentives compared to more highly taxed fossil fuels. Similarly, the Commission plans to channel financial flows to low-carbon investments and **review taxonomy** for this purpose.

Hydrogen will thereby benefit from extra funding means, not to mention the national **Recovery and Resilience Plans** making available available close to €700bn and of which 37% should be directed at ‘climate expenses’. This adds up to further investment tools like the **Just Transition Mechanism** (made up of a Just Transition Fund, a just transition scheme under InvestEU, and a public sector loan facility with the European Investment Bank backed by the EU budget), **Horizon Europe** (particularly new the public-private partnership Clean Hydrogen for Europe), Connecting Europe Facility (CEF), InvestEU, among others.

2. National Incentives and Policies

2.1. Scope

Content

The National Policies part of the Observatory module on “Policy, Regulation, Codes)” provides users with a comprehensive overview of the most relevant policies on national or regional level that directly or indirectly affect the development and deployment of the hydrogen technologies covered by the Observatory.

Information is organized around six major chapters described in the table below.

Table 5: Categories of national policies covered by the Fuel Cells and Hydrogen Observatory

Sector	Explanation of context
1. Fuel cell electric vehicles	Policies that may prevent or support FCEVs and/or the substitution of conventional vehicles with zero-emission solutions
2. Stationary power	Policies that may prevent or support the deployment of stationary fuel cells and/or the substitution of grid electricity / gas with heat and power produced from fuel cells
3. Hydrogen as a fuel and hydrogen refuelling Infrastructure	Policies that may prevent or support hydrogen as a fuel / hydrogen refuelling stations and/or the substitution of fossil fuels with hydrogen
4. Hydrogen production, transmission, and distribution	Policies that may prevent or support production of hydrogen and its subsequent transmission and distribution
5. Hydrogen in the industry	Policies that may prevent or support the introduction of hydrogen in industrial processes, substituting conventional methods/fossil fuels
6. General questions	Strategy and planning policies such as hydrogen roadmaps as well as various renewable electricity subsidy policies

This report presents an analytical overview of the currently gathered national policies data structured around the six above-mentioned chapters. This report summarises information on several key questions in each chapter, but it is not exhaustive as it does not address all the questions included in the Observatory. Each chapter provides an introduction into the sector and presents preliminary results based on gathered data. It focuses on key insights in each chapter that provide informational value about the proliferation and scale of policies impacting the various hydrogen sectors.

2.2. Methodology

National respondents

Given the diverse scope of the policies monitored, no single authority could provide the data required for the Observatory. As a result, **data collection at the national level** has been done by **an extensive team of national contributors**. Their unique knowledge, expertise, and language skills ensured an efficient data collection process. Contributors include governmental organizations such as national energy agencies, national hydrogen associations, research centres, and ministries as well as individual experts.

Verification

Respondents' answers have been revised by Hydrogen Europe to the best of their ability to ensure both consistency and factual correctness of the information provided. Given the changing nature of policies, **data will be revised** on an annual basis.

Technical background

The data collection process has been implemented, from a technical perspective with the support of the consortia's technological partner, Inycom. Drupal questionnaires and data storage in a SQL database format were used. The platform's interface is complemented with Tableau for automatic creation of maps and other visualizations.

2.3. Geographical Coverage

Since the hydrogen sector is developing with different objectives around the world due to countries' different demands, policies adopted to support its further development also differ widely. In view of these developments, it is important to cover not only EU members, but also other major economies focused on hydrogen development.⁸

A more global policy coverage will allow for a more comprehensive analytical and comparative work given the inclusion of major economies.

The geographical coverage of the National Policies part of the FCH Observatory includes **38 entities**. These 38 entities are comprised of 37 countries and one sub-national unit, the State of California.⁹

As of writing of this report in June 2021, the FCH Observatory received responses from 34 out of the 38 entities.¹⁰ As a result, the data included online and in this report covers these 34 countries, 26 of which are members of the EU/EEA/UK.¹¹ Figure 4 visualizes the geographical coverage.

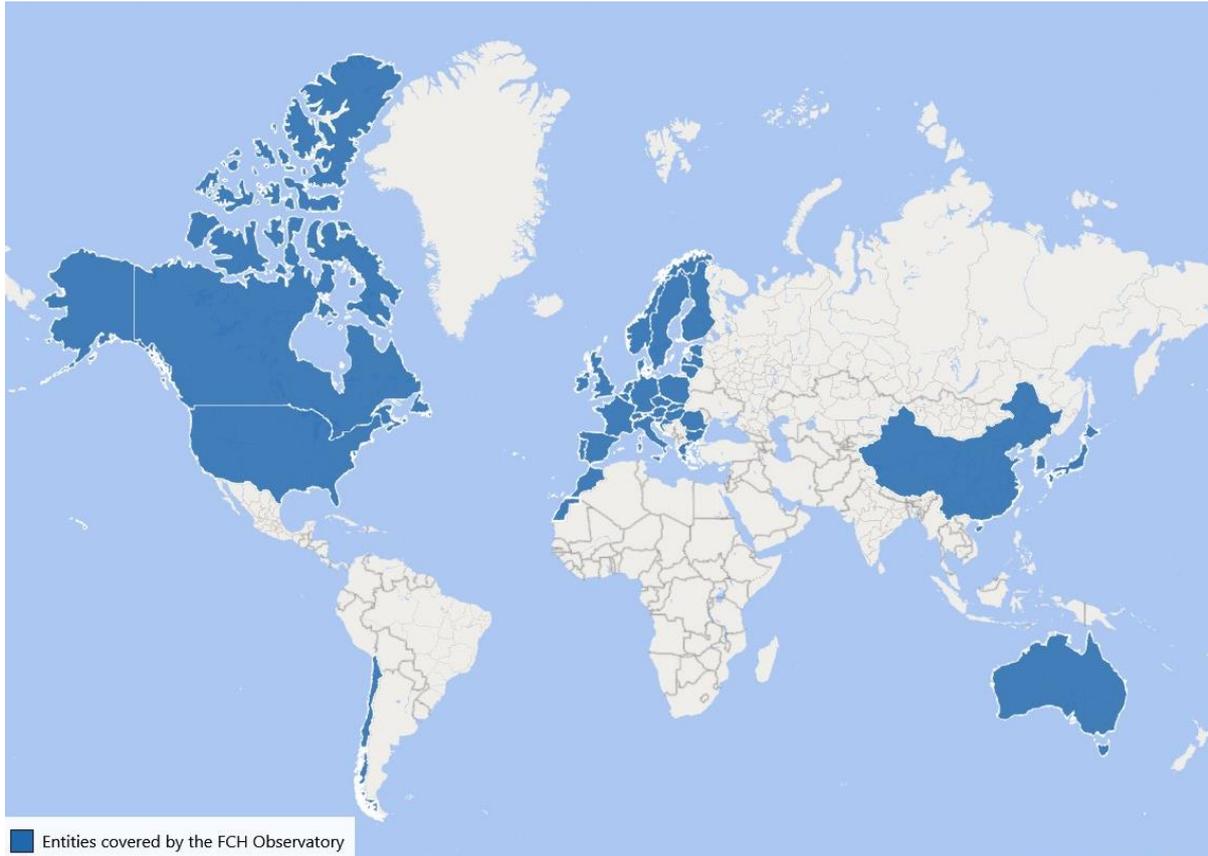
⁸ Major non-EU/EEA hydrogen economies already being tracked include Australia, Chile, China, Japan, and South Korea.

⁹ When this report refers to USA, its data is represented by the State of California.

¹⁰ The entities for which data is only available from April 2020 and have not been updated as of writing of this report include Australia, China, Japan, Morocco.

¹¹ The EU/EEA/UK countries for which information is not available on the portal nor in this report include Cyprus, Latvia, Luxembourg, and Malta.

Figure 4: Geographical coverage of the Fuel Cells and Hydrogen Observatory in terms of national policies¹²



2.4. Fuel Cell Electric Vehicles

The chapter covering policies on Fuel Cell Electric Vehicles covers questions related to different means of FCEV support via six different policy categories.

Table 6: Main questions answered in the FCEV chapter

Fuel cell electric vehicles chapter questions (selection)
Is there a purchase subsidy offered to FCEVs?
Are there any registration tax benefits offered to FCEVs
Are there any ownership tax benefits offered to FCEVs
Are there any company tax benefits offered to FCEVs
Are there other financial benefits and/or subsidies offered to FCEVs?
Are there any non-economic benefits / incentives applicable to FCEV's?

The questionnaire sought to answer whether policies are in place, their economic value (in EUR or as % of the vehicle cost or tax due), which modes of transport they apply to (heavy duty vehicles, passenger cars, boats etc.), and any other relevant details about the policy.

Policies for FCEVs are widespread among the surveyed countries. **31 out of the 34 countries** included in this survey have **at least one policy supporting FCEVs** with **25 of them having three or more policies**

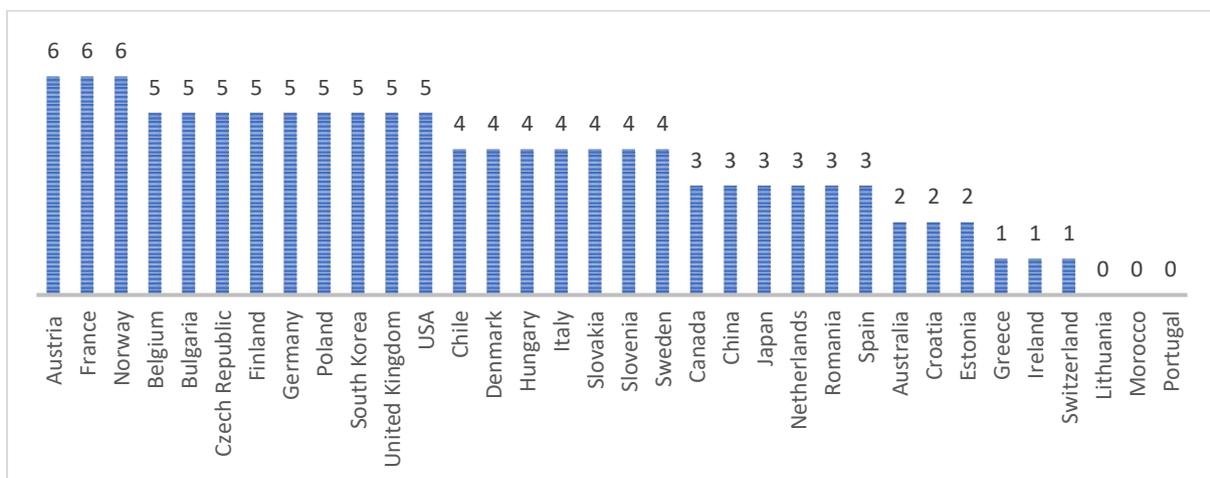
¹² Information for the United States of America is represented by California.

in place. For EU/EEA/UK, 24 out of 26 countries have at least one policy and 19 countries have three or more FCEV policies.

As evident in Figure 5, **Austria, France, and Norway** have the **largest number of policies supporting FCEV** vehicles with all six financial and non-economic incentives in place. Countries with five policy categories include Belgium, Bulgaria, Czech Republic, Finland, Germany, Poland, South Korea, United Kingdom, and USA.

On the other end of the spectrum, **Lithuania, Morocco, and Portugal** are the only countries with **no FCEV supporting policies** even though they all have at least some BEV support policy in place. In Portugal’s case, BEV support includes exemption from annual road tax, purchase subsidy, deductible VAT for companies as well as some non-economic benefits such as access to bus lanes, free parking, and free circulation in some downtown areas.

Figure 5: Number of FCEV policies adopted by country

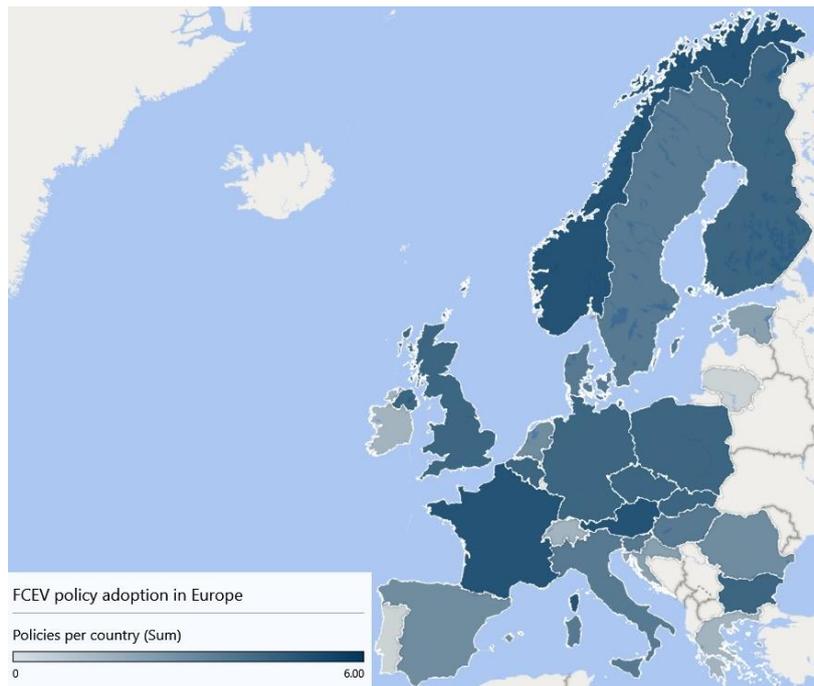


While various FCEV and BEV policies have been adopted across Europe, they are not equally represented as BEV policies continue to be more common. There are 12 EU/EEA/UK countries in which there is a BEV policy that excludes FCEVs.¹³ Some of the examples that exclude FCEVs are Slovakia’s purchase subsidies and accelerated depreciation policies applicable only for PHEVs and BEVs.

Current adoption of FCEV policies in Europe based on Figure 6 does not suggest any geographical trend with all regions being represented among both the most and least supportive.

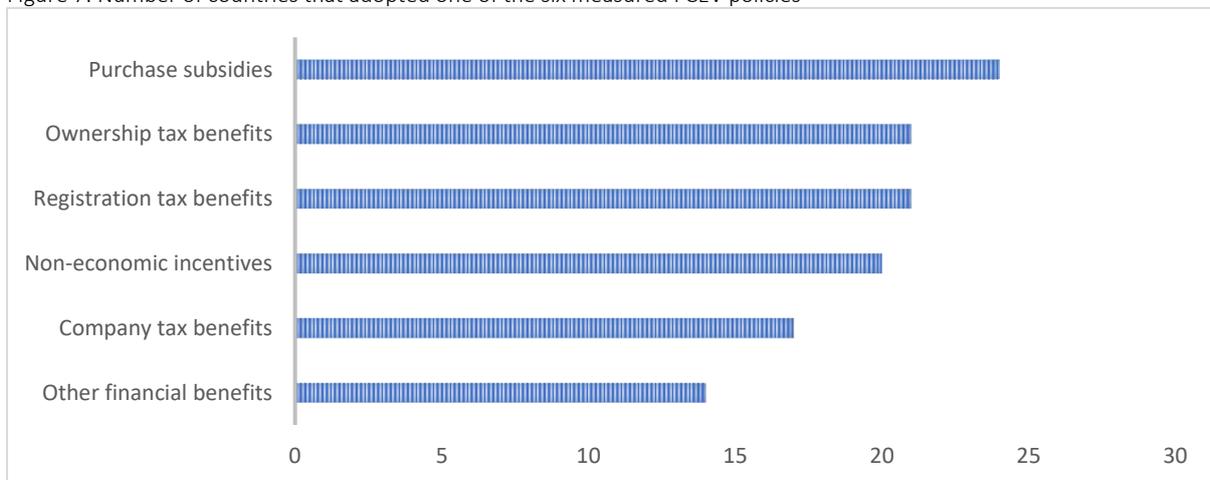
¹³ Countries in which there is at least one policy intended to promote electric mobility that excludes FCEVs: Croatia, Finland, Germany, Hungary, Ireland, Italy, Lithuania, Netherlands, Norway, Portugal, Slovakia, Sweden.

Figure 6: Intensity of FCEV policy adoption in Europe



Considering all applications and modes of transport, the **most commonly implemented policies are purchase subsidies**, as they are present in **24 out of 34** countries, followed by registration tax benefits and ownership tax benefits in 20 countries.¹⁴

Figure 7: Number of countries that adopted one of the six measured FCEV policies



The structure and scale of the provided policy support varies widely among countries. Some countries use absolute values while others use percentages, but most of them limit their policy support up to a specific amount, especially in the case of purchase subsidies.

The most common FCEV support policy are **purchase subsidies**. They are among the most common and well-known policy instruments for supporting emerging technologies as they decrease the capital investment and bridge the gap between the established and emerging technology.

¹⁴ Registration tax benefits are present in 16, purchase subsidies in 18, and ownership tax benefits in 18 out of the 26 EU/EEA/UK countries included in this report.

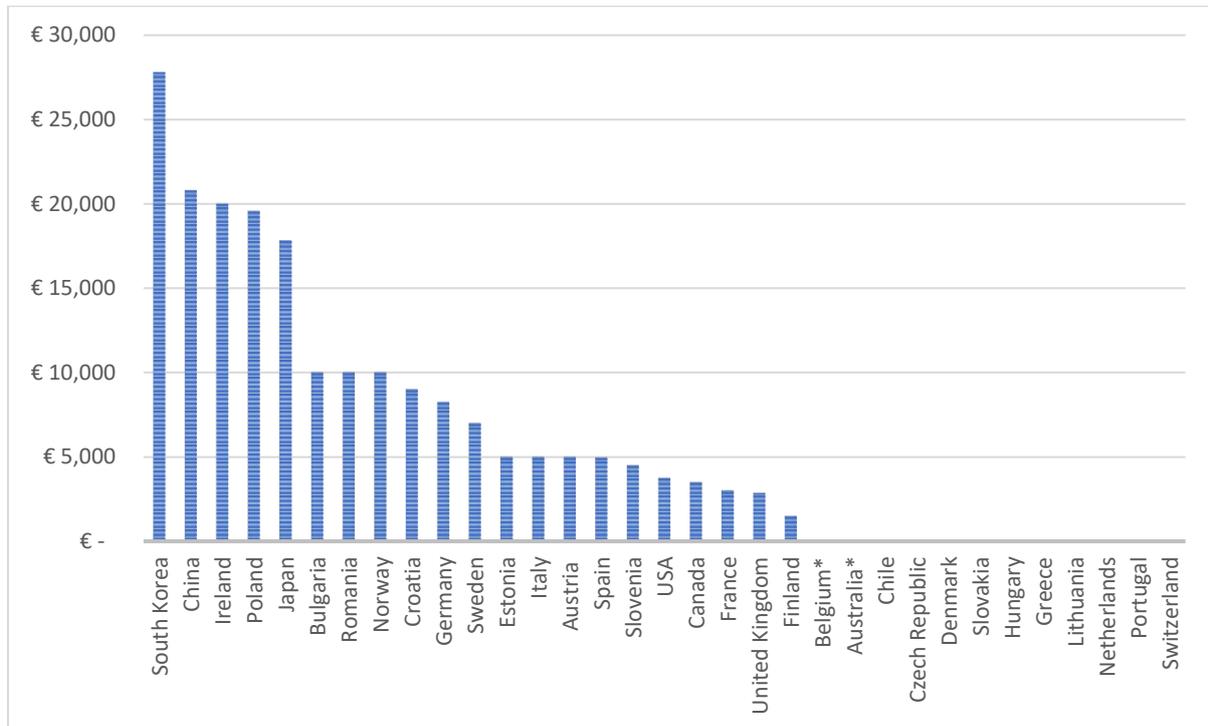
24 countries out of the 34 countries that are a part of this report currently have **purchase subsidies for passenger car FCEVs**.¹⁵ All 24 of those countries also have purchase subsidies for passenger car BEVs. Countries **with purchase subsidies for BEV but which exclude FCEVs include Croatia, Hungary, Ireland, Lithuania, Netherlands, Norway, Portugal, and Slovakia**.

Countries with some form of current subsidies for internal combustion engines include Australia, Czech Republic, Estonia, Finland, Italy, Japan, and Sweden – all of which also have BEV and FCEV purchase subsidies in place.

The most common applications for **FCEV purchase subsidies** include **passenger cars in 23 countries, light duty vehicles in 15 countries, buses and coaches in 16 countries, heavy duty vehicles in 14 countries**, and motorcycles and scooters in six countries. Non-road mobile machinery is only supported in Austria and Belgium. Figure 8 presents values of purchase subsidies for FCEV passenger cars.

These figures range 27,800 EUR in South Korea to approximately 1,500 EUR in Finland. The absolute values are only indicative as in some countries, the subsidy can differ depending on the vehicle and additional conditions. Countries with * have policies for which information in absolute numbers is not available.

Figure 8: Overview of purchase subsidies for passenger cars across covered countries

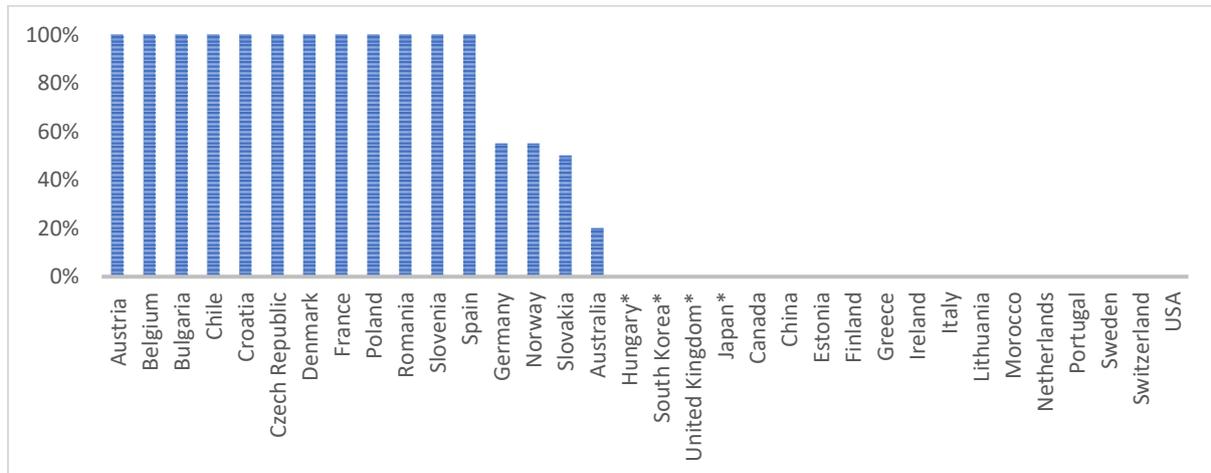


Registration tax benefits for FCEVs are commonplace with 20 countries providing at least some registration tax benefit and 13 countries providing at least 50%. In comparison, 22 countries provide registration tax benefits for battery electric vehicles. The two countries with registration tax benefits for battery and not fuel cell passenger cars are Netherlands and Ireland. Figure 9 below provides an

¹⁵ 17 out of 26 for EU/EEA/UK.

overview of registration tax benefit values for passenger FCEVs. Countries with * have policies with absolute values or other representations that cannot be displayed in Figure 9.¹⁶

Figure 9: Overview of % values of registration tax benefits for passenger cars across covered countries



Equally common as registration tax benefits are **ownership tax benefits** being present in 20 countries. Belgium, Bulgaria, Denmark, France, Germany, Italy, Romania, and Slovenia have a 100 % tax exemption of their various versions of ownership taxes. Slovakia provides 50% reduction of the annual tax. Finland’s benefits amount to ~150 EUR annually, UK’s to 166 EUR, South Korea’s to 100 EUR, and Hungary’s 60-110 EUR.

With fuel cell electric vehicle fleets being promoted to replace the current fleets of ICE vehicles, more than half of the surveyed countries provide **company tax benefits** for passenger cars. Slovenia offers tax base reduction equal to 40% of the vehicle’s purchase price. The Netherlands allows for tax reduction equal to 36% of the purchase price. Germany provides 100% tax benefit/reduction on FCEV purchases. Austria provides up to 6,667 EUR company tax benefit for FCEV purchases and Hungary’s amounts to between 840-1,680 EUR/ year.

Lastly, 17 countries currently provide **other economic benefits** which include not having to pay for tolls in the Czech Republic or a reduction of the tax that an employee has to pay for using an employer-owned car in Sweden.

19 countries also provide **non-economic benefits** such as free parking in Austria, Bulgaria, Czech Republic, Denmark, Germany, Hungary, Norway, Poland, Spain, and USA. Another common benefit is free access to restricted zones and exemptions from driving bans France, Germany, Poland, and Spain which is especially relevant for light and heavy-duty trucks that will have to contend with these bans or restrictions in upcoming years.

¹⁶ South Korea provides up to 5,095 EUR registration tax exemption. Hungary’s registration tax benefit ranges between 760-1500 EUR. United Kingdom’s registration tax benefit amounts to maximum 2,455 EUR. Japan also has registration tax benefit in place, but its value has yet to be determined.

2.5. Stationary Power

The stationary power chapter covers policy support for stationary fuel cells providing electricity and/or heat.

Table 7: Main questions answered in the stationary power chapter

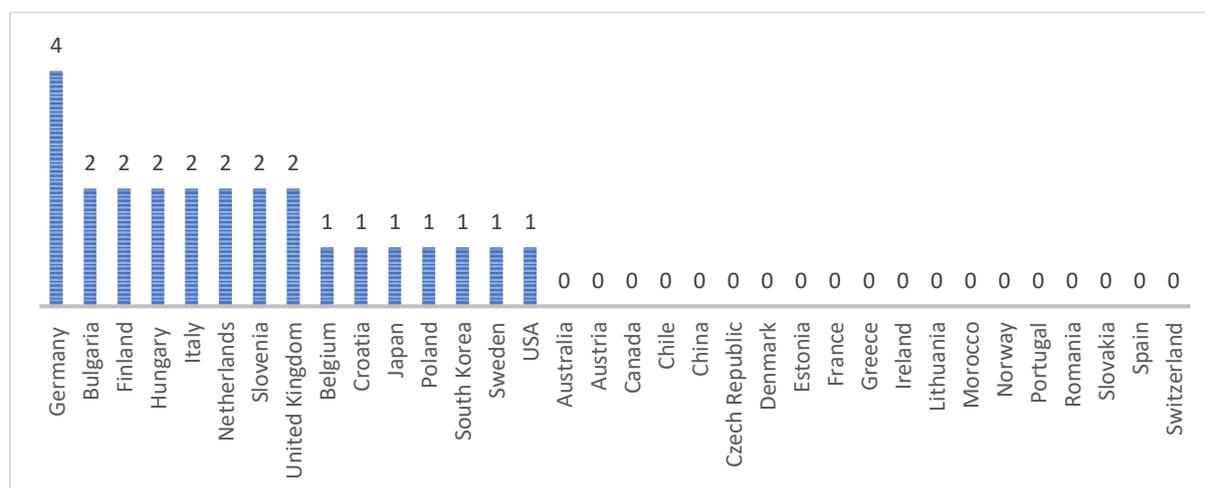
Stationary power chapter questions (selection)
Is there a purchase (CAPEX) ¹⁷ support offered to stationary fuel cell applications?
Are there feed-in tariffs for electricity generated by stationary fuel cell applications?
Are there feed-in premiums for electricity generated by stationary fuel cell applications?
Do quota obligation and certificate schemes exist for electricity generated by stationary fuel cell applications?
Do tax incentives exist that might support the deployment of stationary fuel cell applications?
Are there any other policies (e.g. incentives or obligations) that support or inhibit the replacement of conventional stationary power applications with stationary fuel cells?

The questionnaire sought to answer whether the policies are in place, their economic value (in EUR or as % of the investment or tax due), which applications they apply to (CHP, non-CHP, gensets), and any other relevant details about the policy.

The chapter also explores whether similar support mechanisms are available for conventional stationary power application.

Policy support for stationary power is less common compared to FCEV subsidies. Only **15 out of the 34 countries** included in the report have at least one policy in place.¹⁸ The **leaders are Germany with four different policies**, followed by Bulgaria, Finland, Italy, Netherlands, Slovenia, and United Kingdom with two policies in place each.

Figure 10: Number of stationary fuel cell policies adopted by country

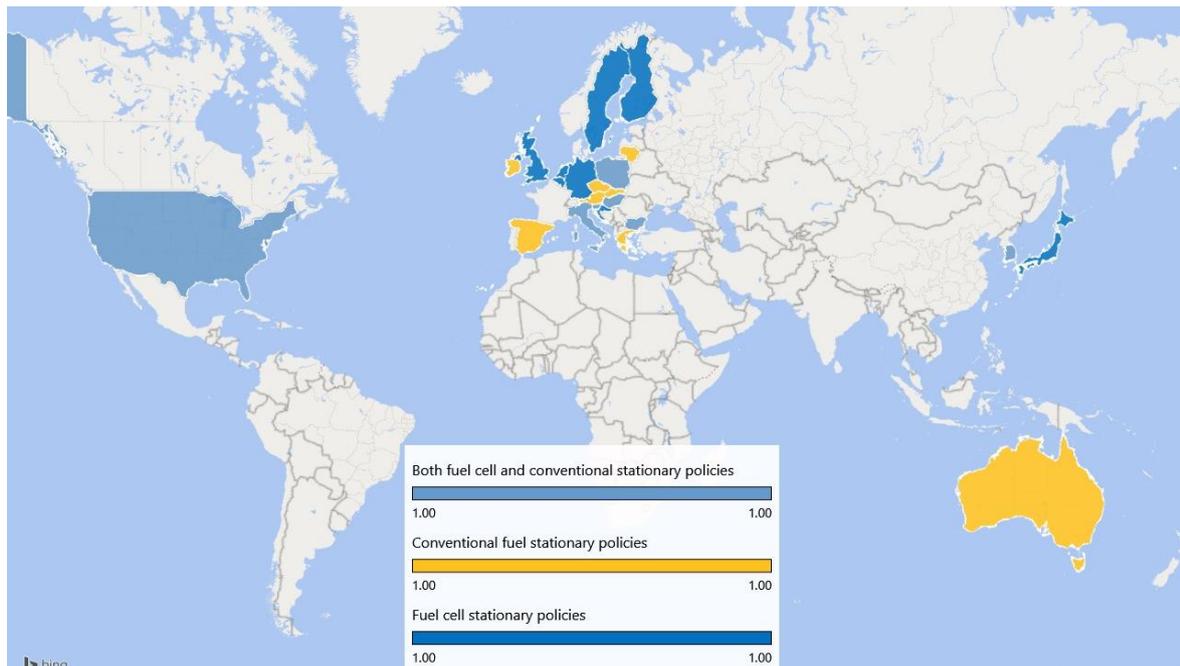


As evidenced by Figure 10, there is no clear geographical distinction that would help explain the number of adopted policies in the surveyed countries. Figure 11 shows **eight countries**, in grey, **with subsidies for conventional stationary power applications** that lack stationary fuel cell subsidies.

¹⁷ CAPEX refers to Capital Expenditure.

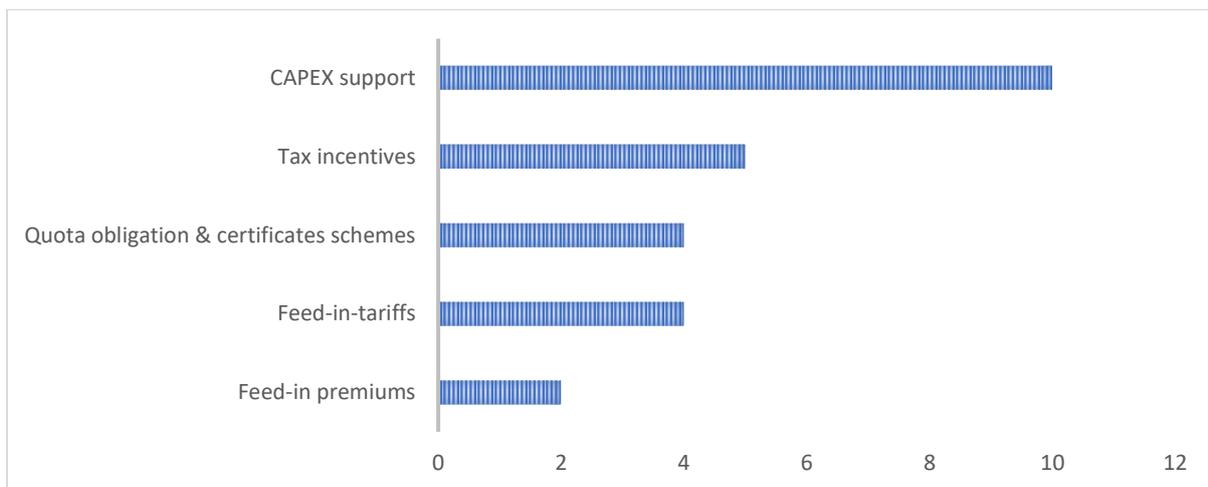
¹⁸ For EU/EEA/UK, it is 12 out of 26 countries.

Figure 11: Geographical coverage of fuel cell and conventional stationary power subsidies



According to Figure 12, the **most common** stationary power policy is **CAPEX support**, available in ten countries followed by **tax incentives** in five countries.

Figure 12: Number of countries that adopted one of the six measured stationary power policies



CAPEX support are some of the most common and well-known policy instruments. They decrease the necessary capital investment thus reducing the difference between the established and emerging technology.

Ten countries out of the 34 that are a part of this report currently have **CAPEX support for stationary fuel cell power applications**. These include Belgium, Bulgaria, Finland, Germany, Italy, Japan, Netherlands, South Korea, United Kingdom, and USA. Out of the 34, **nine have CAPEX support policies for conventional stationary power technologies, but not fuel cell technologies**. These include Austria, Bulgaria, Greece, Ireland, Lithuania, Poland, Slovakia, Slovenia, and USA.

The most common applications for stationary power CAPEX subsidies include **combined heat and power in 10 countries, other non-CHP stationary power applications in five countries, and genset CAPEX subsidies only in the Netherlands**.

2.6. Hydrogen as Fuel and Hydrogen Refuelling Infrastructure

The hydrogen as fuel and hydrogen refuelling infrastructure chapter covers various policy instruments used to promote the build-up of refuelling infrastructure and the use of hydrogen as a fuel.

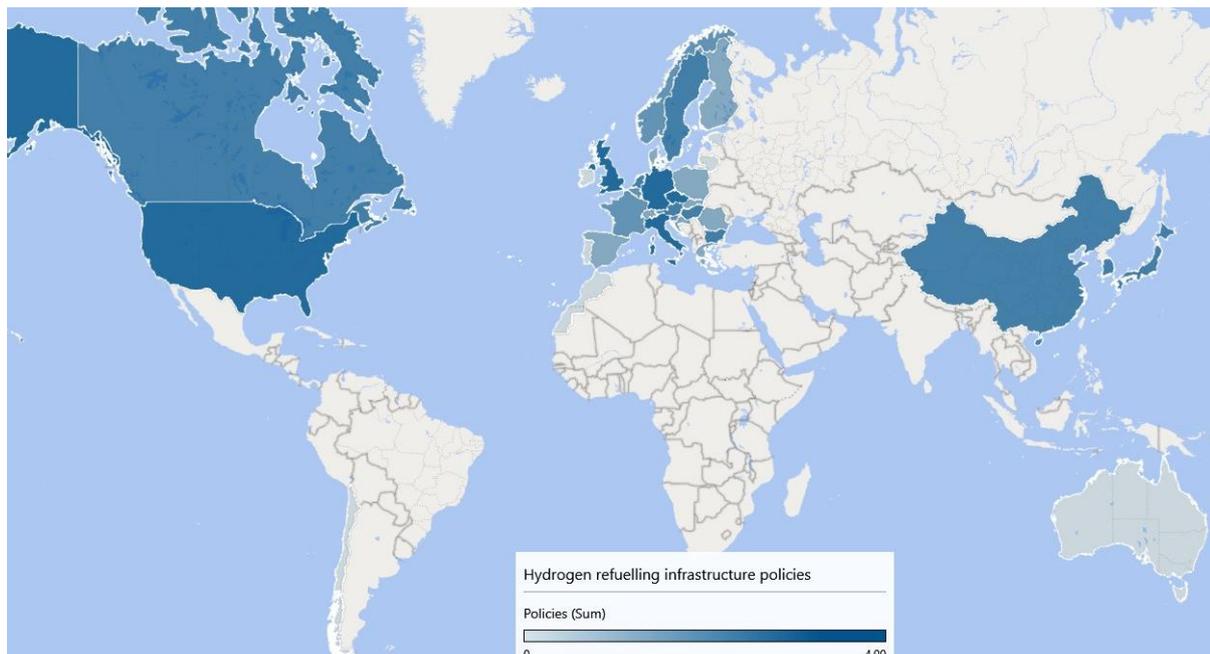
Table 4: Main questions answered in the hydrogen as fuel and hydrogen refuelling infrastructure chapter

Hydrogen as fuel and hydrogen refuelling infrastructure chapter questions (selection)
Is there any CAPEX support offered for HRSs in your country?
Is hydrogen used as fuel taxed in your country?
Are there any mandates / obligations in place requiring the construction of HRSs?
Are there clear rules or guidelines in place that cover permitting of HRS?
Are there any other policies (e.g. incentives or obligations) that support or inhibit the development of HRS in your country?

The questionnaire sought to answer whether the policies are in place, their economic value and any other relevant details about the policy.

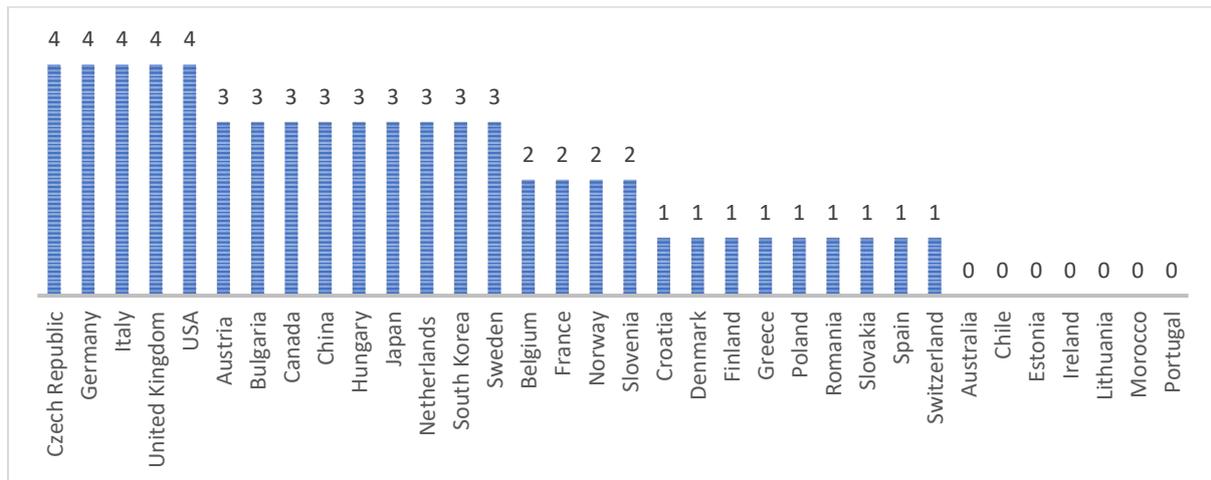
Figure 13 and Figure 14 provide an overview of countries with the most and least ambitious refuelling support policies with **Czech Republic, Germany, Italy, United Kingdom, and USA** having adopted **four different policies**.

Figure 13: Geographical coverage and intensity of subsidies for hydrogen refuelling infrastructure



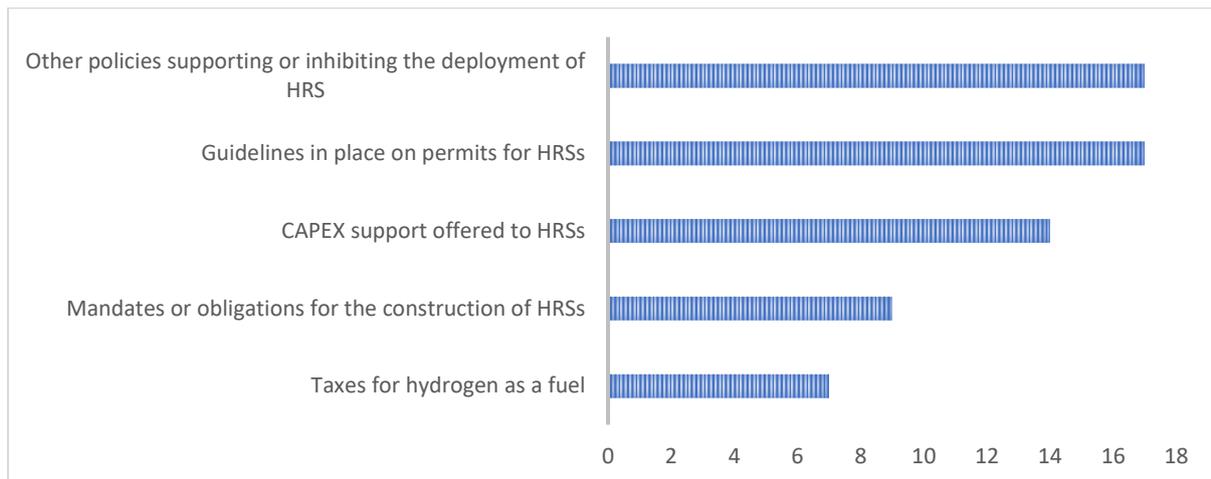
Nine countries have three policies in place including Austria, Bulgaria, Canada, China, Hungary, Japan, Netherlands, South Korea, Sweden.

Figure 14: Number of hydrogen refuelling infrastructure policies adopted by country



The most common refuelling infrastructure policies include permitting guidelines for HRS in 17 countries, other policies supporting HRS deployments in 17 countries, and CAPEX support in 14 countries.¹⁹

Figure 15: Number of countries that have adopted one of the five measured hydrogen as a fuel and refuelling infrastructure policies



Seven countries tax hydrogen as fuel (Austria, Canada, Hungary, Poland, Slovenia, United Kingdom, USA). Hungary taxes hydrogen fuel as natural gas while Poland taxes it at 0.04 EUR/kg. In Austria, hydrogen used as a fuel is treated the same as natural gas and taxed at 0.021 EUR/m³. France, Finland, Slovenia, and the United Kingdom are planning to introduce or revise their hydrogen fuel taxation. This is the least common policy in this category.

The other policies provided by survey respondents cover a wide range of government and industry initiatives. Slovakia is planning to introduce various incentives for HRS development to achieve the HRS targets of its Alternative fuel action plan. In Germany, companies created an industry initiative, H2 MOBILITY, whose primary task is the establishment of a nationwide infrastructure for hydrogen mobility. In the course of 2021, the government is also expected to publish decrees that will define rules and regulations related to installation and operation of HRS. Currently, the Swedish government policy requires fuel stations that sell over 1000 m³ of petrol or diesel to provide at least one alternative

¹⁹ Permitting guidelines are present in 13, CAPEX support in 9, and other policies in 14 out of the 26 EU/EEA/UK countries measured in this report.

fuel. This requirement is currently most commonly satisfied with E85, but could also incentivize HRS deployment in the future. In the Netherlands, quantitative risk analysis necessary for HRS installation is being developed that will simplify the safety guidelines and thus overall HRS deployment.

2.7. Hydrogen Production, Transmission, and Distribution

This chapter covers policies that support the production of hydrogen, its transmission, and distribution. Policies providing funding for hydrogen production could significantly contribute to scaling of the emerging electrolytic and low-carbon hydrogen production markets. Policies covering transmission and distribution of hydrogen in either the natural gas network or in dedicated hydrogen infrastructure are also covered by the chapter.

Table 8: Main questions answered in the hydrogen production, transmission, and distribution chapter

Hydrogen production, transmission, and distribution chapter questions (selection)
Is there any CAPEX support for renewable/low-carbon hydrogen production plants ?
Is there any OPEX support (e.g. in the form of carbon contract for difference or any other form of OPEX support) for renewable/low-carbon hydrogen production plants ?
Is there any exemption from or reduction of certain electricity price components for the electricity used for production of renewable/low-carbon hydrogen?
Is there any feed-in tariff for hydrogen when injected into the gas grid?
Is there a feed-in premium for hydrogen when injected into the gas grid?
Is any quota system in place for renewable content of the gas mix in the gas grid?
Are there any exemptions from or reduction of gas network fees and tariffs for hydrogen injected into the gas grid?
Is there a legal hydrogen concentration limit into the gas grid?

The policies supporting production, transmission, and distribution of hydrogen are less prevalent than policies in other sectors, such as transport.

The most common ones are **CAPEX subsidies** with 13 countries providing CAPEX subsidies in some form for renewable or low-carbon hydrogen production plants.²⁰ These funding sources are implemented through different instruments. In California, there are regular grant funding opportunities. Bulgaria is preparing its support scheme for renewable hydrogen with up to 50% CAPEX support as a part of its National Recovery and Resilience Plan. In Germany, one of the CAPEX subsidies concerns electrolyzers built specifically for hydrogen production for the transport sector with a funding rate of 45%. In Austria, hydrogen production plants continue to be eligible for funding from Kommunalkredit Public Consulting. In Belgium, the Flemish government includes support of renewable or low-carbon hydrogen production through its “Strategische ecologiesteun” and supports 20% to 40% of the required CAPEX for projects with minimal investment costs of three million EUR. Denmark announces call for support for which projects can apply and funding is awarded on a case by case basis. In Sweden, hydrogen production projects can get funding through “Industriklivet” initiative aimed at reducing emissions from industrial production. In Finland, projects introducing new technology, including electrolyzers can receive up to 40% of investment subsidy with specific amount to be decided on a case-by-case basis.

²⁰ Eight of those are in EU/EEA/UK.

There are five countries with some form of an **exemption from or reduction of electricity price components when producing hydrogen**. In Sweden, all electrolytic processes, including electrolytic hydrogen production, are exempt from electricity tax. In Denmark, as a part of energy tax deductions, electricity for hydrogen production is exempted from taxation. In Germany, under the German Renewable Energy Sources Act (EEG) 2021, the EEG levy for electricity consumed by a company to produce green hydrogen, regardless of its intended use, will be reduced to zero. In case of use of grid electricity with guarantees of origin, electrolyzers are exempt from grid charges under the Energy Industry Act. In France, electrolytic processes are exempted from the domestic tax on final consumption. In addition, consumers with stable or counter-cyclical consumption profile can benefit from a tariff reduction for use of the public electricity network (TURPE). The reduction cannot exceed 90%, the consumption point must have utilization of at least 7000 hours/year and/or minimum rate of use in off-peak of at least 44%.

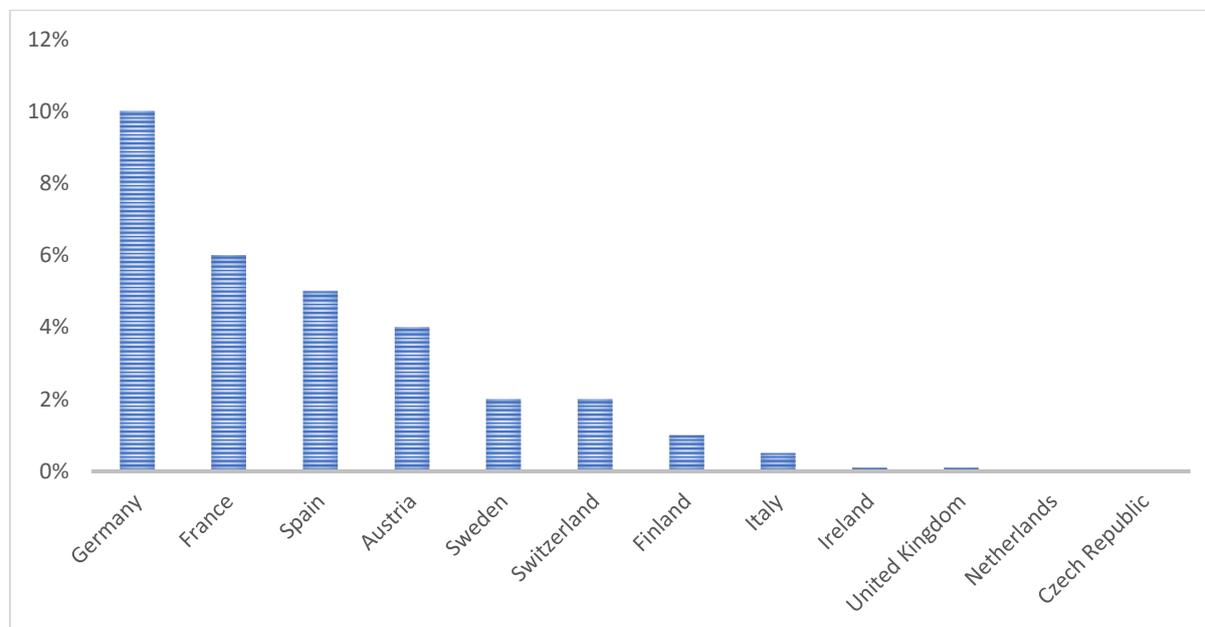
Nine countries (Czech Republic, Denmark, Estonia, France, Italy, Netherlands, Sweden, UK, and USA) currently provide tariffs or premiums for injection of biogas or synthetic methane into the gas grid. While excluding hydrogen for now these existing policies provide an opportunity for hydrogen to be included.

France and Germany provide **exemptions or reductions from gas network fees and tariffs** with Germany treating hydrogen similarly to biogas.

Out of the 34 countries covered in this report, **Denmark and Germany** are the only two countries with a **specific policy on the allocation of gas grid connection costs** between network operator and hydrogen production plant operator. In Germany, the connection cost split is 75% by the network operator and 25% by the connecting party with specific limits and details for connections of 10 km.

In terms of non-financial policies, the most common policy is a **legal hydrogen concentration limit in the gas grid**. Countries' acceptable H₂ limits range from 0% in Czech Republic, 0.1% in the United Kingdom to 5% in Spain, and 10% in Germany.

Figure 16: Overview of countries with legal limits of hydrogen concentration in their gas grids²¹



²¹ Non-graphically represented values include Ireland (0.1%), United Kingdom (0.1%), Netherlands (TSO 0.02%, DSO 0.5%), and Czech Republic (0%).

Another supporting policy is **guarantees of origin (GoO)** for renewable hydrogen. These have been or are in the process of being established in Flanders **Belgium, France, and the United Kingdom**. Similar to GoO in renewable electricity production, they provide potential buyers with certainty that the hydrogen was produced from renewable sources.

2.8. Hydrogen in Industry

Even though hydrogen has been used in the industry for decades, the future use of renewable or low-carbon hydrogen for heat, as a feedstock, or as a chemical agent are some of its most promising use cases. This chapter of the Observatory explores policies supporting increased usage of clean hydrogen in industry.

Table 9: Main questions answered in the hydrogen in the industry chapter

Hydrogen in the industry chapter questions (selection)
Are there any CAPEX subsidies for renewable/low-carbon hydrogen production plants used in industry and aimed at decarbonizing / reducing emissions for industry?
Is there any national funding for low-carbon demonstration projects in industry which involve the use of renewable or low carbon hydrogen?

The questionnaire sought to answer whether the policies are in place, their economic value, and any other relevant details about the policy.

The most common policies are **low-carbon hydrogen demonstration subsidies**. These exist in **14** of the 34 surveyed countries and provide funding for hydrogen demonstration projects.²² Countries with relevant support include Australia, Austria, Bulgaria, Denmark, Finland, France, Germany, Lithuania, Netherlands, South Korea, Spain, Sweden, Switzerland, and the United Kingdom.

Denmark’s funding is available through the Danish Energy Agency. **Finland’s** includes hydrogen demonstrations under its **Energy Aid** program providing a wide range of funding to various projects and technologies under specific conditions. **The Netherlands** supports pilots and demonstration projects via **Demonstration Energy and Climate Innovation 2021+ policy**. In the **United Kingdom**, grant funding is offered under the Industrial Energy Transformation Fund (IETF) with £30 million in 2020 and **£285 million during 2021 - 2024**. Additional grant funding for hydrogen is also available under an Industrial Cluster Mission fund aimed at establishing at least one low-carbon cluster by 2030 and a net-zero carbon industrial cluster by 2040.

CAPEX subsidies for renewable/low carbon non-demonstration hydrogen production projects used in industry are in effect in **six countries Austria, Belgium, Bulgaria, Finland, Germany, and Netherlands**. Austria provides up to 1.5 million EUR in CAPEX costs through KPC (Kommunalkredit Public Consulting) that has the possibility to fund up to 30% of the environmentally relevant additional CAPEX costs of demonstration and innovation projects. **The Flemish government in Belgium covers 20 to 40% of the involved capital expenditure** with a maximum of 1 million EUR through its Ecology bonus Flanders program. This is a financial subsidy for SMEs and large companies to encourage them to make their processes more environmentally friendly and energy efficient. Similarly, to subsidies for demonstration projects, Bulgaria’s various operational programs can also be used for CAPEX subsidies for specific renewable hydrogen projects. Finland’s Energy Aid program provides up to 40% of the initial investment to new technologies and demonstration projects that achieve reduction of greenhouse gas emissions and/or energy savings. The **Netherlands’s Energy Investment Allowance provides tax deductions up to 45% of the investment** under certain conditions.

²² 12 out of 26 for EU/EEA/UK countries.

2.9. Hydrogen Roadmaps and Strategies

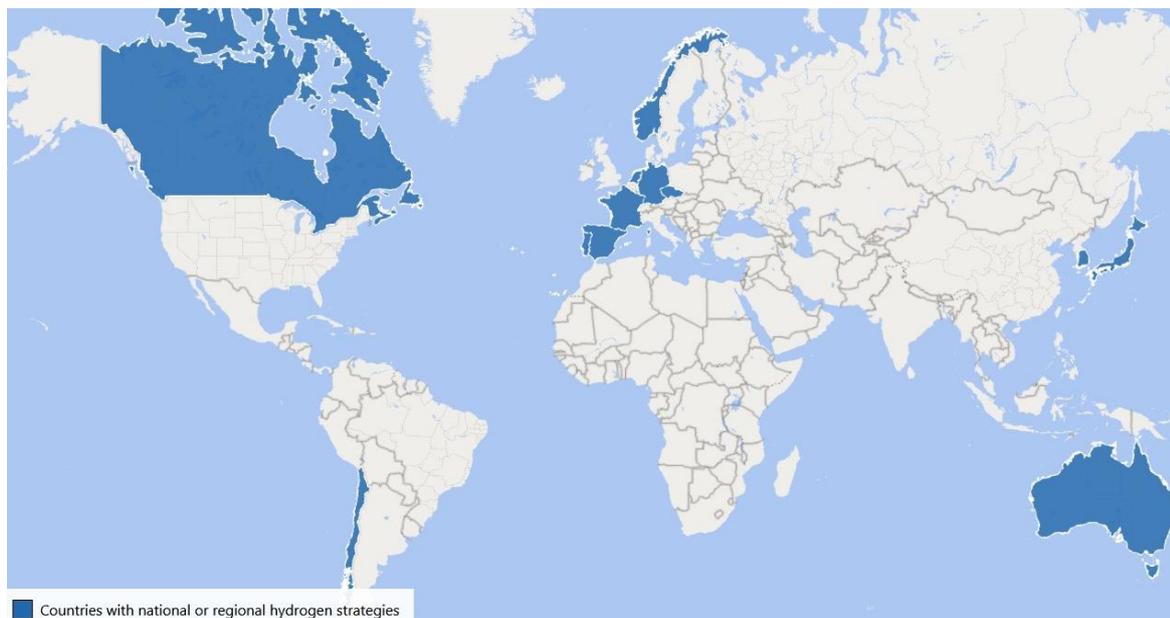
Hydrogen roadmaps and strategies are relatively commonplace among the surveyed countries with **12 countries**, displayed in Figure 17, having individual **national or regional hydrogen roadmaps or strategies**.²³

Australia’s National Hydrogen Strategy specifies Australia’s potential through multiple scenarios, presents benefits of developing hydrogen in the various sectors, and identifies means of developing a hydrogen economy. Germany’s strategy identified 9 bn EUR of spending on hydrogen technologies and related international cooperation. It also set a target of 5 GW of installed electrolysis capacity by 2030. The French strategy identified 7.2 bn EUR of funding to be spent on hydrogen development. The Spanish strategy set 4 GW electrolysis capacity target and identified 8.9 bn EUR of spending from both private and public sector. The Dutch Government Strategy on Hydrogen outlines the historical role of Netherlands as an energy hub, stresses the future importance of renewable gases in the future energy system with hydrogen at its core, and aims to for 3 GW of electrolysis capacity by 2030.

From outside Europe, Chile’s hydrogen strategy aims to develop 25-40 GW of electrolysis capacity by 2030 and mobilize 8 bn USD from public and private funding sources by 2025.

In addition to the already adopted strategies, numerous countries are in various stages of development of their strategies. These include, among others, Austria, Bulgaria, Czech Republic (national), Greece, Hungary, Italy, Poland, Romania, Slovakia, Sweden, and United Kingdom.

Figure 17: Map of countries with national or regional hydrogen strategies



²³ Out of these 12 countries, EU/EEA/UK countries are Czech Republic (regional), France, Germany, Netherlands, Norway, Portugal, and Spain. Others include Australia, Canada, Chile, Japan, South Korea.

3. Acknowledgements

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Estonia	Estonian Hydrogen Association
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France	AFHYPAC
Germany	German Hydrogen and Fuel Cell Association (DWV)
Greece	National Centre for Scientific Research “Demokritos”
Hungary	Hungarian Hydrogen & Fuel Cell Association
Ireland	Hydrogen Ireland / Sustainable Energy Authority of Ireland
Italy	Italian Hydrogen and Fuel Cell Association
Lithuania	Lithuanian Hydrogen Energy Association
Netherlands	NEN
Poland	Institute of Power Engineering
Portugal	Aragon Hydrogen Foundation
Romania	Romanian Association for Hydrogen Energy
Slovakia	Slovak National Association, Ministry of Economy
Slovenia	Energy Agency of Savinjska, Šaleška and Koroška region
Spain	Aragon Hydrogen Foundation
Sweden	Hydrogen Sweden
ASSOCIATED COUNTRIES	
Norway	Norwegian Hydrogen Forum
Switzerland	Swiss Federal Office of Energy
Non-EU/EEA COUNTRIES	
Australia	Hydrogen Mobility Australia and the Government of Western Australia
California/United States of America	California Hydrogen Business Council and California Fuel Cell Partnership
Canada	CHFCA-Canadian Hydrogen and Fuel Cell Association
Chile	Chilean Hydrogen Association
China	Hack Heyward
Japan	New Energy and Industrial Technology Development Organization and Japan Electrical Manufacturers’ Association
Morocco	Adil GAOUI, AMHID
South Korea	H2Korea
United Kingdom	UK Hydrogen and Fuel Cell Association

Chapter 4

2021 Standards Report

July 2021



Disclaimer

This report is based on data gathered as part of the Fuel cells and Hydrogen Observatory as at 31 December 2020. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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Executive Summary

The Fuel Cells and Hydrogen Observatory (FCHO) is an ambitious project to collect available valuable sector information in a single go-to source and make it available to all interested stakeholders. The Standards module within the FCH gives an overview of developments within existing standards and the addition of new standards, representing the progress of the market.

The development of the international market of fuel cells and hydrogen (FCH) requires refocusing and revision of existing standards, as well as the addition of new standards when existing standards cannot to be applied to new developments. Standardization can be considered a reflection of developments in the FCH market, as expert knowledge determines the content of standards. Moreover, standardization requests for the development of new standards are based on market tendencies and market development, thereby representing the focus of the market.

The Standards module aims to list new and revised standards occurred in 2020 and beginning of 2021. Furthermore, the subjects of new and revised standards are illuminated, in order to give an insight in subjects that are currently deemed as most important by experts representing the FCH market. Main points of focus appear to be the improvement of FCH infrastructure, adding standardization work on refuelling points, storage and transport and the improvement of safety around usage of fuel cells and hydrogen in society.

Purpose:	<p>The standards module of the FCHO presents a large number of standards relevant for the deployment of hydrogen and fuel cells. The standards are categorized per application, enhancing ease of access and findability. The development of sector-relevant standards facilitate and enhance economies of scale, interoperability, comparability, safety, and many other issues.</p> <p>https://www.fchobservatory.eu/observatory/Policy-and-RCS/Standards</p>
Scope:	<p>This report presents the developments in European and international standards for the year 2020. Standards from the following standards developing organizations are included: CEN, CENELEC, ISO, IEC, OIML.</p>
Key Findings:	<p>The development of sector relevant standards on an international level continued to grow in 2020; on a European level many standards are still in the process of being drafted. In 2020 12 new standards have been published, mainly on the subject of fuel cell technologies.</p> <p>The recently established committee CEN-CLC JTC 6 (Hydrogen in energy systems) has not published standards yet, but is working on drafting standards on, for example, Guarantees of Origin.</p>
Previous Reports	<p>The first report was published in September 2020. This report is the 2nd Annual report.</p>

1. Standards

1.1. Introduction

The Standards data stream aims to provide users of the fuel cells and Hydrogen Observatory with all relevant European and international European Standards and other technical specifications for a wide range of fuel cell and hydrogen related applications. Standards are voluntary jointly applicable agreements on any given topic between all parties concerned. Standardization refers to the consensus-driven processes outside of government¹ which solve a myriad of problems, from safety to compatibility. A standard can address a process, a product or a service. An agreement on any topic is reached when all stakeholders at the table reach a consensus. All relevant stakeholders can participate in the process of drafting the standard. Standardization occurs on a national level, regional (e.g. European) level and international level.

1.2. Standardization Developing Organizations: structure

In this report standards from the following Standardization Developing Organizations (SDO) have been included:

- International Organization for Standardization (ISO)
- International Electrotechnical Commission (IEC)
- European Committee for Standardization (CEN)
- European Committee for Electrotechnical Standardization (CENELEC)
- International Organization of Legal Metrology (OIML)

Members of European and International Standardization Bodies are delegated from their National Committees (NCs). Standards are often initiated by industries and thus reflect economic and social interests of the several sectors present in member countries. Standardization requests can also occur through consumer interest or legislators. Standards thus reflect the general societal/market interest, as they are driven by business. Members of NCs often are experts in the field and have the knowledge necessary to initiate relevant subjects, playing into general market tendencies.

1.3. Recent developments & trends

In 2020 there has been significant progress on international and European standards development. See Appendix 1 for a detailed overview of every newly published or initiated standardization work. In order to give a reflection of market developments in 2020, the committees that have been publishing and initiating new work in 2020 are described under section 2.1. The committees publishing and initiating the largest extent of work are focusing on fuel cell technologies, hydrogen technologies and the usage of hydrogen in road vehicles.

¹ Note: government(al institutions) can still be stakeholders of an issue, and therefore be part of the standardization process.

2. Published standards and relevant initiatives in 2020

2.1. Overview of Committees and recent standardization work

CEN/TC 268 - Cryogenic vessels and specific hydrogen technologies applications

Standardization in the field of insulated vessels (vacuum or non- vacuum) for the storage and the transport of refrigerated liquefied gases, as defined in Class 2 of "Recommendations on the Transport of dangerous goods - Model regulation", in particular concerning the design of the vessels and their safety accessories, gas/materials compatibility, insulation performance, the operational requirements of the equipment and accessories².

Recently published standards mainly focus on the preparation of standards for hydrogen refuelling points e.g. incorporating filling procedures and determining connection devices for refuelling of gaseous hydrogen.

CEN/TC 23 - Transportable gas cylinders

Standardization of transportable gas cylinders, their fittings, and requirements relating to their design, testing and operation. The scope does not include LPG cylinder covered by CEN/TC 286 or non-refillable cartridges covered by CEN/TC 157. The scope does not include containers for cryogenic gases covered by CEN/TC 268³.

Recently published standards focus on the transport of hydrogen in transportable gas cylinders (carbon composite cylinders and tubes) and the stationary storage of gaseous hydrogen.

CEN/CLC/JTC 6 - Hydrogen in energy systems

Standardization in the field of systems, devices and connections for the production, storage, transport and distribution, measurement and use of hydrogen from renewable energy sources and other sources, in the context of the European strategy for the development and acceptance of the hydrogen market. The scope includes cross cutting items such as: terminology, Guarantee of Origin, interfaces, operational management, relevant hydrogen safety issues, training and education⁴.

CEN/CLC/JTC 6 are currently still in the stage of drafting standards, focusing on vocabulary and safety regarding hydrogen in energy systems. Below most recent developments in the several Working Groups (WG) of CEN/CLC/JTC6 are illuminated.

WG1: In January 2021 the Technical Board of CEN/CENELEC formally agreed to the New Work Item Proposal "Vocabulary H2 in energy systems". This project will be developed under Vienna Agreement (CEN lead) according to the decisions taken by CEN-CLC/JTC6 and ISO/TC 197. Thus, the standard will be internationally adopted by the ISO/TC 197.

² <https://standards.iteh.ai/catalog/tc/cen/ab96cfd0-50bb-4a88-9c20-2b2cb7c57a5f/cen-tc-268>

³

https://standards.cen.eu/dyn/www/f?p=204:7:0:::FSP_ORG_ID:6007&cs=13572AFEAD545F99222FA40984860854B

⁴ https://www.cenelec.eu/dyn/www/f?p=104:7:1312062867558001:::FSP_ORG_ID,FSP_LANG_ID:2121095,25

WG2: focusing on Guarantees of Origin, in extension of the REDII that was published in 2018. In the REDII the standard EN16325 “Guarantees of Origin related to energy – guarantee of Origin for electricity” was adopted.

WG3: focusing on safety. A New Work Item Proposal for the development of a Technical Report: “Safe use of hydrogen in built constructions” has been accepted. Most important subjects within the technical report are the following: prevention of occurrence, considering hydrogen properties, safe design approach, operational aspects; limiting the effect of consequences of fires and explosions; emergency response in case of incidents, considering knowledge transfer, firefighting emergency preparedness and practices and drills.

CEN/CLC/JTC 14/WG 5 – Energy management and energy efficiency in the framework of energy transition

Standardization in the field of energy management within the energy transition framework in close coordination with CEN/CENELEC sectorial strategy including, but not limited to, subjects such as:

- Energy management systems
- Energy audits
- Energy efficiency and energy performance improvement
- Energy and savings calculation methodologies
- Energy efficiency improvement financing (For example: Valuation of Energy Related Investments, Energy Performance Contracting minimum requirements, etc.)
- Energy services providers
- Energy measurement and monitoring
- Role of enabling technologies and RES within the energy management and energy efficiency framework

CEN/CLC JTC 14/WG5 is currently working on Guarantees of Origin for electricity, gaseous hydrocarbons, hydrogen and heating & cooling.

CEN/TC 234 - Gas infrastructure

I) Standardisation of functional requirements in the field of gas infrastructure* from the input of gas into the on-shore transmission network up to the inlet connection of gas appliances; II) Determination and coordination of the gas infrastructure aspects in the technical work dealt with by other CEN/TCs and any other bodies, whether or not reporting to the Sector Forum Gas Infrastructure; III) To act as a focus for standardisation issues in the field of gas infrastructure⁵.

**including transmission, distribution, storage, compression, regulation and metering, installation, injection of non-conventional gases, gas quality issues and others.*

CEN/TC 234 has initiated standardization work regarding hydrogen in the gas infrastructure, specifically regarding the injection of hydrogen into natural gas networks.

5

https://standards.cen.eu/dyn/www/f?p=204:7:0:::FSP_ORG_ID:6215&cs=164D8136B9DA5808851E88A0BB973C593

IEC/TC 105 - Fuel cell technologies

To prepare international standards regarding fuel cell (FC) technologies for all FC types and various associated applications such as stationary FC power systems for distributed power generators and combined heat and power systems, FCs for transportation such as propulsion systems (see note below), range extenders, auxiliary power units, portable FC power systems, micro FC power systems, reverse operating FC power systems, and general electrochemical flow systems and processes⁶.

The IEC/TC 105 has both published and initiated several new standards and subjects, reflecting the current focus of industries on the advancing technology of fuel cells. Recently published standards mainly focus on test procedures and safety of fuel cell modules (in reverse mode). As the market recognizes the importance of environmental aspects, a newly published standard focuses on the evaluation methodology for the environmental performance of fuel cell power system, based of life cycle thinking. New initiatives focus on the development of micro fuel cell power systems and their safety aspects. In total, the IEC/TC 105 has published 5 new standards in 2020 and has initiated 11 standardization subjects in several forms.

ISO/TC 197 - Hydrogen technologies

Standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen⁷.

New publications and initiatives focus on land vehicle hydrogen refuelling. A standard have been written about connection devices, and standardization work has been initiated on several other parts important to the refuelling of hydrogen land vehicles. Other points of focus is fuel quality control and hydrogen refuelling protocols.

ISO/TC 22 - Road vehicles

All questions of standardization concerning compatibility, interchangeability and safety, with particular reference to terminology and test procedures (including the characteristics of instrumentation) for evaluating the performance of the types of road vehicles and their equipment as defined in the relevant items of Article 1 of the convention on Road Traffic, Vienna in 1968 concluded under the auspices of the United Nations⁸.

New initiatives proposed by the ISO/TC 22 are mainly focusing on compressed hydrogen for the use of road vehicles and all parts that should be considered in the usage of compressed hydrogen in road vehicles.

Additional updates on European standardization work: SFEM and AFID
CEN-CENELEC Sector Forum Energy Management (SFEM) Working Group Hydrogen

2.2. Background information on the SFEM WG Hydrogen

The main objective of the CEN-CENELEC SFEM WG Hydrogen is to perform an analysis on the state-of-the-art technology and standardization, and a gap analysis on the main barriers including challenges and needs. A second objective is to establish contact with key stakeholders from the gas sector, electricity supply, mobility and the Fuel cells and Hydrogen Joint Undertaking (FCH JU) in order to

⁶ <https://standards.iteh.ai/catalog/tc/iso/d449eb98-4a92-4482-b515-cdfa3d53bd44/iec-tc-105>

⁷ <https://www.iso.org/committee/54560.html>

⁸ <https://www.iso.org/committee/46706.html>

perform the work in the most effective way and to have broad support from the stakeholders to identify the key challenges. Furthermore, there is an important link to EC services (DG JRC, DG RTD, DG ENER and DG GROW). The final objective is to set a long-term collaborative framework (liaison) with major bodies for strengthening cooperation between regulatory work, standardization work and RDI programs (e.g. European Commission, JRC, FCH 2 JU, IEA Task 38, ISO, IEC). There is a regular exchange of information with the RCS strategy coordination group of the FCH JU.

Last year, the SFEM WG Hydrogen published an updated report:

<https://ec.europa.eu/jrc/en/publication/cen-cenelec-sector-forum-energy-management-working-group-hydrogen-2018-update-report>

A draft guideline has been written by the CEN Sector Forum Energy Management WG multi-fuels: “draft CEN/CENELEC guide³⁷ for multi-fuel stations”. This guide provides guidance on multi-fuel stations. It was prepared to facilitate the integration of alternative fuels in existing fuelling stations and to facilitate the design, authorization and operation of multi-fuel stations. The guide focuses on multiple subjects, for example the internal and external separation distances applied for different fuels and guidance on the design and operation of Emergency Shut Down systems⁹.

2.3. Links to Technical Committees work

For an up to date and current overview of all Working Programs *and* all published standards per relevant Technical Committee (TC) and Subcommittee (SC), please consult the table below and use the hyperlinks:

Standardization Organization	Technical committee	Committee title	Link to TC Work Programme	Link to TC Published standards
CEN	CEN/TC 23	Transportable gas cylinders	CEN/TC 23 Work Programme	CEN/TC 23 Published Standards
CEN	CEN/TC 49	Gas cooking appliances	CEN/TC 49 Work Programme	CEN/TC 49 Published Standards
CEN	CEN/TC 62	Independent gas-fired space heaters	CEN/TC 62 Work Programme	CEN/TC 62 Published Standards
CEN	CEN/TC 69	Industrial valves	CEN/TC 69 Work Programme	CEN/TC 69 Published Standards
CEN	CEN/TC 109	Central heating boilers using gaseous fuels	CEN/TC 109 Work Programme	CEN/TC 109 Published Standards
CEN	CEN/TC 185	Fasteners	CEN/TC 185 Work Programme	CEN/TC 185 Published Standards
CEN	CEN/TC 197	Pumps	CEN/TC 197 Work Programme	CEN/TC 197 Published Standards
CEN	CEN/TC 208	Elastomeric seals for joints in pipework and pipelines	CEN/TC 208 Work Programme	CEN/TC 208 Published Standards
CEN	CEN/TC 234	Gas infrastructure	CEN/TC 234 Work Programme	CEN/TC 234 Published Standards
CEN	CEN/TC 235	Gas pressure regulators and associated safety devices for use in gas transmission and distribution	CEN/TC 235 Work Programme	CEN/TC 235 Published Standards

⁹

<https://www.cencenelec.eu/standards/Sectorsold/SustainableEnergy/Management/Pages/SectorForumEnergyMgmt.aspx>

CEN	CEN/TC 236	Non industrial manually operated shut-off valves for gas and particular combinations valves-other products	CEN/TC 236 Work Programme	CEN/TC 236 Published Standards
CEN	CEN/TC 238	Test gases, test pressures, appliance categories and gas appliance types	CEN/TC 238 Work Programme	CEN/TC 238 Published Standards
CEN	CEN/TC 268	Cryogenic vessels and specific hydrogen technologies applications	CEN/TC 268 Work Programme	CEN/TC 268 Published Standards
CEN	CEN/TC 282	Installation and equipment for LNG	CEN/TC 282 Work Programme	CEN/TC 282 Published Standards
IEC	IEC/TC 21	Secondary cells and batteries	IEC/TC 21 Work Programme	IEC/TC 21 Published Standards
IEC	IEC/TC 31	Equipment for explosive atmospheres	IEC/TC 31 Work Programme	IEC/TC 31 Published Standards
IEC	IEC/TC 105	Fuel cell technologies	IEC/TC 105 Work Programme	IEC/TC 105 Published Standards
ISO	ISO/TC 22	Road vehicles	ISO/TC 22 Work Programme	ISO/TC 22 Published Standards
ISO	ISO/TC 58	Gas cylinders	ISO/TC 58 Work Programme	ISO/TC 58 Published Standards
ISO	ISO/TC 138	Plastics pipes, fittings and valves for the transport of fluids	ISO/TC 138 Work Programme	ISO/TC 138 Published Standards
ISO	ISO/TC 163	Thermal performance and energy use in the built environment	ISO/TC 163 Work Programme	ISO/TC 163 Published Standards
ISO	ISO/TC 192	Gas turbines	ISO/TC 192 Work Programme	ISO/TC 192 Published Standards
ISO	ISO/TC 193	Natural gas	ISO/TC 193 Work Programme	ISO/TC 193 Published Standards
ISO	ISO/TC 197	Hydrogen technologies	ISO/TC 197 Work Programme	ISO/TC 197 Published Standards
OIML	OIML/TC 8	Measurement of quantities of fluids	OIML/TC 8 Work Programme	OIML/TC 8 Published Standards
OIML	OIML/TC 8/SC 6	Measurement of cryogenic liquids	OIML/TC 8/SC 6 Work Programme	OIML/TC 8/SC 6 Published Standards

3. FCHO Standards module

3.1. Used data and data-architecture

For the Standards data stream - NEN set up an architecture to demonstrate the amount of data available from public sources, see Figure 1 below.

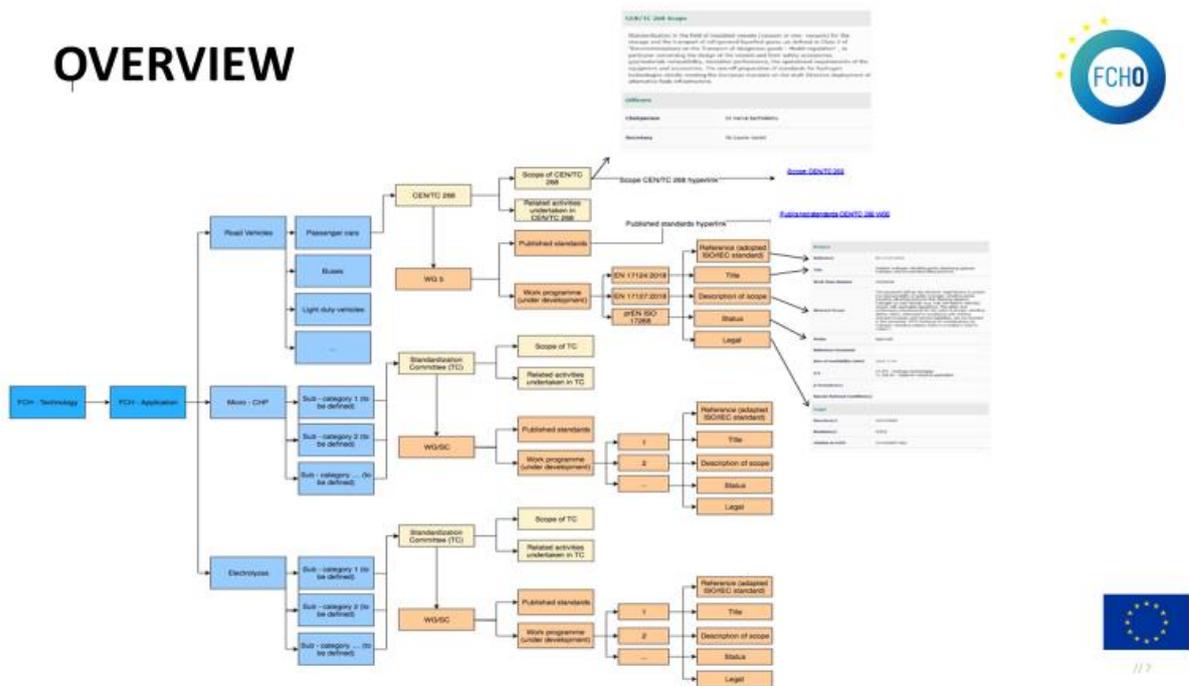


Figure 1. Data stream standards architecture

3.1.1. Standardization Developing Bodies

For the purpose of this Observatory standards from the following Standardization Developing Organizations (SDO) have been included:

- International Organization for Standardization (ISO)
- International Electrotechnical Commission (IEC)
- European Committee for Standardization (CEN)
- European Committee for Electrotechnical Standardization (CENELEC)
- International Organization of Legal Metrology (OIML)

National standards were initially included but later removed due to language barriers and doubling of standards. Relevant national standards are often introduced into regional (European) and/or international standards drafting process. As the standard data stream also includes standards under development (being drafted), it ensures that no relevant developments are left out of the Observatory.

3.1.2. Data per standard

Publicly available data from the SDO portals included:

- Code or reference of the standard
- Title of the standard
- Description of the standard
- Status of the standard (published or being drafted)
- Hyperlink to specific standard
- Hyperlink to the SDO Technical Committee responsible for drafting the Standard
- Hyperlink to the SDO Technical Committee scope
- In some cases: related Legal EU Directive
- In some cases: related legal Mandate
- In some cases: Citation in the Official Journal of the European Union

Where possible hyperlinks were used in order to refer to the owner of the original data (i.e. the online portals of ISO, IEC, CEN, CENELEC, and OIML). This is a measure in order to avoid outdated information on the Observatory.

3.2. Scope

The ‘standards data stream’ used the *Application List* as provided by E4tech in order to determine the scope for the database. This Application List contained categories, sub-categories, classes, and in some cases sub-classes. An example; category: Transport (motive power); sub-category: Road vehicles; class: Heavy good vehicles; sub-class: 3.5-7.5t.

For the purpose of accessibility, the consideration for inclusion of standards in the Observatory is determined by their relevance to hydrogen-specific applications. When identifying relevant standards for passenger cars, for example, standards such as *ISO 18164:2005 - Passenger car, truck, bus and motorcycle tyres — Methods of measuring rolling resistance* were excluded.

Any given standard can apply to various categories, sub-categories, classes and even sub-classes. For the purpose of findability and user friendliness, standards have been *tagged* with all relevant categories to sub-classes.

3.3. Online presentation of data

On the online portal of the Observatory there are two entry paths for users for finding the correct and relevant standards. The first entry path is through a *free search*, where users are able to search on standard codes, titles, or any terms used in the description of that standard. The second entry path is through an interactive menu, where users are able to select categories and go into further detail per click; from category to sub-category, and from sub-category to class. Having found the correct standard, users are able to click and open a pop-up with further details on that specific standard.

3.4. Revision and consequences

3.4.1. ISO and IEC

Every International Standard and other deliverable published by ISO or jointly with IEC shall be subject to systematic review in order to determine whether it should be confirmed, revised, amended (for International Standard), converted to another form of deliverable, or withdrawn, according to Table 1. A committee may at any time between systematic reviews pass a resolution initiating a revision of a deliverable.

For minor changes to International Standards, e.g. updating and editorial changes, that do not impact the technical content, a shortened procedure called “minor revision” may be applied. This is comprised only of the proposal for a minor revision by the committee (through a resolution and completion of ISO form 8B), approval and publication stages. Subsequent to the resolution of the responsible technical committee and consultation of the responsible ISO Technical Programme Manager, a final draft of the revised deliverable shall be circulated for an 8 week FDIS vote, and 12 weeks in the case of Vienna Agreement documents. The Foreword of the next edition of the deliverable shall indicate that it is a minor revision and list the updates and editorial changes made.

Table 1 — Timing of systematic reviews

Deliverable	Max. elapsed time before systematic review	Max. number of times deliverable may be confirmed	Max. life
International Standard	5 years	Not limited	Not limited
Technical Specification	3 years	Once recommended	6 years recommended
Publicly Available Specification	3 years	Once	6 years (If not converted after this period, the deliverable is proposed for withdrawal)
Technical Report	Not specified	Not specified	Not limited

A systematic review will typically be initiated in the following circumstances:

- (all deliverables) on the initiative and as a responsibility of the secretariat of the responsible committee, typically as the result of the elapse of the specified period since publication or the last confirmation of the document, or
- (for International Standards and Technical Specifications) a default action by ISO Central Secretariat if a systematic review of the International Standard or Technical Specification concerned has not been initiated by the secretariat of the responsible committee, or
- (all deliverables) at the request of one or more National Body, or

— (all deliverables) at the request of the CEO.

The timing of a systematic review is normally based either on the year of publication or, where a document has already been confirmed, on the year in which it was last confirmed. However, it is not necessary to wait for the maximum period to elapse before a document is reviewed.

3.4.2. CEN and CENELEC

The responsible technical body shall ensure that European Standards (ENs) are periodically reviewed. The periodical review shall occur at intervals not exceeding five years. The review may be initiated earlier at the request of the responsible technical body. In CENELEC, such request shall be approved by the Technical Board. If there is no technical body, the responsibility for review shall rest with the Technical Board.

As a result of the review the EN shall be

- a. confirmed, or
- b. amended, or
- c. revised as a new edition with a new date, or
- d. withdrawn.

Every effort shall be made to reach a unanimous agreement of the CEN/CENELEC national members and partner organizations participating in the Technical Committee or Technical Board on the choice between these four possibilities. If unanimity is not possible, the chair shall seek consensus. If consensus cannot be achieved despite all efforts, a decision can be made by majority of the CEN/CENELEC national members, while duly recording any possible sustained opposition from CEN/CENELEC national members and/or participating partner organizations.

The resulting decision shall be communicated to all CEN/CENELEC national members for action to be taken with respect to their national implementations.

For European Standards adopting ISO or IEC publications (including common modifications), no review process is initiated at European level. These standards will be subject to the review carried out by ISO or IEC, respectively.

Technical Specifications are not amended but replaced by a new edition with a new date of edition. Corrigenda published by the CEN-CENELEC Management Centre (CCMC) are, however, possible. The responsible CEN/CENELEC technical body shall ensure that Technical Specifications are reviewed at intervals of not more than three years, starting from their date of availability. The aim of such review shall be to re-examine the situation which resulted in the publication of a Technical Specification and if possible to achieve the agreement necessary for the publication of an EN to replace the Technical Specification, the other options being an extension for another three years or the withdrawal of the Technical Specification. Any decision to confirm the Technical Specification for another three years shall be accompanied with a valid justification of the responsible technical body.

3.4.3. OIML

All OIML publications are subject to periodic review. Five years after publication, the International Bureau of Legal Metrology (BIML) shall organize an enquiry amongst members of the appropriate TC or SC, with a three-month voting deadline, to decide if a publication should be

- a. re-confirmed in its existing form,
- b. revised, or
- c. withdrawn.

The decision shall be valid when two-thirds of the votes cast by the TC's, SC's or Project Group's P-members¹⁰ are in favor of option a), b), or c). Abstentions and failures to reply are not considered as votes cast.

The BIML shall report on the outcome of the review to the International Committee of Legal Metrology (CIML), which shall make a decision, based on the result of the TC/SC vote, whether the publication should be

- a. reconfirmed, in which case the BIML shall amend the cover page of the publication and references to it on the OIML web site to indicate both the original date of publication and the latest date of reconfirmation, and notify all CIML Members, or
- b. revised, in which case the BIML shall develop a project proposal with the appropriate TC or SC secretariat for CIML approval, or
- c. withdrawn.

¹⁰ Participating members are called "P" members

Appendix 1 - Detailed list of newly published and initiated standards

This appendix gives a description of the International and European committees that have recently published or initiated new standards. Annex 1 gives a detailed list of all relevant standards that have been published or initiated in 2020. an international level, and new and relevant initiatives on standards development. Publications are standards that are officially published and effective. Initiatives are “topics of interest” as expressed by Standardization committees, but that are still under construction (drafting stage).

CEN/TC 268 - Cryogenic vessels and specific hydrogen technologies applications

New publications

- EN 17127:2020 - Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols
- EN ISO 17268:2020 - Gaseous hydrogen land vehicle refuelling connection devices (ISO/FDIS 17268:2019)

New initiatives

- Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles

CEN/TC 23 - Transportable gas cylinders

New publications

- EN 17339:2020 - Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen
- EN 17533:2020 - Gaseous hydrogen - Cylinders and tubes for stationary storage

CEN/CLC/JTC 6 - Hydrogen in energy systems

New initiatives

- Safe use of hydrogen in built constructions
- prEN ISO 24078 - Hydrogen in energy systems – vocabulary
- PrTR xxxx – Safe use of hydrogen in built constructions

CEN/CLC/JTC 14/WG 5

New initiatives

prEN 16325 rev - Guarantees of Origin for electricity, gaseous hydrocarbons, and hydrogen, and heating & cooling

CEN/TC 234 - Gas infrastructure

New initiatives

- prCEN/TR XXX - Gas infrastructure - Consequences of hydrogen in the gas infrastructure and identification of related standardisation need in the scope of CEN/TC 234
- Gas infrastructure - Plants for the injection of renewable gases into natural gas networks - Part 3: Specific requirements regarding hydrogen

IEC/TC 105 - Fuel cell technologies

New publications

- IEC 62282-2-100:2020 - Fuel cell technologies - Part 2-100: Fuel cell modules – Safety
- IEC 62282-8-101:2020 - Fuel cell technologies - Part 8-101: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation
- IEC 62282-8-201:2020 - Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems
- IEC TS 62282-9-101:2020 - Fuel cell technologies - Part 9-101: Evaluation methodology for the environmental performance of fuel cell power systems based on life cycle thinking - Streamlined life-cycle considered environmental performance characterization of stationary fuel cell combined heat and power systems for residential applications

New initiatives

- PNW 105-844 ED1 - Fuel cell technologies - Part 6-401: Micro fuel cell power systems – Power, data interchangeability and performance test methods for laptop computers
- IEC 62282-3-201/AMD1 ED2 - Amendment 1 - Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems
- IEC 62282-4-1000 ED1 Fuel cell technologies – Part 4-1000: Fuel cell power systems for rolling stock– Performance requirements and test methods
- IEC 62282-4-101 ED2 Fuel cell technologies – Part 4-101: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) – Fuel cell power systems for electrically powered industrial trucks – Safety
- IEC 62282-4-202 ED1 Fuel cell technologies - Part 4-202: Fuel cell Power Systems for unmanned aircraft systems - Performance test methods
- IEC 62282-4-600 ED1 Fuel cell technologies - Part 4-600: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) - Fuel cell/battery hybrid power pack systems performance test methods for excavators
- IEC 62282-6-101 ED1 Fuel cell technologies - Part 6-101: Micro fuel cell power systems - Safety - General requirements
- IEC 62282-6-106 ED1 - Fuel cell technologies – Part 6-106: Micro fuel cell power systems – Safety – Indirect Class 8 (corrosive) compounds
- IEC 62282-6-107 ED1 Fuel cell technologies - Part 6-107: Micro fuel cell power systems – Safety – Indirect water-reactive (Division 4.3) compounds
- IEC 62282-7-2 ED1 Fuel cell technologies - Part 7-2: Test methods - Single cell and stack performance tests for solid oxide fuel cells (SOFCs)
- IEC 62282-8-301 ED1 Fuel cell technologies – Part 8-301 Energy storage systems using fuel cell modules in reverse mode – Power to methane energy systems based on solid oxide cells including reversible operation - Performance test methods

ISO/TC 197 - Hydrogen technologies

New publications

- ISO 17268:2020 - Gaseous hydrogen land vehicle refuelling connection devices
- ISO 19880-1:2020 - Gaseous hydrogen — Fuelling stations — Part 1: General requirements

New initiatives

- ISO/AWI 14687 - Hydrogen fuel quality — Product specification
- ISO/AWI TR 15916 - Basic considerations for the safety of hydrogen systems
- ISO/AWI 17268 - Gaseous hydrogen land vehicle refuelling connection devices
- ISO/AWI 19880-5 - Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies
- ISO/CD 19880-6 - Gaseous hydrogen — Fuelling stations — Part 6: Fittings
- ISO 19880-8:2019/FDAMD 1 - Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control — Amendment 1
- ISO/AWI 19880-9 - Gaseous hydrogen — Fuelling stations — Part 9: Sampling for fuel quality analysis
- ISO/AWI 19881 -Gaseous hydrogen — Land vehicle fuel containers
- ISO/AWI 19882 -Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
- ISO/AWI 19884 - Gaseous hydrogen — Cylinders and tubes for stationary storage
- ISO/AWI 19885-1 - Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 1: Design and development process for fuelling protocols
- ISO/AWI 19885-2 - Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 2: Definition of communications between the vehicle and dispenser control systems
- ISO/AWI 19885-3 - Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 3: High flow hydrogen fuelling protocols for heavy duty road vehicles
- ISO/AWI 19887 - Gaseous Hydrogen — Fuel system components for hydrogen fuelled vehicles
- ISO/AWI TR 22734-2 - Hydrogen generators using water electrolysis — Part 2: Testing guidance for performing electricity grid service
- prEN ISO 24078 - Hydrogen in energy systems – vocabulary (Vienna Agreement with CEN/JTC6 for International purposes)

ISO/TC 22 - Road vehicles

New initiatives

- ISO/CD 23828.2 - Fuel cell road vehicles — Energy consumption measurement — Vehicles fuelled with compressed hydrogen
- ISO/WD 12619-1 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 1: General requirements and definitions
- ISO/WD 12619-2 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 2: Performance and general test methods
- ISO/WD 12619-3 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 3: Pressure regulator
- ISO/WD 12619-4 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 4: Check valve
- ISO/WD 12619-5 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 5: Manual cylinder valve
- ISO/WD 12619-6 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 6: Automatic valve

- ISO/WD 12619-7 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 7: Gas injector
- ISO/WD 12619-8 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 8: Pressure indicator
- ISO/WD 12619-9 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 9: Pressure relief valve (PRV)
- ISO/WD 12619-10 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 10: Pressure relief device (PRD)
- ISO/WD 12619-11 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 11: Excess flow valve
- ISO/WD 12619-12 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 12: Gas-tight housing and ventilation hoses
- ISO/WD 12619-13 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 13: Rigid fuel line in stainless steel
- ISO/WD 12619-14 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 14: Flexible fuel line
- ISO/WD 12619-15 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 15: Filter
- ISO/WD 12619-16 - Road vehicles — Compressed gaseous hydrogen (CGH₂) and hydrogen/natural gas blends fuel system components — Part 16: Fittings

Chapter 5
2021 Patent Report
July 2021



Disclaimer

This report is based on data gathered as part of the Fuel Cells and Hydrogen Observatory for the period up to 31 December 2020. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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This report was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from <https://www.fchobservatory.eu/>

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Executive summary

The Fuel Cells and Hydrogen Observatory is an ambitious project to collect available valuable sector information in a single go-to source and make it available to all interested stakeholders.

Patents are tools to protect innovation. Most countries in the world operate a first-to-file system and so patent application statistics provide a bellwether for research and development activities. Further, because patent offices around the world classify patent applications according to a universally accepted classification system patent statistics can be conveniently separated into categories of interest. In short, patent statistics can be used to indicate who is doing what, where and when.

Purpose:	The patents module of the FCHO presents a range of statistical patent data as an indicator of research and development activity in the sector and the change in that activity over time. https://www.fchobservatory.eu/observatory/patents
Scope:	Fuel cell, hydrogen deployment and comparable technology patent application data is presented on a global basis. This first report provides a snapshot of patent data in the period January 2014 – December 2020. The report will be updated periodically, providing an indication of trends in filing and grant statistics.
Key Findings:	Over the period, overall total patent filings for fuel cell technologies increased; The USA and China appear to be the most important jurisdictions for filing fuel cell patent applications whereas South East Asian automotive companies are the most prolific filers of patent applications; The numbers of patent applications filed for specific fuel cell chemistries appears to be in decline; Patent applications for mobile fuel cell technologies dominate the fuel cell deployment sector, far outpacing both stationary and portable fuel cells; Patent applications for hydrogen production dominate the hydrogen economy patent filings and hydrogen storage patent applications outpace those for hydrogen distribution; Comparable technology patent application data looks at patent filing and grant statistics for battery technologies.

1. Introduction

This Report covers the period **2014** to **2020** except where otherwise indicated.

Patents are monopoly rights granted by Patent Offices in respect of inventions which are new, inventive and industrially applicable. Patents are territorial and are granted by individual national or regional patent offices in respect of those territories. As such, the geographical extent of filing of a patent application is an indicator of the perceived value an inventor has for the underlying invention.

Almost all countries around the world have adopted a 'first-to-file' system which awards the first inventor to file a patent application at a Patent Office. This means that inventors are encouraged to file patent applications early in the research and development process and, because of this, patent filing statistics are a significant marker of research and development activity. For many inventions patents are the only source of published technical information relating to the underlying principles upon which an invention is founded.

Patent applications are published eighteen months after filing. In many cases this is the first time the public can see information relating to the invention.

All patents are classified by experienced patent examiners according to patent classification systems. The universally accepted patent classification system is called the International Patent Classification (IPC). This means that the patent literature provides a vast and well-categorised resource which is readily divisible into relevant technical groupings.

During the process of seeking granted patent rights, the disclosed invention is assessed by patent examiners. In light of that assessment, many patent applications are abandoned before grant because the disclosed 'invention' is found to be old or obvious.

Accordingly, once a patent has been granted it is a valuable business tool which can be used to prevent others from operating in the defined area, in the territory covered by the patent. In most countries, patents expire twenty years after the date of filing.

This report examines the state of recent patent activity in the fuel cell space. The report provides statistical data across the world's major IP authorities concerning:

- **Total fuel cell activity:** providing a marker for fuel cell R&D activity in comparison with overall trends in patent filings
- **Major commercial patent filers:** providing a picture of the major layers in fuel cell patent filings
- **Major academic patent filers:** providing a view of the major academic filers
- **Patent activity by technology:** showing the trends in patent filings for major fuel cell technologies
- **Patent activity in the hydrogen economy:** showing how deployment of hydrogen infrastructure is changing over time
- **Patent activity in the area of batteries:** showing the trends in patent filings and grant statistics of lithium batteries

Data was sourced in accordance with the methodologies described below.

1.1. Methodology

2014-2018 data was collected over the weekend of 22/23 February 2020 and was verified by a second data download the following weekend. 2019-2020 data was collected on 23 February 2021¹. All data was subsequently re-validated.

Raw patent data was obtained from PatBase² by extraction using patent classification codes.

Although the latest data was extracted in February 2021, we are conscious that some results indicate a decline in 2020 filing statistics. This may be as a result of the data set being incomplete. Further, data may be subject to change as a result of re-assignment of classifications which occurs periodically.

Global patent activity data was obtained from the World Intellectual Property Organization (WIPO)³ and was only available up to 2019.

With regards to patent analysis, all patent applications are classified by their technology type according to the Cooperative Patent Classification (CPC) system.

The Cooperative Patent Classification (CPC) is an extension of the International Patent Classification (IPC) system and is jointly managed by the EPO and the US Patent and Trademark Office.⁴ The CPC system has a more refined classification system and so this was the classification system of choice in extracting and manipulating the raw data.⁵

Fuel cells are classified in H01M8^{6,7} and Y02E60/50. We have used those classification symbols to isolate fuel cell patent data.

¹ Data was downloaded in late February to allow for the database to ensure compilation of the 2020 dataset. The 2020 data may be subject to change, which will be reviewed in subsequent reports.

² PatBase is a commercial patent database product provided by MineSoft and RWS. It is considered to be an industry-leading database due to its coverage and data treatment protocols which seek to remove double counting of patent applications.

³ https://www.wipo.int/publications/en/WIPO_Statistics_Database

⁴ <https://www.epo.org/searching-for-patents/helpful-resources/first-time-here/classification/cpc.html>

⁵ Because classification is carried out by patent examiners, we are reliant on a correct classification being applied. Where plural classifications are applied the results will be abstracted into each data set. Accordingly, the data is likely to provide an indicator of trends rather than an absolute position.

⁶ We note that WIPO accords fuel cell technology a wider classification <http://www.wipo.int/classifications/ipc/en/> than simply H01M8* but cross referencing within those classifications identifies patent publications which are not fuel-cell related. Hence, we have used the more precise classification symbol than that proposed by WIPO.

⁷ <http://web2.wipo.int/ipcpub/#viewmode=f&symbol=H01M0008000000&refresh=page>

The full list of classifications used throughout the report are listed in Table 1.1.1.

Table 1.1.1. List of classification codes searched for each category.

Category	Classification Codes
Fuel Cells	H01M8, Y02E60/50
Direct Alcohol Fuel Cells and Direct Methanol Fuel Cells	H01M8/1011 & Y02E60/523
Molten Carbonate Fuel Cells	H01M2008/147 & Y02E60/526
Alkaline Fuel Cells	H01M8/083
Phosphoric Acid Fuel Cells	H01M8/086
Proton Exchange Membrane Fuel Cell	H01M8/1018 & Y02E60/521
Solid Oxide Fuel Cells	H01M2008/1293 & Y02E60/525
Mobile Fuel Cells	H01M2250/20
Stationary Fuel Cells	H01M2250/10
Portable Fuel Cells	H01M2250/30
Hydrogen Storage	Y02E60/32
Hydrogen Distribution	Y02E60/34
Hydrogen Production of Non-Carbon Containing Sources including Electrolysers	Y02E60/36
Lithium Batteries	H01M 10/052

We have not truncated our search results to look only at patent applications at the European Patent Office (EPO) and US Patent & Trademark Office (USPTO), but rather have investigated the position globally and across the so-called 'Big 5' Patent Office group of China (State Intellectual Property Office – SIPO), Republic of Korea (Korean Intellectual Property Office – KIPO), Japan (Japan Patent Office – JPO), EPO and USPTO.

WIPO administers the Patent Cooperation Treaty (PCT), an international system which allows patent applicants to file a single patent application which covers approximately 153 territories worldwide. Although patents are granted nationally, the PCT is an increasingly important system for the filing of patent applications and is included in the data, as indicated.

The list of fuel cell manufacturers and distributors was compiled from the patent statistics data.

Information on the top academic filers was obtained by filtering the results.

The data presented herein is publication data for the calendar years 2014 to 2020, with the exception that when comparing the data to that published by WIPO it is presented for calendar years 2014 to 2019.

2. Fuel Cell Manufacturers and Distributors

The companies and organisations represented within this section are manufacturers and distributors of fuel cells.

2.1. Fuel Cell Manufacturers and Leading Research Organisations

Table 2.1.1 shows the top 20 companies and organisations identified in this review for filing fuel cell patent applications and the sector in which they operate.

Table 2.1.1. List of global fuel cell manufacturers and leading research organisations.

Name	Country	Sector
Audi AG	Germany	Automotive
Bosch GMBH	Germany	Engineering & Energy Technology
Commissariat Energie Atomique	France	Energy Research
Daimler AG	Germany/USA	Automotive
General Motors (GM) Global Tech Operations	USA	Automotive
Honda	Japan	Automotive
Hyundai	South Korea	Automotive
Intelligent Energy	UK	Fuel Cells
JX Nippon	Japan	Energy
Kia	South Korea	Automotive
Korea Research Institute (Including Inst of Ceramic, Eng and Tech, Inst Energy Research, Inst Mach and Materials, Inst Science and Tech, Inst Industrial Tech)	South Korea	Research
Kyocera Corp	Japan	Electronics
LG (Including LG Chemical Ltd and LG Fuel Cell Systems)	South Korea (HQ), USA, UK	Electronics
NGK (including NGK Spark Plug Co and NGK Insulators)	Japan	Electronics
Nissan	Japan	Automotive
Panasonic	Japan	Electronics
Samsung	South Korea	Electronics
Toray Ind	Japan	Chemistry & Research
Toyota	Japan	Automotive
Volkswagen	Germany	Automotive

When looking at granted patents, the top 20 companies and organisations identified in this review differ from those of filed fuel cell patent applications (Table 2.1.1) only in three cases: Bloom Energy Corp, Ford Motor Co and the French National Centre for Scientific Research (CNRS) take the place of Bosch GMBH, Daimler AG and Volkswagen. The sector in which these additional three companies operate can be found in Table 2.1.2. The remaining 17 companies and organisations are the same for both published fuel cell applications and granted fuel cell patents.

Table 2.1.2. List of global fuel cell manufacturers and leading research organisations.

Name	Country	Sector
Bloom Energy Corp	USA	Fuel Cells
Ford Motor Co	USA	Automotive
French National Centre for Scientific Research	France	Research

2.2. Geographical Distribution

Turning to Figure 2.2.1, it is evident that Japan and South Korea have the largest presence amongst the top 20 distributors and manufacturers within the fuel cell sector, in terms of both manufacturers of published fuel cell patent applications (blue bars) and granted fuel cell patents (orange line). Whilst countries such as the UK feature only one company within the top 20 distributors and manufacturers of fuel cells, they are a prominent entity (Intelligent Energy).

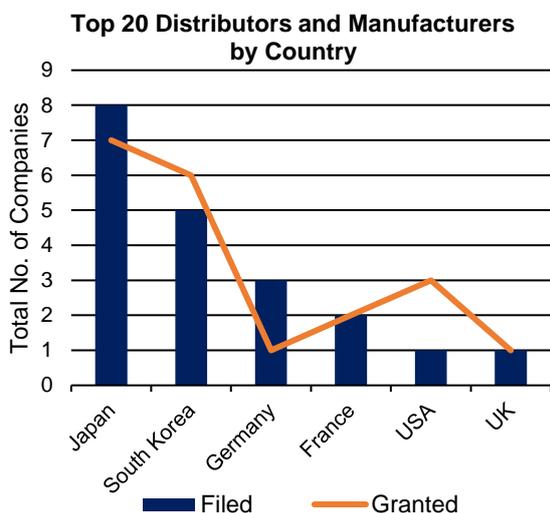


Figure 2.2.1. Top 20 fuel cell distributors and manufacturers by country.

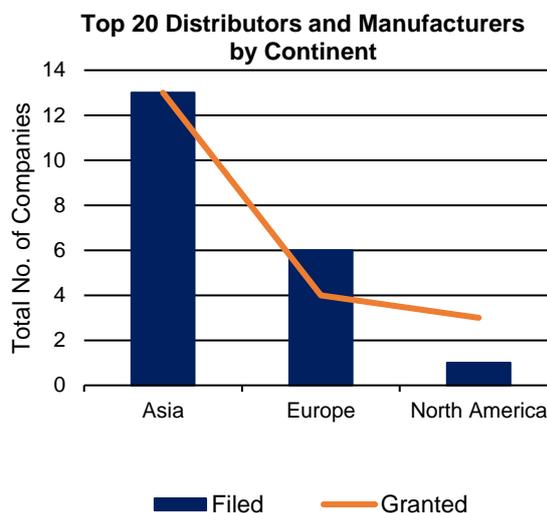


Figure 2.2.2. Global distribution of the Top 20 fuel cell manufacturers by continent.

Globally, 13 of the top 20 fuel cell companies of published applications are located in Asia (Figure 2.2.2), with the rest of the top 20 companies located in Europe and North America.

3. Patent Analysis

3.1. Setting the Scene

To assist in quantifying patent activity in the fuel cells area, we first present data showing overall patent activity for the years 2014 to 2019.

Patent applications are typically published 18 months after filing. Although some applications are undoubtedly abandoned between filing and publication (and hence do not reach the public domain), the number of published patent applications provides an indication of the patent application filing position (with an 18-month lag).

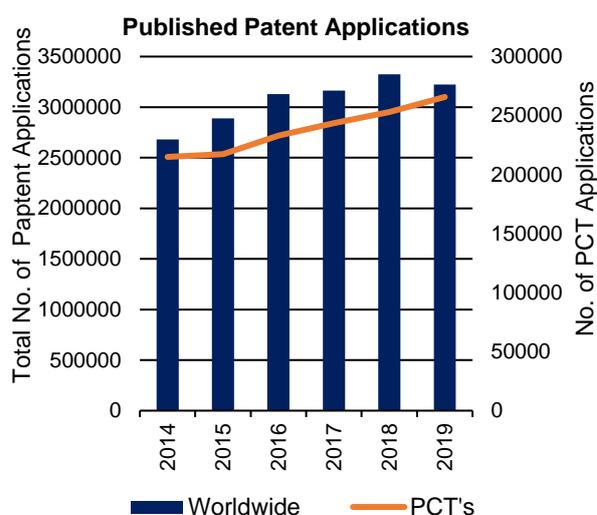


Figure 3.1.1. Published total patent applications vs. published PCT patent applications for 2014 to 2019.

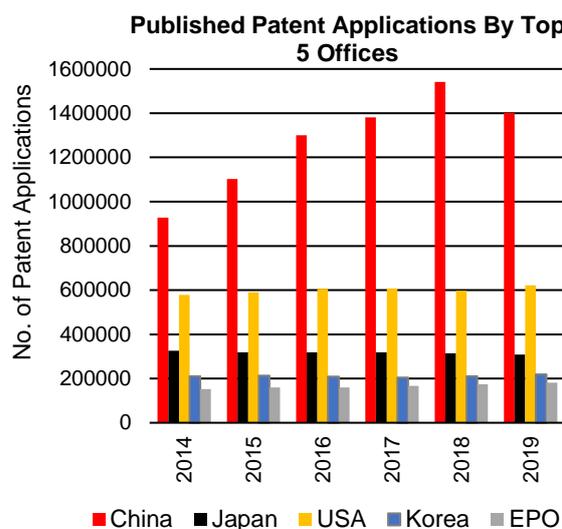


Figure 3.1.2. Published patent applications for the years 2014 to 2019.

Figure 3.1.1 shows both the total number of patent applications published worldwide (blue bars) and those pursued via the PCT route (orange line) have risen year-on-year between 2014 and 2018. Whilst the number of PCT patent applications continues to rise in 2019, the total number of patent applications published worldwide shows a marginal decline.

The patent offices worldwide which are considered the most important, and which receive the largest numbers of filings, are those of China, Japan, the USA, Europe and the Republic of Korea. Figure 3.1.2 shows that whilst the trends in the number of published patent applications vary between the top 5 offices, their position relative to one another remains unchanged. China is the stand-out growth territory in terms of the absolute number of published patent applications, with the increase in filings attributed to both an increase in filings by Chinese residents and overseas innovators seeking local protection. We believe the increased growth in China is at least in part accounted for by the government initiatives, which provide various subsidies and other incentives. However, many Chinese businesses do not file patent applications in countries outside of China, which accounts for the lower relative increase in PCT filings, despite it becoming an ever more popular route for applicants.

3.2. Fuel Cell Patent Activity

3.2.1. Filing Statistics

Figure 3.2.1 shows the annual publication of fuel cell patents (orange line) in comparison to the total published patent application data (blue bars).

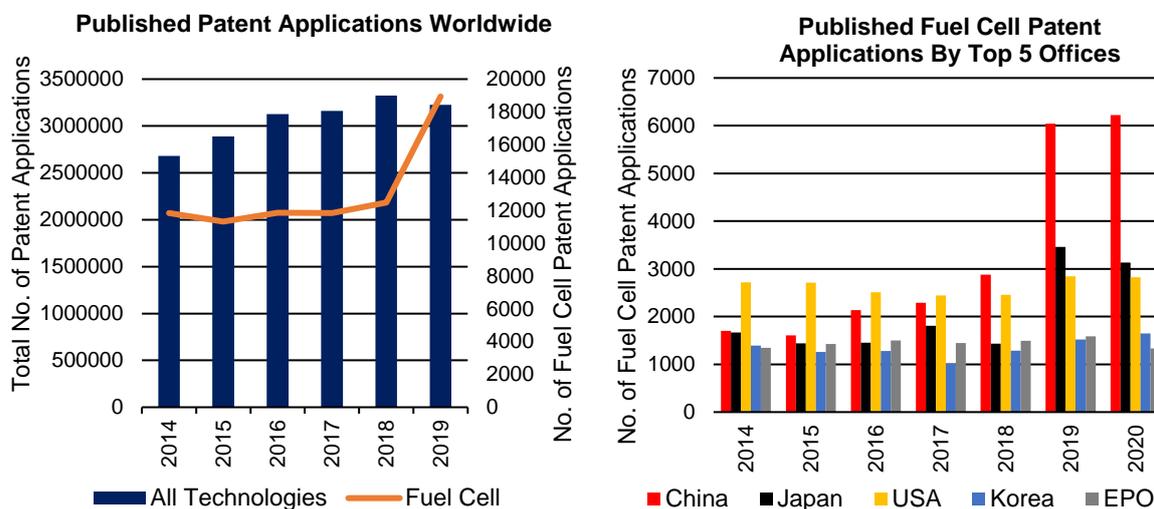


Figure 3.2.1. Published total patent applications vs. published fuel cell patent applications for 2014 to 2019.

Figure 3.2.2. Published fuel cell patent applications for the Top 5 Patent Offices for 2014 to 2020.

The total number of patent filings are increasing annually at a greater rate than the total number of fuel cell patent filings for the period 2014 to 2018. Whilst the number of published fuel cell applications (orange line) appears fairly constant between 2014 and 2018, a large increase is observed between 2018 and 2019. This increase may be accounted for by the reclassification and addition of classifications within the search term (H01M8, Y02E60/50).

The publication data for fuel cell applications published at the Top 5 offices between 2014 and 2020 is shown in Figure 3.2.2. The overall number of fuel cell patents published at the top 5 offices between 2014 and 2018 is relatively constant year-on-year with the drops in some countries being mitigated by the rise in publications in China. As observed with the total number of fuel cell patent application filings (Figure 3.2.1; orange line), a large increase in the number of filings at the SIPO and JPO is observed between 2018 and 2019.

The number of fuel cell patents published annually around the world has remained in excess of 11000 since 2014. In 2019, the increase in the number of applications being published in the fuel cell space appears to be overtaking the overall increase in patent filings.

It is clear that the Chinese Patent Office is becoming an increasingly important office for publishing fuel cell patent applications. This has implications both for fuel cell business wanting to operate in China and for all patent applications when considering prior art searching because of the increasing amount of prior art available only (or perhaps for the first time) in the Chinese language.

3.2.2. Granted Fuel Cell Patents

The number of patents granted is not an effective metric for determining the growth of research and development of fuel cell technology because grant of patents is, at least in part, under the authority of the examiners and the local law under in which they operate. However, it is a useful metric for businesses because it is granted patents which principally affect a business' freedom-to-operate in a specific territory.

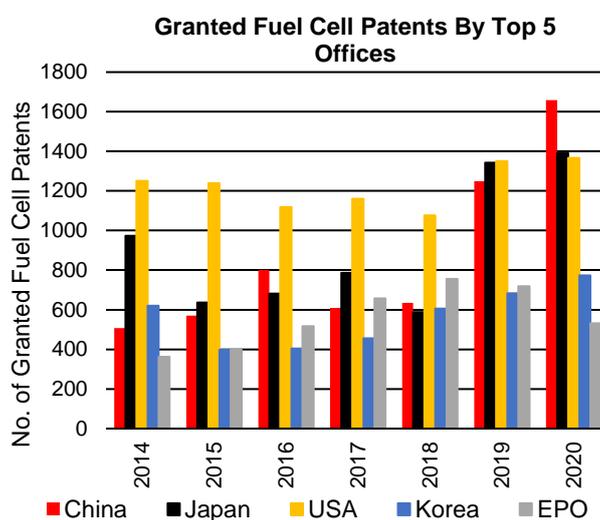


Figure 3.2.3. Granted fuel cell patents for the Top 5 Patent Offices for 2014 to 2020.

The number of fuel cell patents granted annually around the world has remained in excess of 3500 since 2014, with the top 5 offices accounting for over 86% of the total. Whilst the USPTO are the clear leaders in the publication of fuel cell patent applications over the period, the SIPO and the JPO have become increasingly more important territories for granting fuel cell patents since 2018. Businesses wishing to commercialise their fuel cell technology world-wide must continue to consider their patent position in these jurisdictions.

3.2.3. Assignee Data

Data presented below show the top 10 filers of patent applications (Figure 3.2.4) and granted patents (Figure 3.2.6) in the area of fuel cells recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

The top 10 filers for both the published fuel cell applications and the granted fuel cell patents predominantly comprise the same entities. The top 10 lists are dominated by large Japanese corporations, with Toyota steadily in the leading position. Automotive companies dominate the statistics, followed by electronics companies.

3.2.3.1. Filing Statistics

The overall top 10 filers of published fuel cell patent applications for the years 2014 to 2020 are shown in Figure 3.2.4.

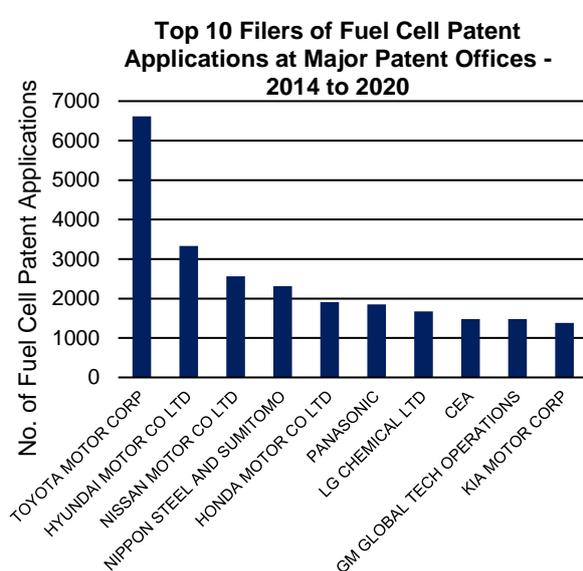


Figure 3.2.4. Top ten filers of published fuel cell patent applications at the Top 5 Patent Offices for 2014 to 2020.

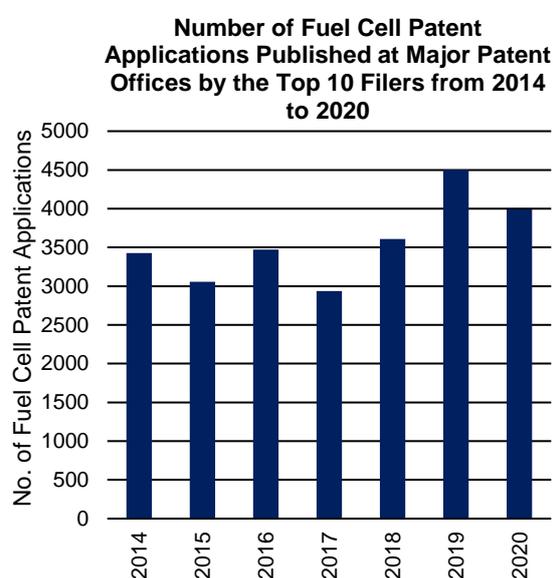


Figure 3.2.5. Number of patent applications published by top 10 filers for the years 2014 to 2020.

As expected, the top 10 are dominated by Japanese and South Korean corporations, with the US (General Motors (GM) Global Tech Operations) and France (Commissariat Energie Atomique (CEA)) making up the remainder.

Toyota appears to be the dominant filer of fuel cell patent applications, with the number of filings accounting for 27% of the filings from the top 10. Toyota retains the position of top filer for each of the years 2014 to 2020. Second place is typically being taken by Hyundai or Nissan. This demonstrates that South east Asian automotive businesses are consistently leading the way in patent filings and, it would be imagined, in fuel cell R&D activity.

Figure 3.2.5 shows the cumulative number of fuel cell patent applications published by the top 10 filers from 2014 to 2020. The overall number of published fuel cell patent applications of the top 10 filers fluctuates around 3300. The data shows stability in the number of fuel cell patents published by the top 10 filers.

3.2.3.2. Granted Fuel Cell Patents

The overall top 10 filers of granted fuel cell patents for the years 2014 to 2020 are shown in Figure 3.2.6.

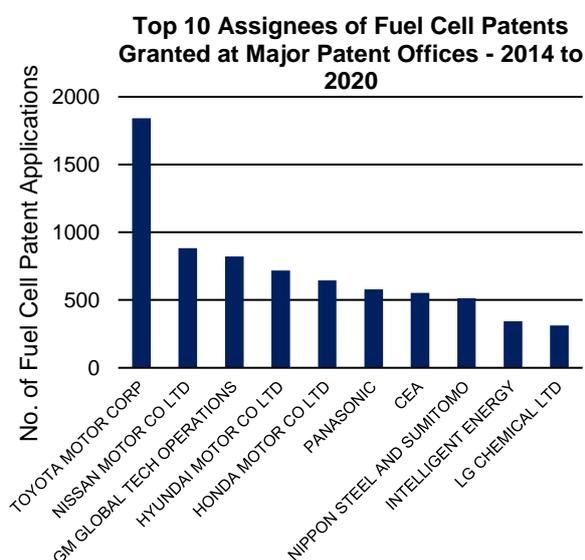


Figure 3.2.6. Top ten filers of granted fuel cell patents at the Top 5 Patent Offices for 2014 to 2020.

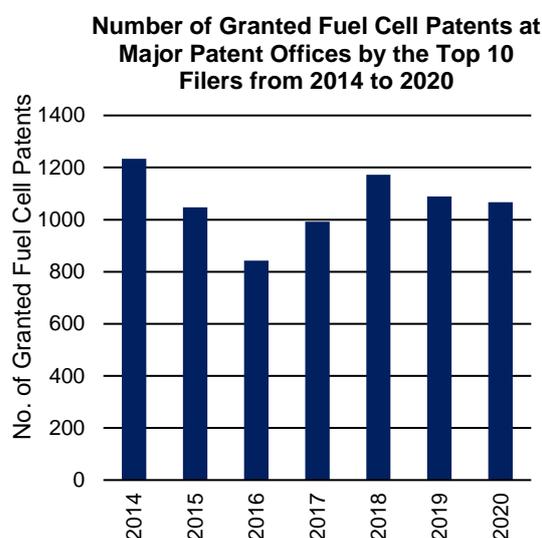


Figure 3.2.7. Number of patents granted by the top 10 filers for the years 2014 to 2020.

The trend in statistics relating to the number of granted fuel cell patents of the top 10 filers largely reflects that of the published patent applications, shown in Figure 3.2.4.

There is only one change in the top 10 filers between publication and granted fuel cell patents, with Intelligent Energy taking the place of Kia Motor Corp.

Toyota remains dominant, accounting for 26% of the granted fuel cell patents out of the top 10 filers.

Unsurprisingly, given the filing statistics, Toyota, Nissan, Hyundai, GM, Panasonic, CEA and Honda feature in the top 10 patentees annually. Toyota retains the position of top filer for each of the years 2014 to 2020.

Figure 3.2.7 shows the cumulative number of fuel cell patents granted by the top 10 filers from 2014 to 2020. The overall number of granted fuel cell patent applications of the top 10 filers fluctuates around 1000.

3.2.4. Academic Patent Filers

3.2.4.1. Geographic Distribution

The geographical distribution of the top 20 university filers of both published fuel cell patent applications (blue bars) and granted fuel cell patents (orange line), for the years 2014 to 2020, are shown in Figures 3.2.8 and 3.2.9.

Out of the universities which filed fuel cell patent applications in the period 2014 to 2020, Chinese universities are by far the most dominant, accounting for over half of the top 20 university filings (Figure 3.2.8). In comparison, the USA and Japan are the leading university recipients of granted fuel cell patents for the period 2014 to 2020 (Figure 3.2.8), which likely indicates that these Universities have been filing patent applications in this space for a longer time than Chinese Universities.

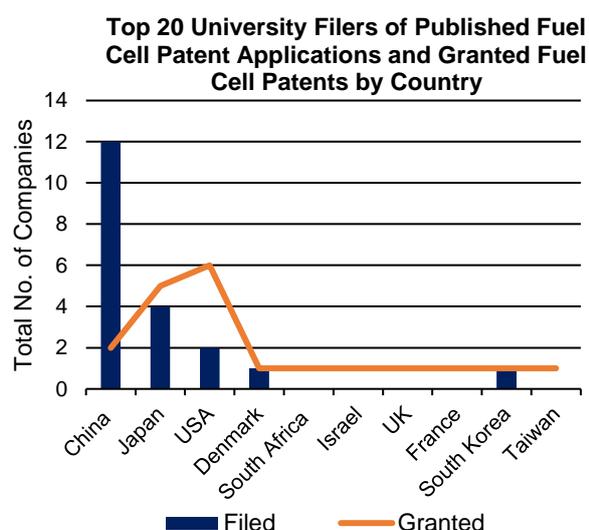


Figure 3.2.8. Top 20 university fuel cell applicants by country.

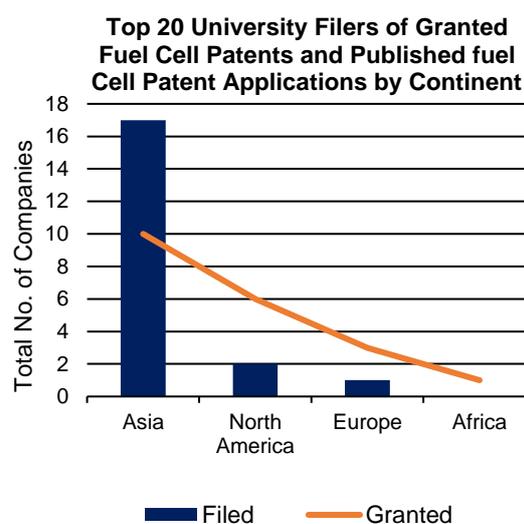


Figure 3.2.9. Distribution of the Top 20 university fuel cell patent applicants by continent.

Asia is the dominant continent in terms of the publication and grant of academic fuel cells patents. Globally, 85% of the top 20 university filers of fuel cell patent applications and 50% of the top 20 university filers of granted fuel cell patents are located in Asia (Figure 3.2.9).

Given that many universities do not progress patent applications to grant for various reasons, it is notable that the major academic players in this space consistently seek to obtain granted patents. This may be due to close ties with commercial entities in the countries of interest.

3.2.4.2. Filing Statistics

The data presented below shows the top 10 university filers of patent applications (Figure 3.2.10) in the area of fuel cells recorded annually (from 2014 to 2020). In each case the bars show the absolute number of patent applications or patents associated with each University.

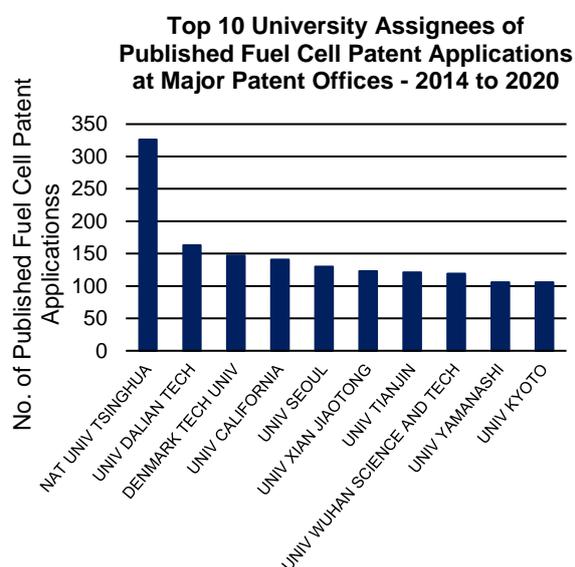


Figure 3.2.10. Top 10 university filers of fuel cell patent applications at the Top 5 Patent Offices for 2014 to 2020.

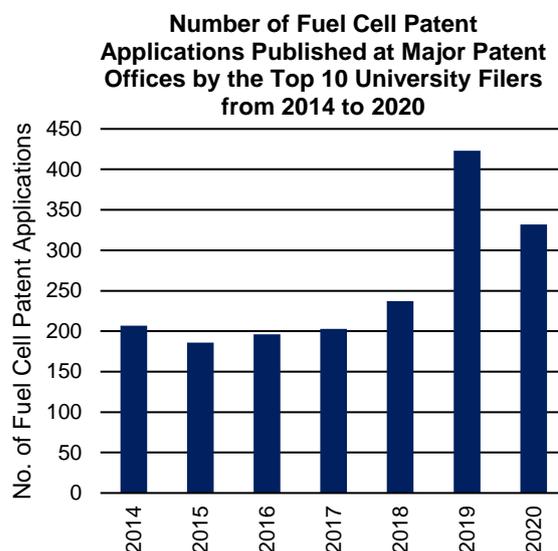


Figure 3.2.11. Number of patent applications published by top 10 university filers for the years 2014 to 2020.

The top 10 academic filers are dominated by Chinese universities.

The National University of Tsinghua is the leading university filer of fuel cell patent applications, filing 326 applications which accounts for 22% of the top 10 university filings.

The remaining 9 of the top 10 university filers of fuel cell patent applications each filed between 106 and 163 applications, each accounting for between 7 and 11% of the top 10 university filings.

The National University of Tsinghua appears to be, worldwide, the most dominant filer of fuel cell applications, featuring in the top two university filers annually from 2014 to 2020. However, there is a great variance in the number of filings reported with a low of 28 in 2016 and a high of 85 in 2019. These figures account for between 14 and 22% annually of the overall number of filings of the top 10 university fuel cell filers.

Figure 3.2.11 shows the cumulative number of fuel cell patent applications published by the top 10 university filers from 2014 to 2020.

The overall number of published fuel cell patent applications of the top 10 filers increased from 2015 to 2019. However, a notable decline in the number of fuel cell patent applications published by the top 10 universities was seen in 2020. The decline in fuel cell applications from 2019 to 2020 appears to be a cumulative effect and is not simply accounted for by a large decrease from a single entity.

3.2.4.3. Granted Fuel Cell Patents

The overall top 10 university filers of granted fuel cell patents for the years 2014 to 2020 is shown in Figure 3.2.12.

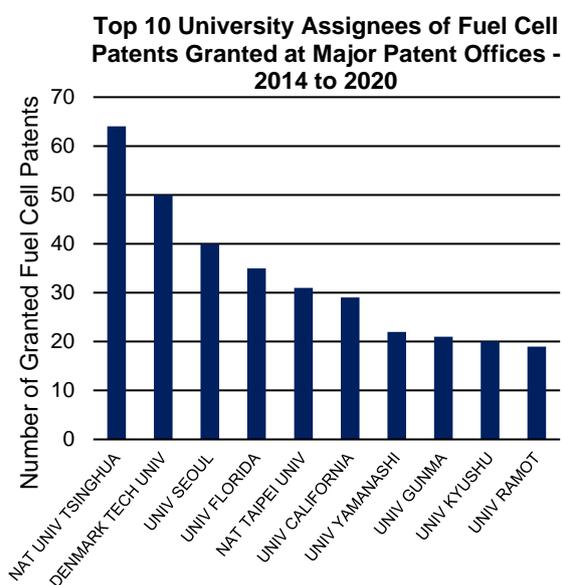


Figure 3.2.12. Top 10 university filers of granted fuel cell patents at the Top 5 Patent Offices for 2014 to 2020.

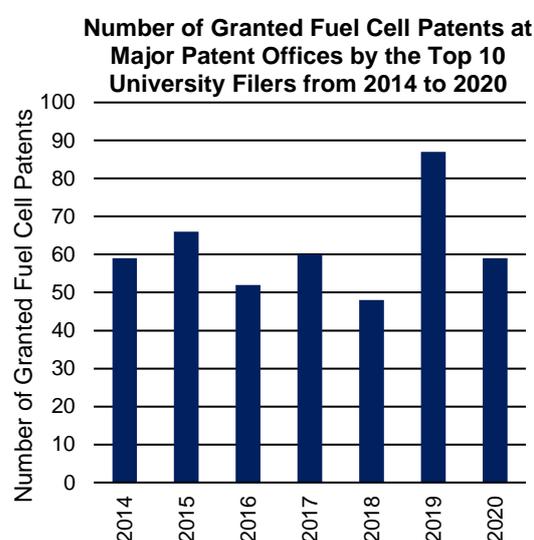


Figure 3.2.13. Number of patents granted to the top 10 university filers for the years 2014 to 2020.

The trend in patent statistics relating to the number of granted fuel cell patents of the top 10 university filers largely reflects that of the published patent applications, shown in Figure 3.2.10. The National University of Tsinghua remains in first and second place, with 4 of the top 10 universities also present in the top 10 university filers of granted fuel cell patents.

The National University of Tsinghua features in the top 3 university filers of granted fuel cell patents annually, except for 2019 when it featured in the top 9 university filers.

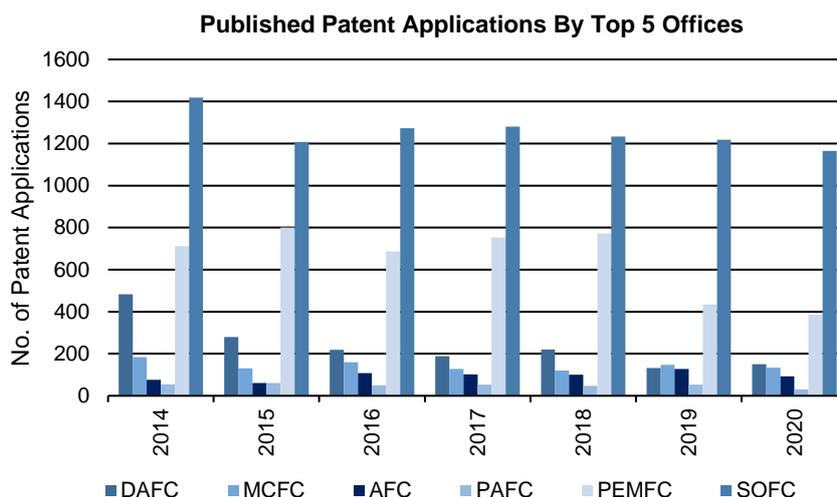
Figure 3.2.13 shows the cumulative number of fuel cell patents granted by the top 10 university filers from 2014 to 2020.

Whilst fluctuations in the numbers of granted fuel cell patents are observed (Figure 3.2.13), there is a notable decline between the numbers reported in 2019 and those reported in 2020, as observed with the number of published fuel cell applications (Figure 3.2.11).

3.3. Fuel Cell Chemistry

The data presented below compares filing statistics according to fuel cell chemistry. The fuel cell chemistries analysed in this section include: direct alcohol fuel cells (DAFCs), molten carbonate fuel cells (MCFCs), alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), proton exchange membrane (PEMFCs) and solid oxide fuel cells (SOFCs).

Figure 3.3.1 shows the change in total filings across the period at the top five offices for each of the fuel cell types.



3.3.1. Total patent applications at the top five patent offices for 2014 to 2020.

The data clearly shows that applications for SOFCs dominate the fuel cell chemistry sector, with PEMFCs being the second most popular. The data also shows that across the board there has been a decrease in the number of patent applications being filed worldwide for these specific fuel cell types, perhaps because of the maturity of the sector.

The following data presents the number of patent applications filed, according to fuel cell chemistry, for the years 2014 to 2020, at the top 5 offices.

The USPTO appears to be the office handling the most patent applications for specific chemistry. Whereas, the office handling the lowest number of patent applications appears to vary for the specific chemistries. The Chinese Patent Office (SIPO) is the second top filer for overall chemistries. This is in line with the overall fuel cell filings at the SIPO being in the top two annually between 2014 and 2020 (see Figure 3.2.2).

Also presented are the top 10 filers of patent applications for each of the individual fuel cell chemistries, for the years 2014 to 2020, for each of the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

3.3.1. Direct Alcohol Fuel Cells

Figure 3.3.2 shows the total patent filings for direct alcohol fuel cells across the top 5 patent offices.

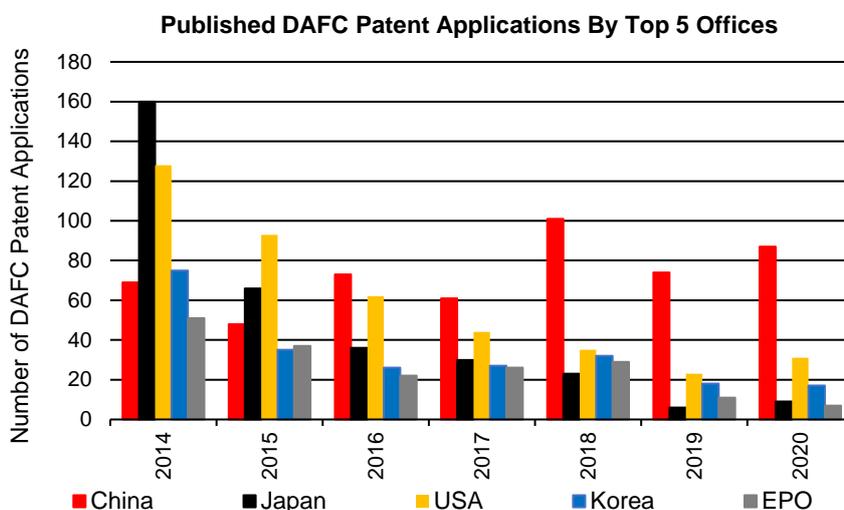


Figure 3.3.2. Direct alcohol fuel cell patent applications for 2014 to 2020.

The data shows that filings at the USPTO, JPO, EPO and KPIO were historically highest in 2014 but that interest in filing patent applications in this technology has significantly waned over the following years. However, the number of DAFC patent applications filed at the SIPO shows an overall increase over the period, with the highest number of filings recorded in 2018 and the second highest number of filings recorded in 2020.

Figure 3.3.3 shows the top 10 assignees of DAFC patent applications, e.g. direct methanol fuel cells (DMFCs), for the top 5 offices over the period 2014 to 2020. The top filers are dominated by Korean entities, with Samsung, LG and the Korean Research Institute being the top three filers of DAFC patent applications over the period.

Figure 3.3.4 shows the cumulative number of DAFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. Whilst fluctuations in the numbers of published DAFC patent applications are observed (Figure 3.3.4), there is a notable overall decline between 2014 and 2020.

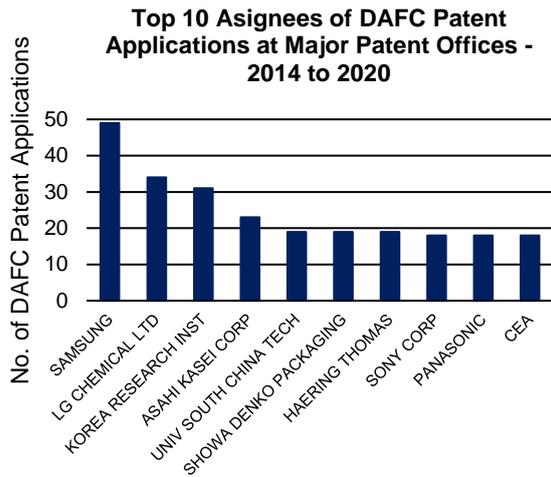


Figure 3.3.3. Top 10 filers of DAFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

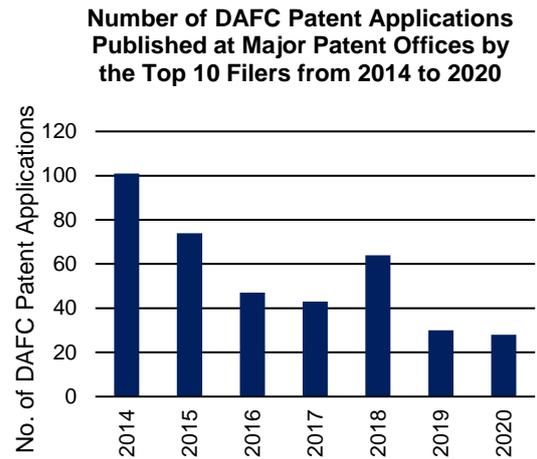
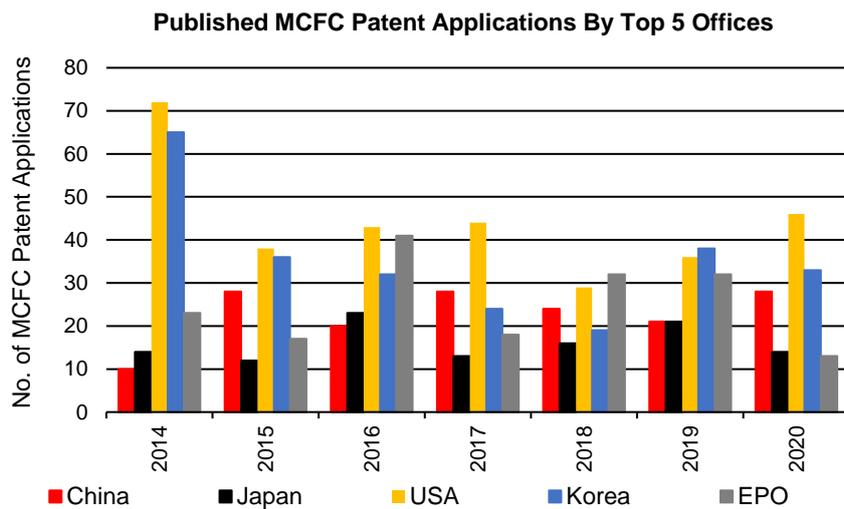


Figure 3.3.4. Number of DAFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.3.2. Molten Carbonate Fuel Cells

Figure 3.3.5 shows the total patent filings for molten carbonate fuel cells across the top 5 patent offices.



3.3.5. Molten Carbonate fuel cell patent applications for 2014 to 2020.

The data shows that filings at the USPTO and KIPO were historically the highest in 2014 but that interest in filing patent applications in this technology in the USA and Korea has significantly waned over the following years, with marginal changes of -36% (USPTO) and -49% (KIPO) over the period. The EPO, SIPO and JPO show fluctuations in the number of patent filings over the period 2014 to 2020.

Figure 3.3.6 shows the top 10 assignees of MCFC patent applications for the top 5 offices over the period 2014 to 2020. The top filers are Exxon Mobil (USA) and Fuel Cell Energy Inc (USA).

Figure 3.3.7 shows the cumulative number of MCFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. Whilst filings of MCFC patent applications by the top 10 filers were historically highest in 2014, an overall decrease in published MCFC patent applications by the top 10 filers is observed between 2015 and 2020 (Figure 3.3.7).

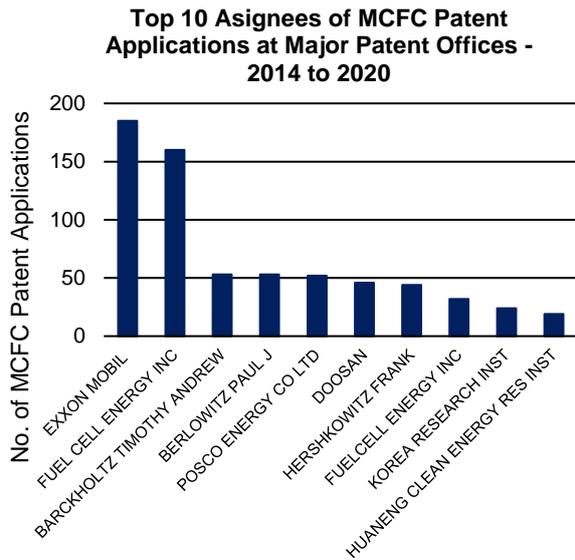


Figure 3.3.6. Top 10 filers of MCFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

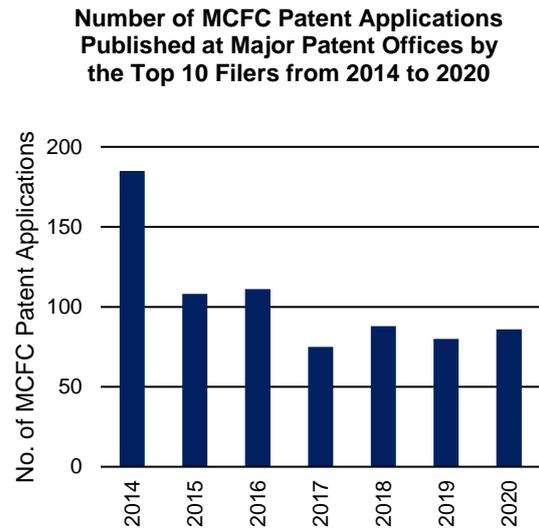
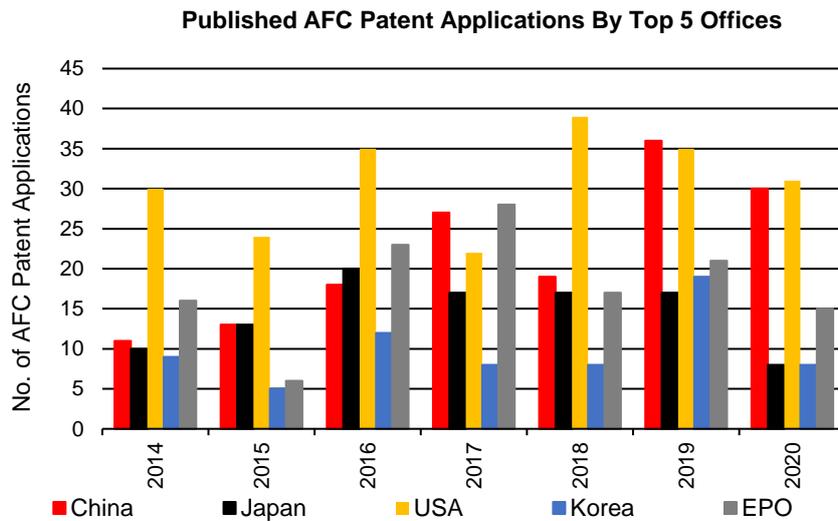


Figure 3.3.7. Number of MCFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.3.3. Alkaline Fuel Cells

Figure 3.3.8 shows the total patent filings for alkaline fuel cells across the top 5 patent offices.



3.3.8. Alkaline fuel cell patent applications for 2014 to 2020.

All 5 offices show variations in the number of AFC patent applications published between 2014 and 2020. However, despite the fluctuation in the number of filings, the USPTO appears to be the most important filing jurisdiction for this technology.

Figure 3.3.9 shows the top 10 assignees of AFC patent applications for the top 5 offices over the period 2014 to 2020. The top filers are BASF Corp (USA), Aquahydrax Pty Ltd (Australia) and NGK (Japan).

Figure 3.3.10 shows fluctuations in the cumulative number of AFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020.

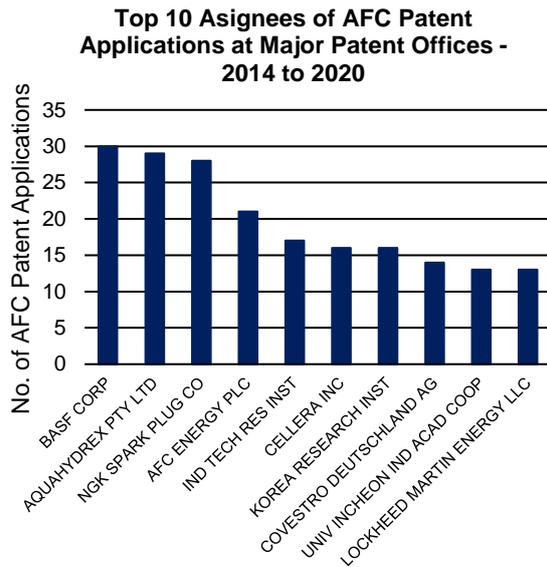


Figure 3.3.9. Top 10 filers of AFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

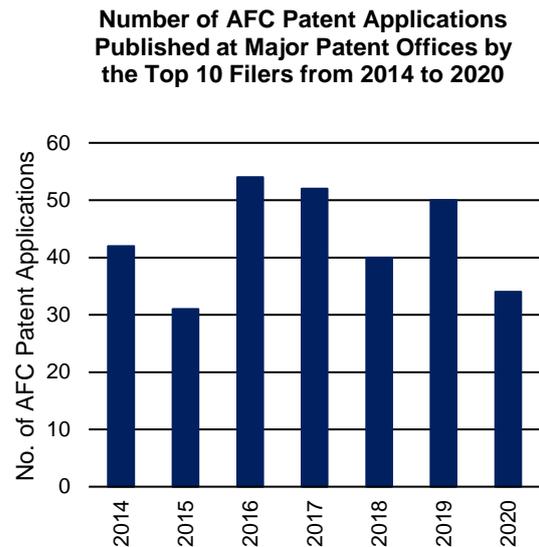
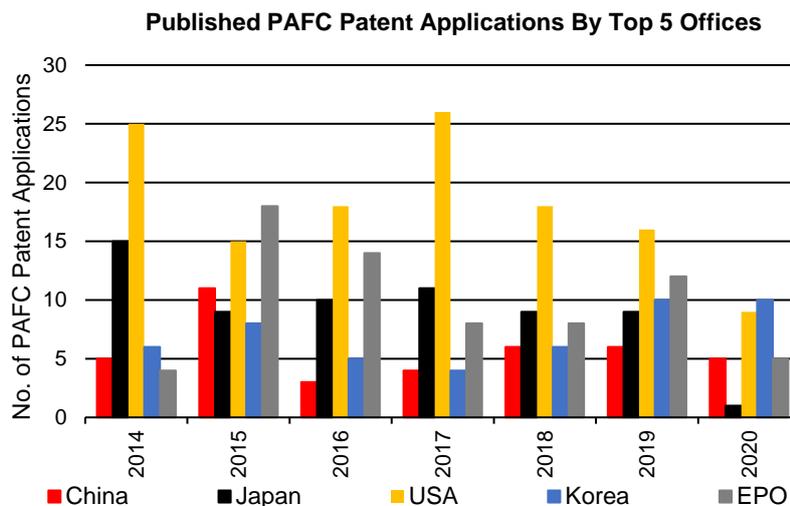


Figure 3.3.10. Number of AFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.3.4. Phosphoric Acid Fuel Cells

Figure 3.3.11 shows the total patent filings for phosphoric acid fuel cells across the top 5 patent offices.



3.3.11. Phosphoric acid fuel cell patent applications for 2014 to 2020.

All 5 offices show variations in the number of PAFC patent applications published between 2014 and 2020 by the top filers. Despite a marginal decrease of -36%, the USPTO again appears to be the most important filer over the period 2014 to 2019. However, filings at the KIPO increased significantly between 2017 and 2020, leading them to become the top filer of PAFC patent applications in 2020.

Figure 3.3.12 shows the top 10 assignees of PAFC patent applications for the top 5 offices over the period 2014 to 2020. Doosan (Korea) are by far the leading filers of PAFC patent applications.

Figure 3.3.13 shows fluctuations in the cumulative number of PAFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020.

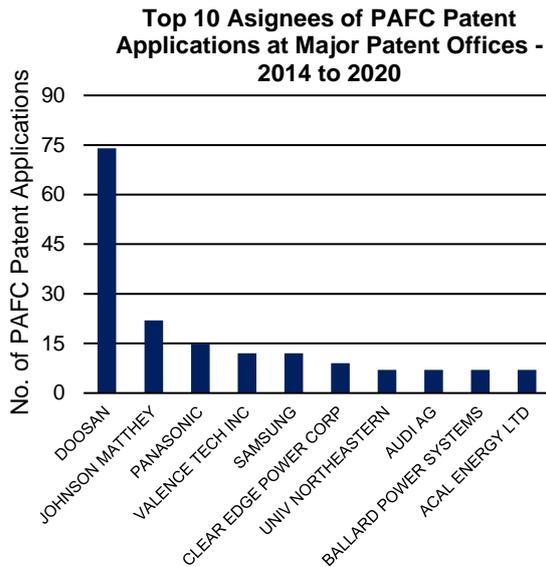


Figure 3.3.12. Top 10 filers of PAFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

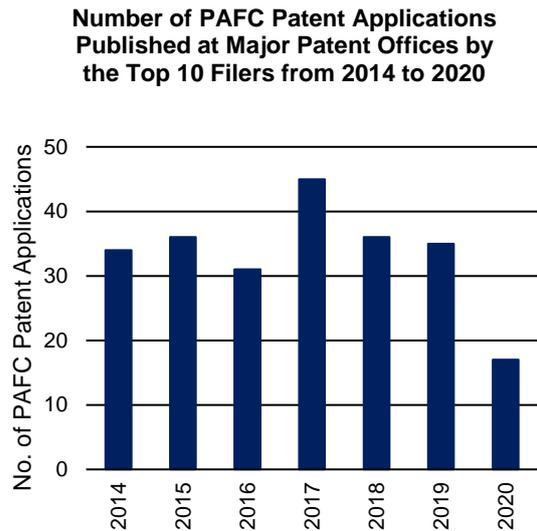
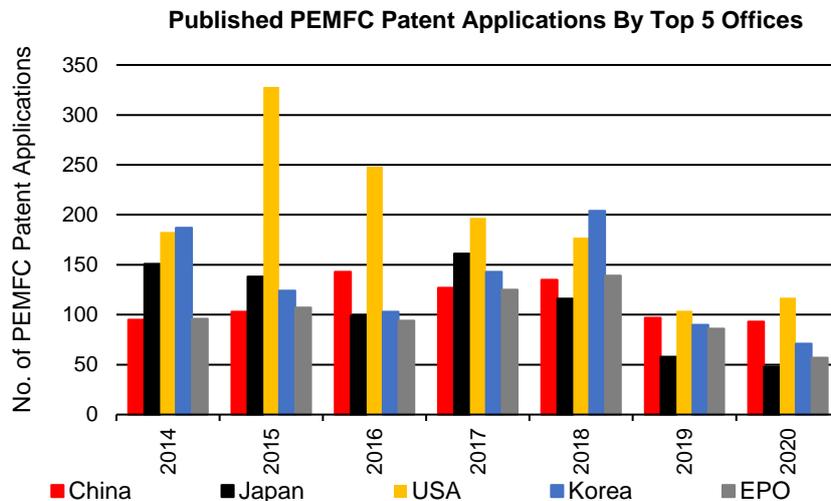


Figure 3.3.13. Number of PAFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.3.5. Proton Exchange Membrane Fuel Cell

Figure 3.3.14 shows the total patent filings for proton exchange membrane fuel cells across the top 5 patent offices.



3.3.14. PEM fuel cell patent applications for 2014 to 2020.

All 5 offices show variations in the number of PEMFC patent applications published between 2014 and 2020. Notably, the data shows a temporary growth in filings at the USPTO between 2014 and 2015 followed by a substantial decline to show a marginal loss over the period of -36%.

Figure 3.3.15 shows the top 10 assignees of PEMFC patent applications for the top 5 offices over the period 2014 to 2020. Many of the top 10 filers come from the automotive sector, with the overall top filers consisting of Toyota (China, USA and Japan) and Hyundai (Korea).

Figure 3.3.16 shows fluctuations in the cumulative number of PEMFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020.

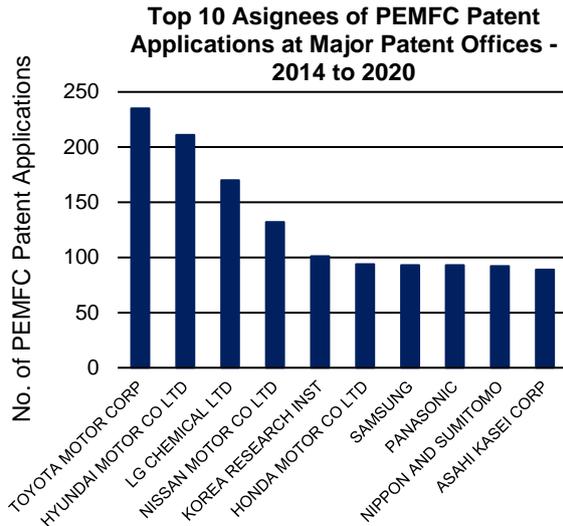


Figure 3.3.15. Top 10 filers of PEMFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

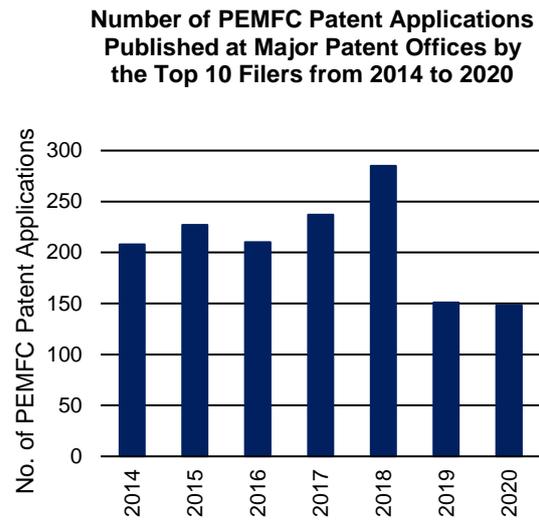
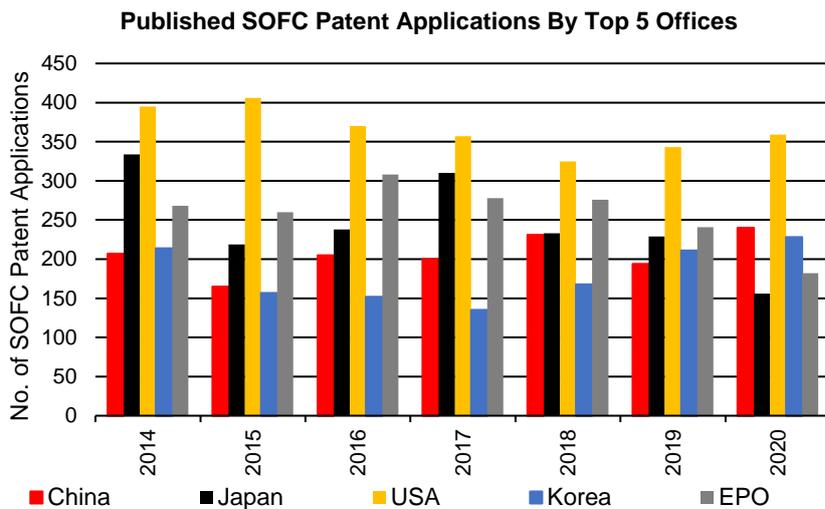


Figure 3.3.16. Number of PEMFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.3.6. Solid Oxide Fuel Cells

Figure 3.3.17 below shows the total patent filings for solid oxide fuel cells across the top 5 patent offices.



3.3.17. Solid oxide fuel cell patent applications for 2014 to 2020.

All 5 offices show variations in the number of SOFC patent applications published between 2014 and 2020. However, the USPTO remains the most dominant filer of SOFC patent applications over the period.

Figure 3.3.18 shows the top 10 assignees of SOFC patent applications for the top 5 offices over the period 2014 to 2020. The top filers over the period are LG (Korea) and NGK (Japan).

Figure 3.3.19 shows the cumulative number of SOFC patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. An overall decrease in published SOFC patent applications by the top 10 filers is observed between 2014 and 2020 (Figure 3.3.19).

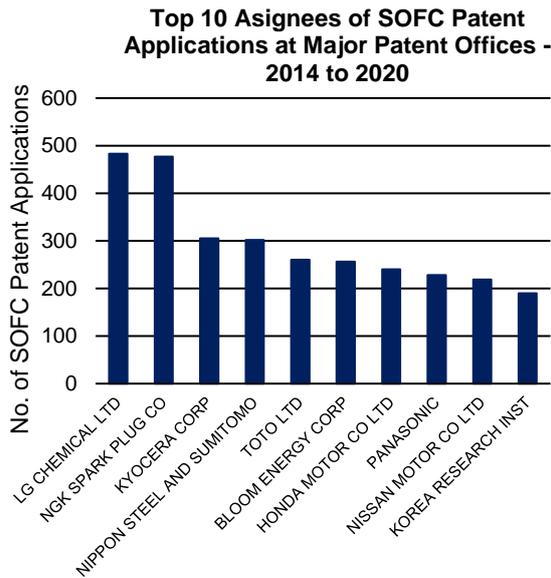


Figure 3.3.18. Top 10 filers of SOFC patent applications at the Top 5 Patent Offices for 2014 to 2020.

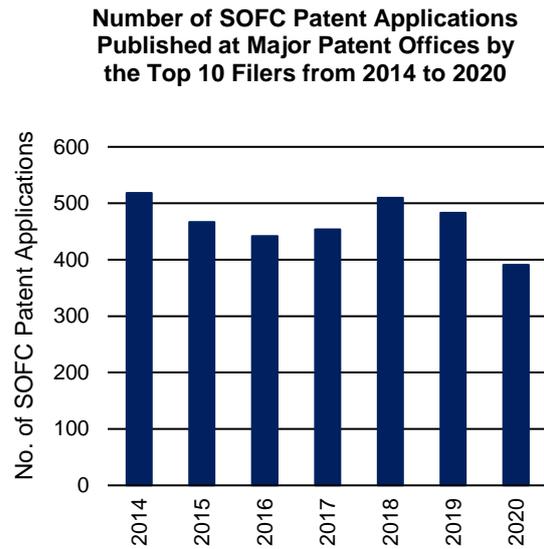
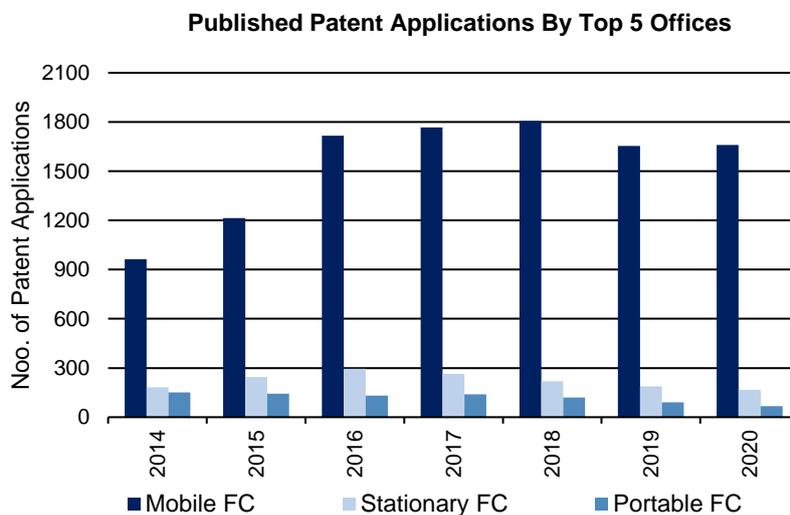


Figure 3.3.19. Number of SOFC patent applications published by the top 10 filers for the years 2014 to 2020.

3.4. Fuel Cell Deployment

The data presented below compares filing statistics according to fuel cell deployment, consisting of: mobile fuel cells, stationary fuel cells and portable fuel cells.

Figure 3.4.1 shows the change in total filings across the period at the top five offices for each of the fuel cell types.



3.4.1. Total patent applications at the top five patent offices for 2014 to 2020.

The data in Figure 3.4.1 clearly shows that applications for mobile fuel cells dominate, with stationary and portable fuel cells being far behind. It is notable that total filings in mobile fuel cells appears to be fairly robust across the period whereas filings for stationary and portable fuel cells appear to be on the decline. We speculate that this may relate to improvements in battery technologies which are obvious technological competitors in portable applications, at least.

The following data presents the number of patent applications filed, according to fuel cell deployment, for the years 2014 to 2020, at the top 5 offices.

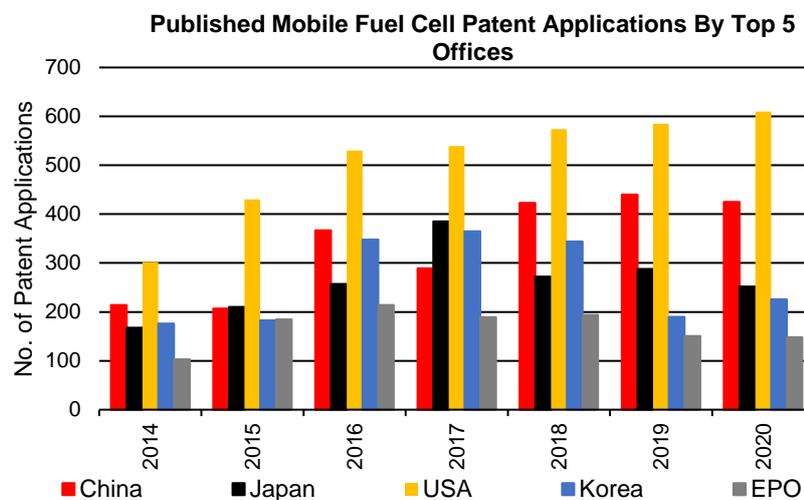
Consistently, the USPTO appears to be the office handling the most patent applications for fuel cell deployment.

Also presented are the top 10 filers of patent applications for mobile, stationary and portable fuel cell, for the years 2014 to 2020, for each of the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

Along with automotive companies such as Toyota, Hyundai and Nissan, Exxon Mobil and Intelligent Energy feature highly in the top 10 assignees.

3.4.1. Mobile Fuel Cells

Figure 3.4.2 shows the total patent filings for mobile fuel cells across the top 5 patent offices.



3.4.2. Mobile fuel cell patent applications for 2014 to 2020.

Over the period, the USPTO appears to be publishing a greater number of mobile fuel cell patent applications than the other major offices, with the EPO publishing the least.

Figure 3.4.3 shows the top 10 assignees of mobile fuel cell patent applications for the top 5 offices over the period 2014 to 2020. The top 10 assignees are unsurprisingly dominated by automotive companies with Toyota (China, Japan and USA) and Hyundai (Korea) being the top filers.

Figure 3.4.4 shows the cumulative number of mobile fuel cell patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. An overall increase in published mobile fuel cell patent applications by the top 10 filers is observed between 2014 and 2020 (Figure 3.4.4).

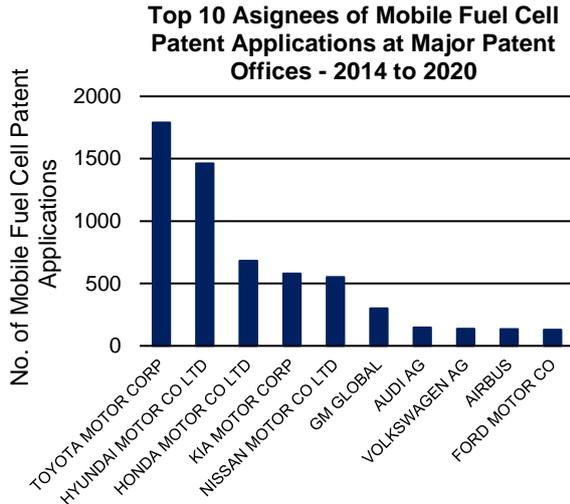


Figure 3.4.3. Top 10 filers of mobile fuel cell patent applications at Top 5 Patent Offices for 2014 to 2020.

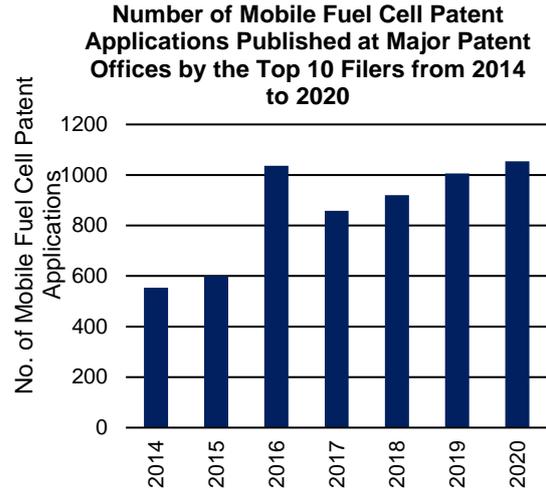
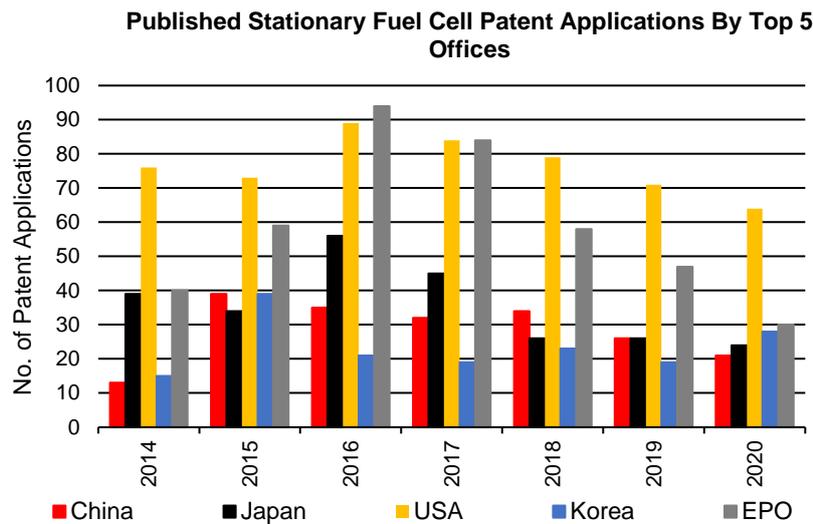


Figure 3.4.4 Number of mobile fuel cell patent applications published by the top 10 filers for the years 2014 to 2020.

3.4.2. Stationary Fuel Cells

Figure 3.4.5 shows the total patent filings for stationary fuel cells at the major patent offices for the period 2014 to 2020.



3.4.5. Stationary fuel cell patent applications for 2014 to 2020.

With the exception of 2016 and 2017, when the EPO were the top filer, the USPTO appears to be publishing a greater number of stationary fuel cell patent applications than the other major offices over the period 2014 to 2020.

Figure 3.4.6 shows the top 10 assignees of stationary fuel cell patent applications for the top 5 offices over the period 2014 to 2020. The top two filers over the period are Exxon Mobil (China, USA and Korea) and Panasonic (EP).

Figure 3.4.7 shows the cumulative number of stationary fuel cell patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. An overall decrease in published stationary fuel cell patent applications by the top 10 filers is observed between 2014 and 2020 (Figure 3.4.7).

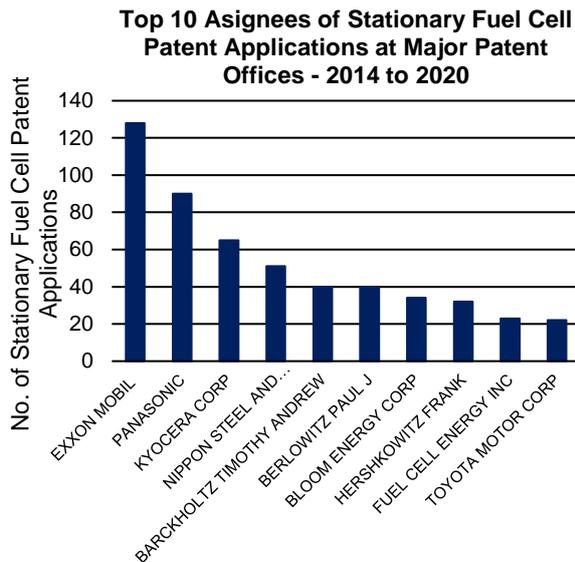


Figure 3.4.6. Top 10 filers of stationary fuel cell patent applications at Top 5 Patent Offices for 2014 to 2020.

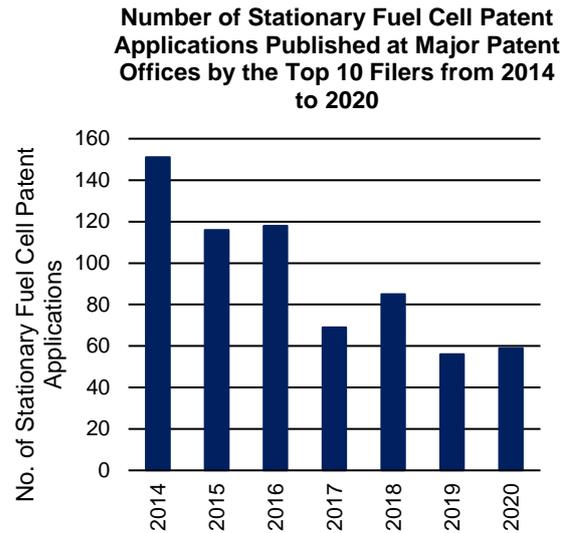
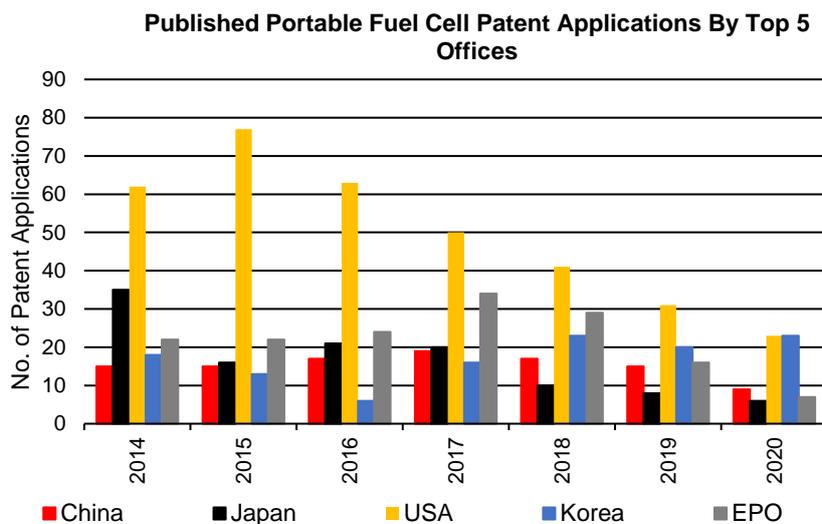


Figure 3.4.7 Number of stationary fuel cell patent applications published by the top 10 filers for the years 2014 to 2020.

3.4.3. Portable Fuel Cells

Figure 3.4.8 shows the total patent filings for portable fuel cells at the major patent offices for the period 2014 to 2020.



3.4.8. Portable fuel cell patent applications for 2014 to 2020.

The figures for patent filings at the USPTO show a marked decline over the period (-50%). Filings at the JPO appear to be trending downwardly whilst the remaining offices (EPO, KIPO and SIPO) show fluctuations between 2014 and 2020.

Figure 3.4.9 shows the top 10 assignees of portable fuel cell patent applications for the top 5 offices over the period 2014 to 2020. Intelligent Energy (China, the USA and Europe) are the top filer of portable fuel cell patent applications over the period.

Figure 3.4.10 shows the cumulative number of portable fuel cell patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. An overall decrease in published portable fuel cell patent applications by the top 10 filers is observed between 2014 and 2020 (Figure 3.4.10).

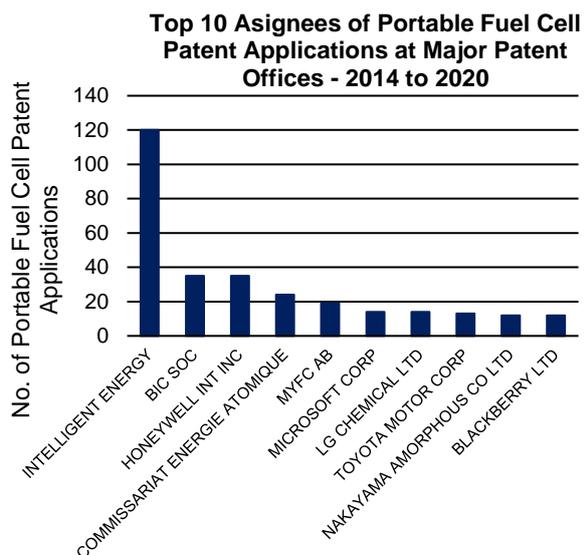


Figure 3.4.9. Top 10 filers of portable fuel cell patent applications at Top 5 Patent Offices for 2014 to 2020.

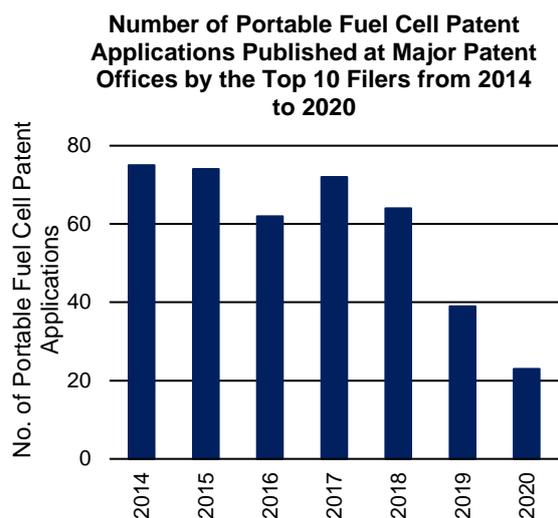
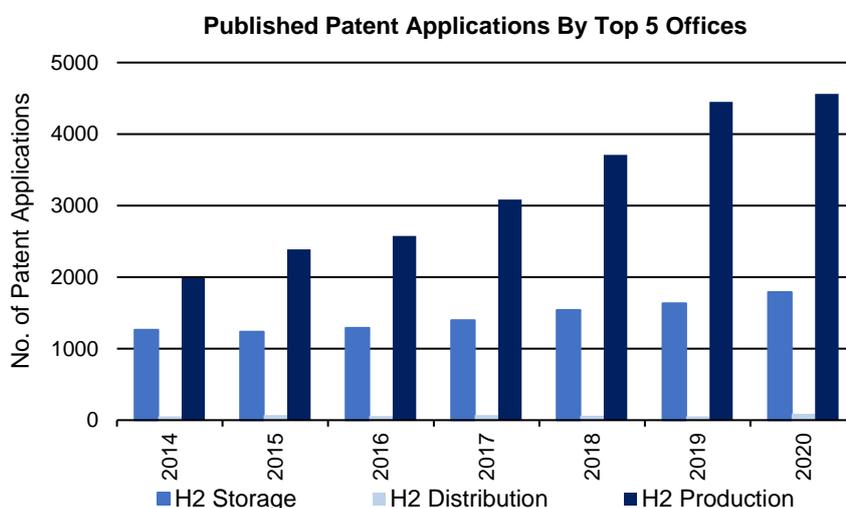


Figure 3.4.10 Number of portable fuel cell patent applications published by the top 10 filers for the years 2014 to 2020.

3.5. Hydrogen Transportation

The data presented below compares filing statistics according to hydrogen transportation, consisting of: hydrogen storage, hydrogen distribution and hydrogen production.

Figure 3.5.1 shows the total filings across the period at the top five offices for hydrogen storage, distribution and production.



3.5.1. Total patent applications at the top five patent offices for 2014 to 2020.

The data in Figure 3.5.1 clearly shows that hydrogen production is the dominant field of endeavour followed by hydrogen storage and then distribution but that, across the piece, the number of filings appears to be increasing.

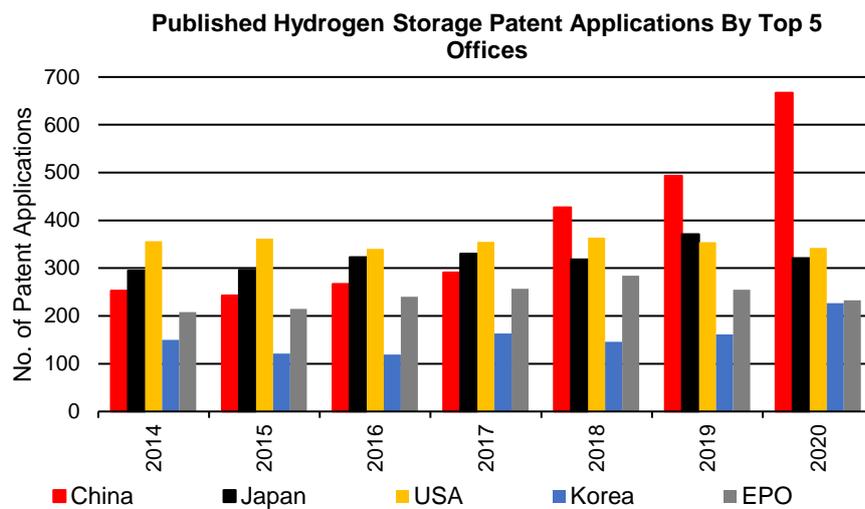
The following data presents the number of patent applications filed, according to hydrogen transportation, for the years 2014 to 2020, at the top 5 offices.

The data shows that China is the most important jurisdiction for businesses filing patent applications in these categories. In contrast, Korea does not appear to be an important jurisdiction for patent applications in these categories.

Also presented are the top 10 filers of patent applications for hydrogen storage, distribution and production, for the years 2014 to 2020, for each of the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

3.5.1. Hydrogen Storage

Figure 3.5.2 shows the total patent filings for hydrogen storage across the top 5 patent offices.



3.5.2. Hydrogen storage patent applications for 2014 to 2020.

Patent filings at the EPO, JPO, KIPO and SIPO appear to have been relatively flat between 2014 and 2020. In comparison, patent filings in China show a marked incline between 2017 and 2020.

Figure 3.5.3 shows the top 10 assignees of hydrogen storage patent applications for the top 5 offices over the period 2014 to 2020. Toyota (China, USA and Japan) are the top filer over the period.

Figure 3.5.4 shows the cumulative number of hydrogen storage patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. A significant increase in the number of filings is observed between 2018 and 2019 (Figure 3.5.4).

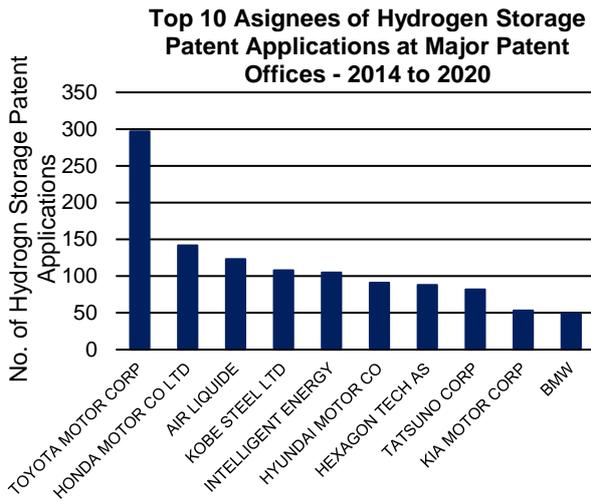


Figure 3.5.3. Top 10 filers of hydrogen storage patent applications at Top 5 Patent Offices for 2014 to 2020.

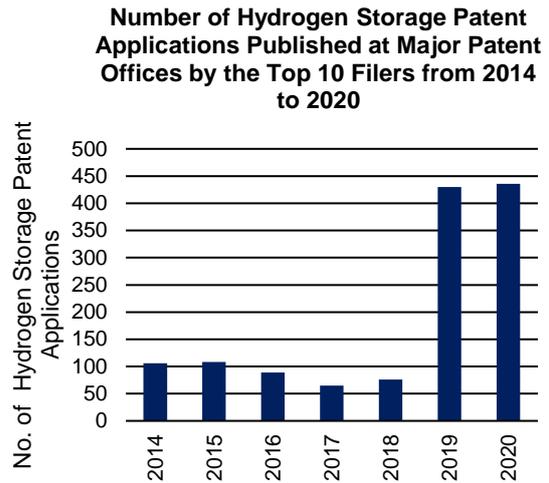
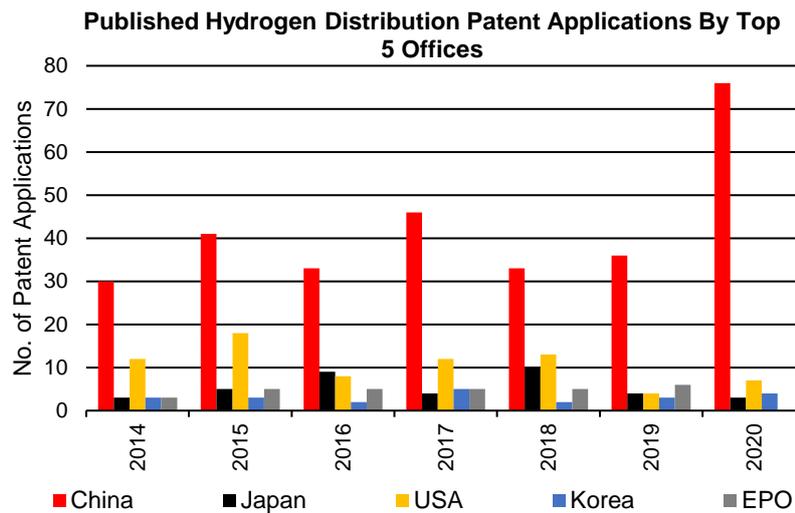


Figure 3.5.4. Number of hydrogen storage patent applications published by the top 10 filers for the years 2014 to 2020.

3.5.2. Hydrogen Distribution

Figure 3.5.5 shows the total patent filings for hydrogen distribution across the top 5 patent offices.



3.5.5. Hydrogen distribution patent applications for 2014 to 2020.

Figure 3.5.5 shows that China is the single most important jurisdiction for hydrogen distribution patent applications. Very few applications are filed in the remaining jurisdictions (Europe, Japan, USA and Korea).

Figure 3.5.6 shows the top 10 assignees of hydrogen distribution patent applications for the top 5 offices over the period 2014 to 2020. China Petroleum and Chem (China) are the top filer over the period.

Figure 3.5.7 shows a fluctuation in the cumulative number of hydrogen distribution patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020.

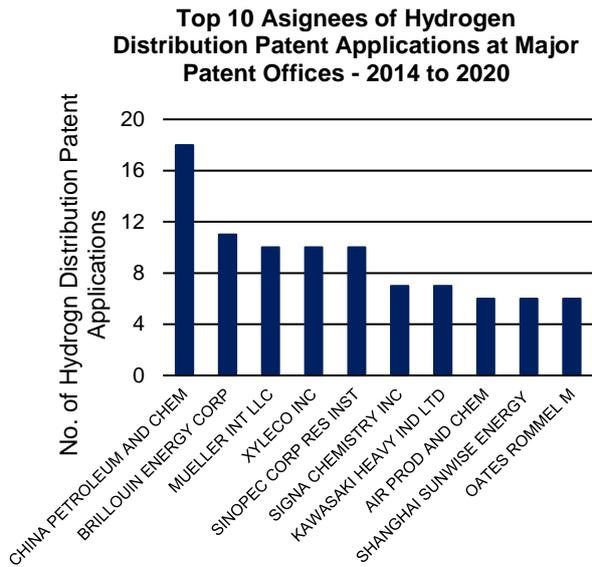


Figure 3.5.6. Top 10 filers of hydrogen distribution patent applications at Top 5 Patent Offices for 2014 to 2020.

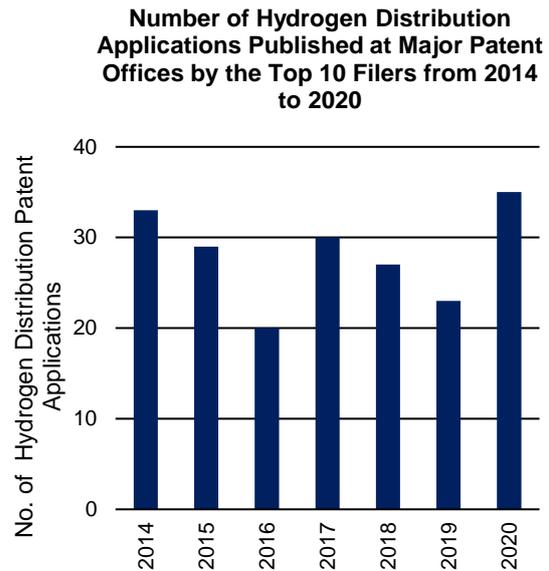
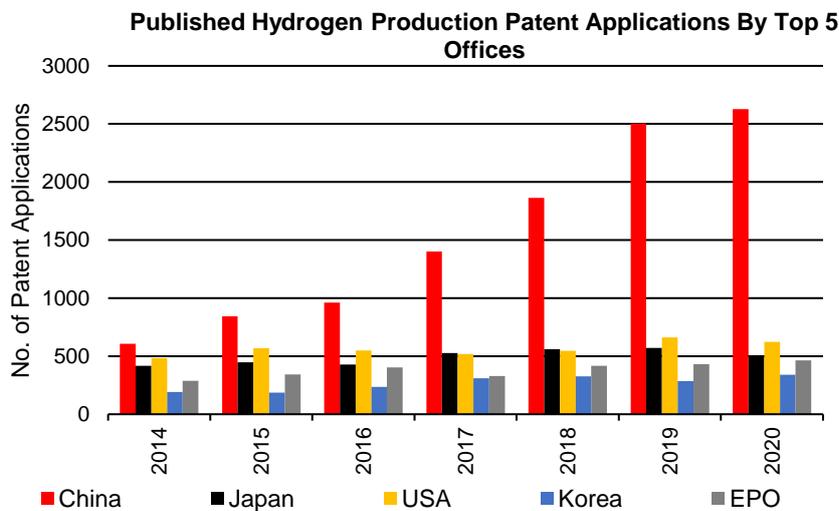


Figure 3.5.7. Number of hydrogen distribution patent applications published by the top 10 filers for the years 2014 to 2020.

3.5.3. Hydrogen Production Non-Carbon-Containing Sources including Electrolysis

Figure 3.5.8 shows the total patent filings for hydrogen production from electrolysis across the top 5 patent offices.



3.5.8. Hydrogen production patent applications for 2014 to 2020.

Figure 3.5.8 shows that China is a very important jurisdiction for hydrogen production patent applications. Significantly fewer applications are filed in the remaining jurisdictions (Europe, Japan, USA and Korea).

Figure 3.5.9 shows the top 10 assignees of hydrogen production patent applications for the top 5 offices over the period 2014 to 2020. The top filers are the CEA (France), Intelligent Energy (China, the USA and Europe) and Panasonic (Japan).

Figure 3.5.10 shows the cumulative number of hydrogen production patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. As observed with the hydrogen storage patent applications, a significant increase in the number of filings is observed between 2018 and 2019.

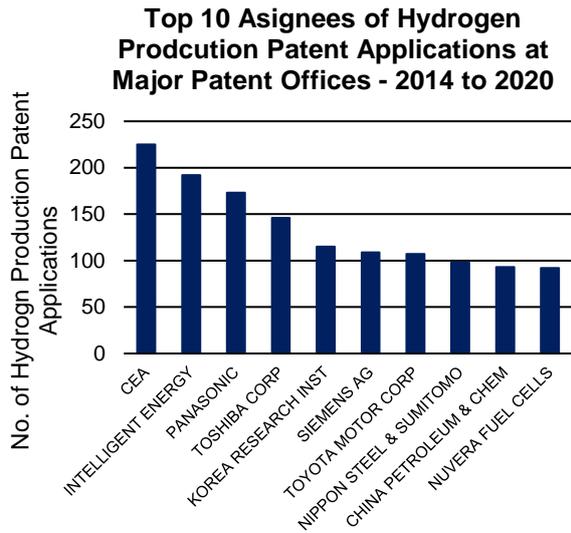


Figure 3.5.9. Top 10 filers of hydrogen production patent applications at Top 5 Patent Offices for 2014 to 2020.

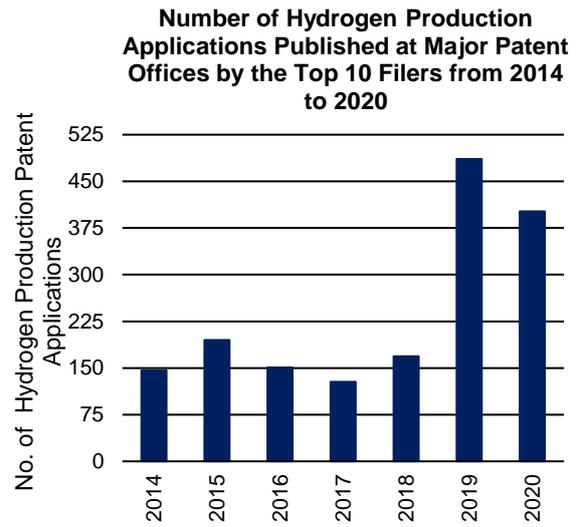


Figure 3.5.10. Number of hydrogen production patent applications published by the top 10 filers for the years 2014 to 2020.

4. Comparable Technologies

The above sections describe the progress in fuel cell technologies through the patent applications. In order to have a more complete picture and to be able to see the progress against other comparable technologies, in this section we assess the patent activity within the sector of battery accumulators and alternative fuel sources.

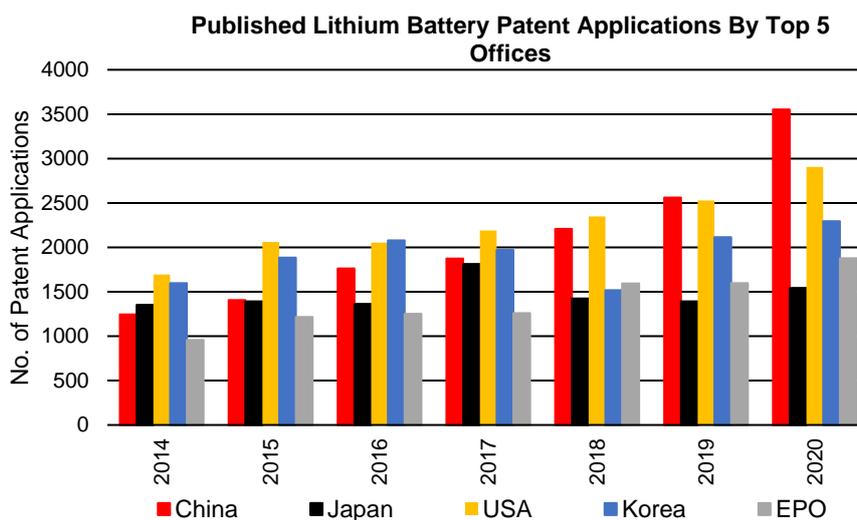
4.1. Lithium Batteries

The data presented below shows that China and the USA are the most important jurisdictions for organisations filing patent applications in the area of lithium batteries.

Also presented are the top 10 filers of patent applications for lithium batteries, for the years 2014 to 2020, for each of the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

4.1.1. Filing Statistics

Figure 4.1.1 shows the total patent filings for lithium batteries across the top 5 patent offices.



4.1.1.1. Lithium battery patent applications for 2014 to 2020.

Figure 4.1.1 shows that China has become an increasingly important jurisdiction for lithium battery patent applications. Whilst Japan, Korea and the EPO show fluctuations in growth of the number of patent applications filed over the period, the overall trend in all jurisdictions is upwards, with growth in the number of patent applications filed being strongest in China and the USA.

Figure 4.1.2 shows the top 10 assignees of lithium battery patent applications for the top 5 offices over the period 2014 to 2020. The top filers are LG, Samsung and Toyota, with LG the dominant entity.

Figure 4.1.3 shows the cumulative number of lithium battery patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. An overall increase in the number of filings is observed between 2014 and 2020.

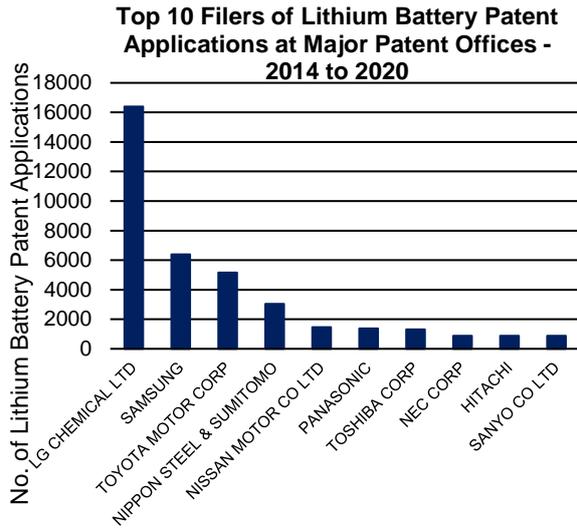


Figure 4.1.2. Top 10 filers of lithium battery patent applications at Top 5 Patent Offices for 2014 to 2020.

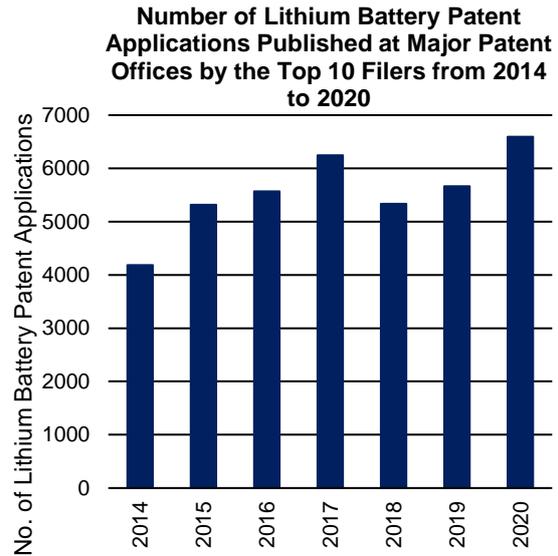
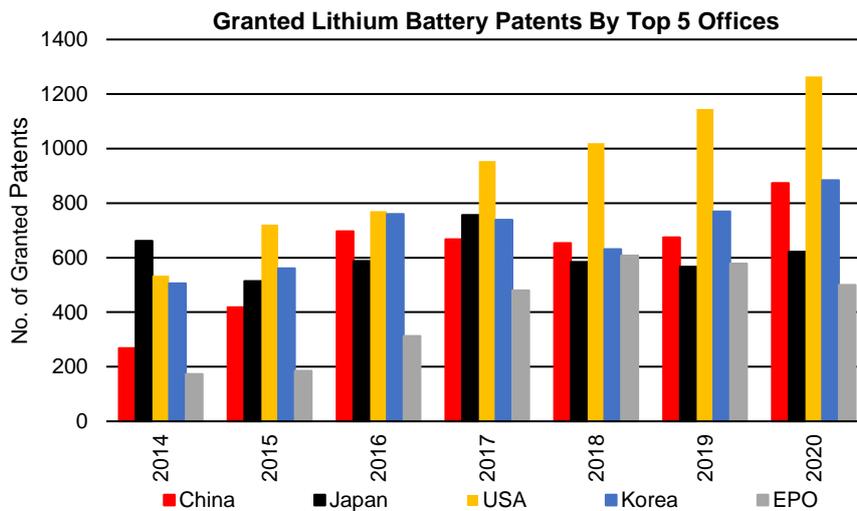


Figure 4.1.3. Number of lithium battery patent applications published by the top 10 filers for the years 2014 to 2020.

4.1.2. Granted Patents

Figure 4.1.4 shows the total number of granted lithium battery patents across the top 5 patent offices.



4.1.4. Granted lithium battery patents for 2014 to 2020.

Figure 4.1.4 shows that the USA is the most important territory for granting lithium battery patents and that the EPO is the least important territory, of the top 5 offices, for granting lithium battery patents.

Figure 4.1.5 shows the top 10 assignees of granted lithium battery patents for the top 5 offices over the period 2014 to 2020. As observed with the number of lithium battery patent applications, the top assignees of granted lithium battery patents are LG, Samsung and Toyota.

Figure 4.1.6 shows the cumulative number of lithium battery patents granted at the top 5 offices by the top 10 assignees. As observed with the cumulative number of lithium battery patent applications, the number of granted patents shows an overall increase between 2014 and 2020.

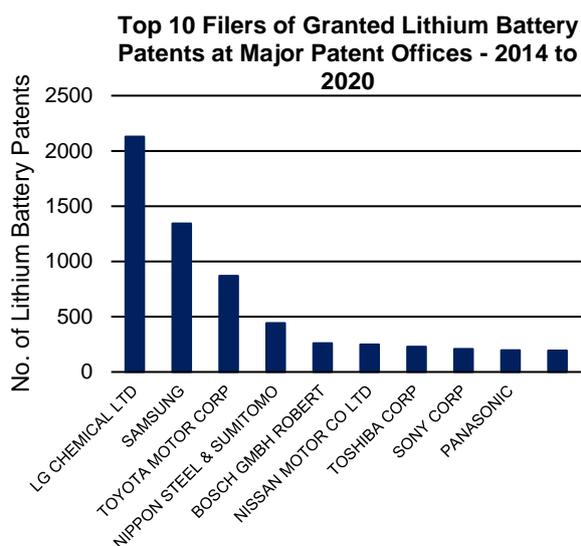


Figure 4.1.5. Top 10 filers of lithium battery patents granted at Top 5 Patent Offices for 2014 to 2020.

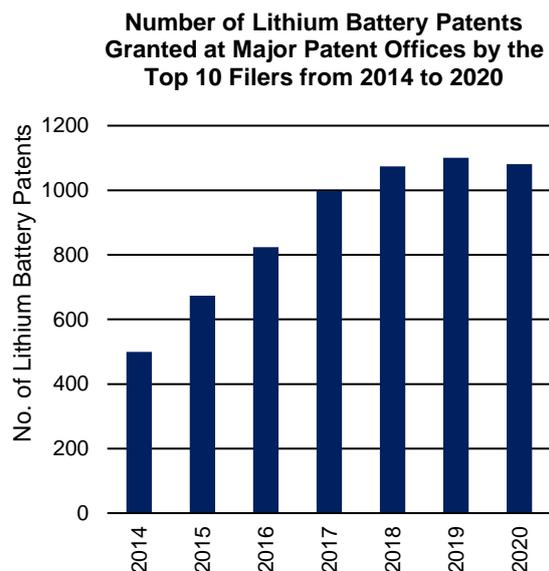


Figure 4.1.6. Number of lithium battery patents granted by the top 10 filers for the years 2014 to 2020.

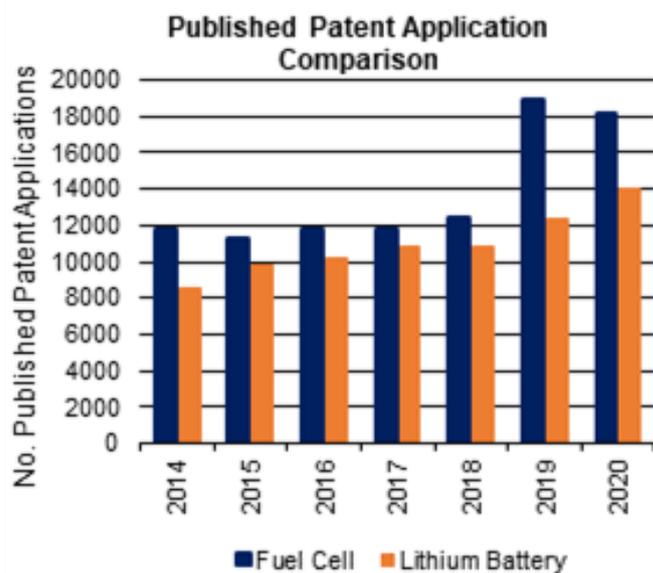


Figure 4.1.6. Comparison of total number of fuel cell patent publications and lithium battery patent publications for the years 2014 to 2020

The relative quanta of fuel cell patent application publications to lithium battery patent application publications is shown above. In both instances the absolute number of application is increasing over the period, with the growth in lithium battery patent applications appearing to grow at a steady annual rate and the fuel cell patent applications showing a more varied growth. The filing statistics for following years will demonstrate how the trends continue.

4.2. Battery Accumulators

Figure 4.2.1 shows a comparison between the total number of patents published worldwide, the number of fuel cell patent applications and the number of battery patent applications (lithium batteries and lead-acid batteries) published worldwide between 2014 and 2019.

All three data sets show an overall increase over the period with the battery patent application data showing a similar trend to those of the total number of patent applications published worldwide.

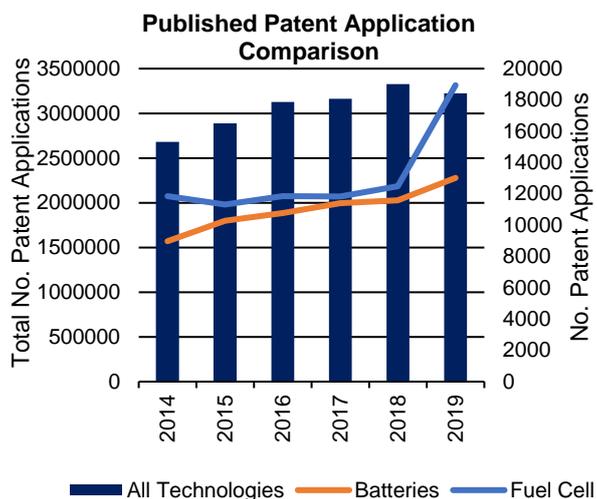
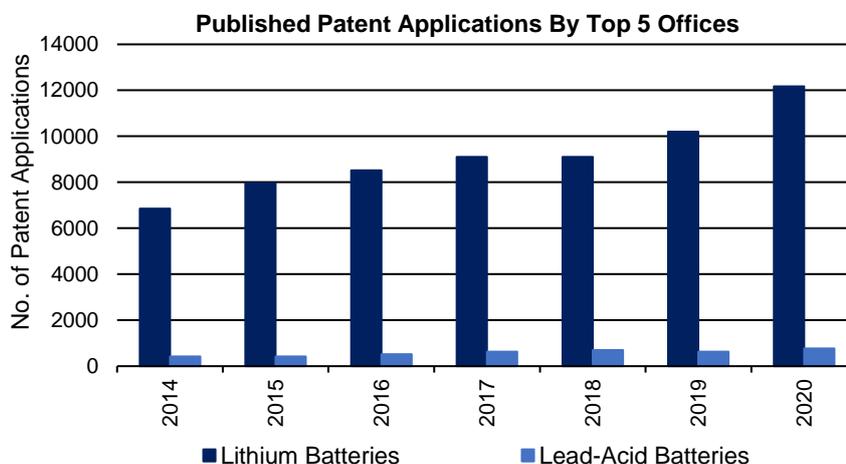


Figure 4.2.1. Top ten filers of hydrogen production patent applications at the Top 5 Patent Offices for 2020.

Table 4.2.1. List of classification codes searched for in battery accumulators.

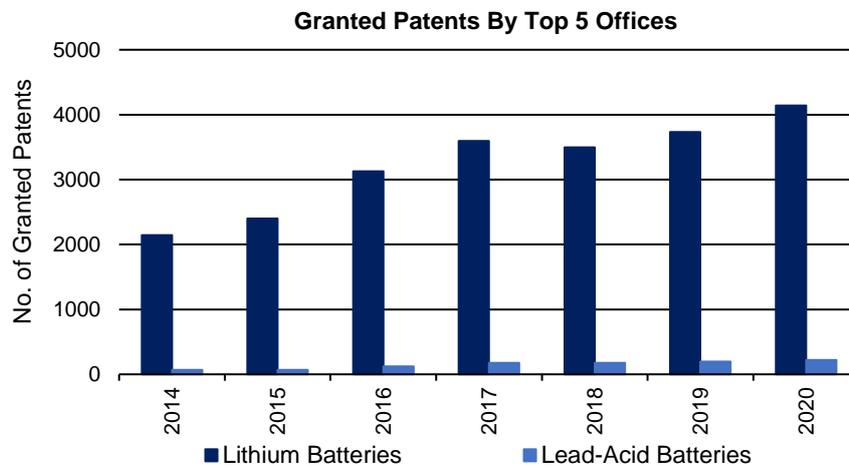
Category	Classification Codes
Lithium Batteries	HO1M10/052
Lead-Acid Batteries	HO1M10/06

Figure 4.2.2 shows the total filings across the period at the top five offices for lithium battery patent applications in comparison to lead-acid battery patent applications. The data clearly shows that lithium batteries are the dominant field of endeavour and that the number of filings are increasing annually over the period.



4.2.2. Total patent applications at the top five patent offices for 2014 to 2020.

The granted patent data (Figure 4.2.3) shows a similar trend to the filing statistics (Figure 4.2.2) with lithium batteries the dominant field of endeavour and the number of granted patents increasing annually over the period.



4.2.3. Total patents granted at the top five patent offices for 2014 to 2020.

4.2.1. Lithium Batteries

The data presented below shows the top 10 university filers of patent applications (Figures 4.2.4 to 4.2.10) and granted patents (Figures 4.2.11 to 4.2.17) in the area of lithium batteries recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

LG, Samsung and Toyota are in the top three assignees annually (for the period 2014 to 2020) for both published lithium battery application and granted lithium battery patents.

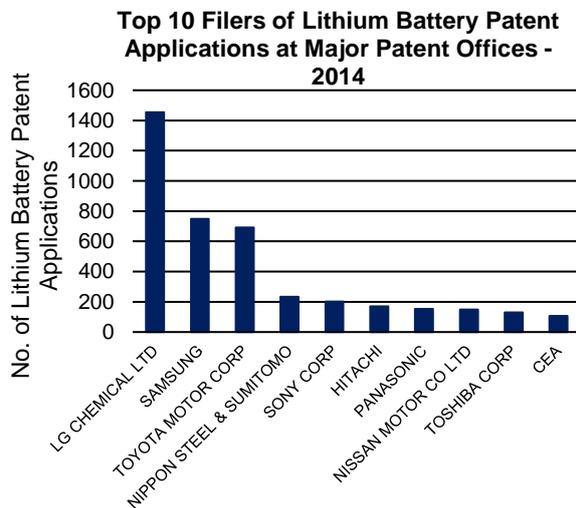


Figure 4.2.4. Top 10 filers of lithium battery patent applications at the Top 5 Patent Offices for 2014.

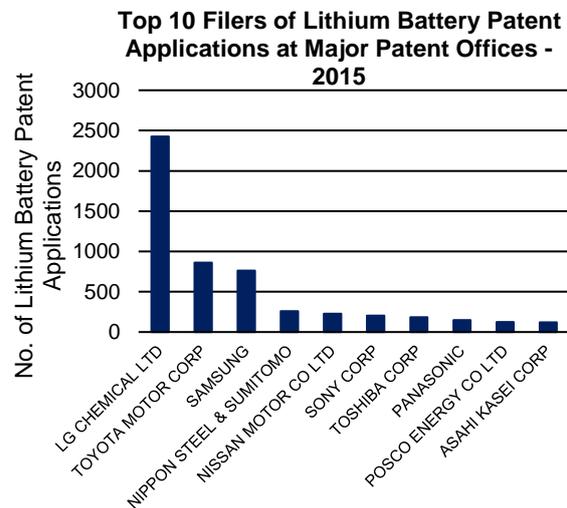


Figure 4.2.5. Top 10 filers of lithium battery patent applications at the Top 5 Offices for 2015.

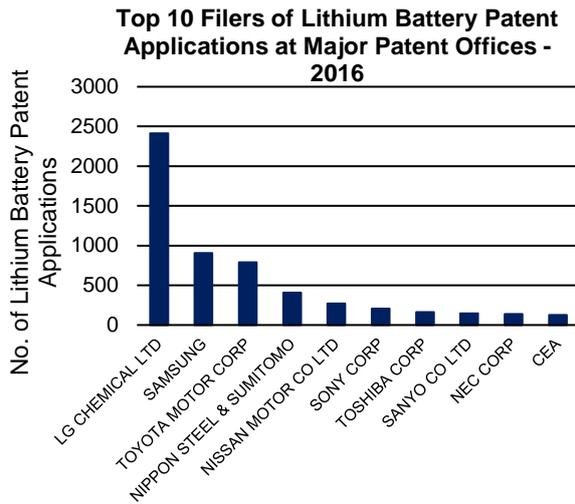


Figure 4.2.6. Top 10 filers of lithium battery patent applications at the Top 5 Patent Offices for 2016.

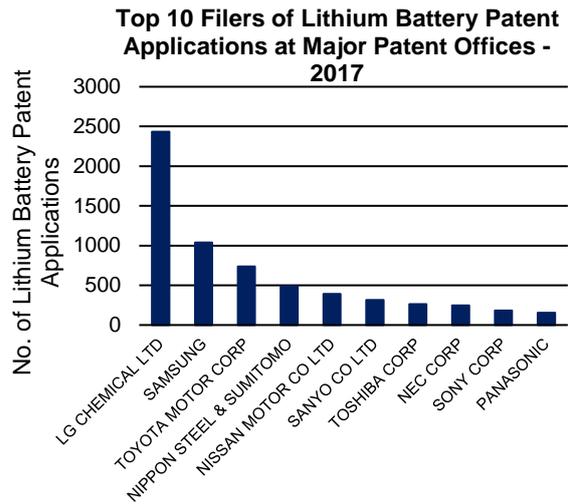


Figure 4.2.7. Top 10 filers of lithium battery patent applications at the Top 5 Offices for 2017.

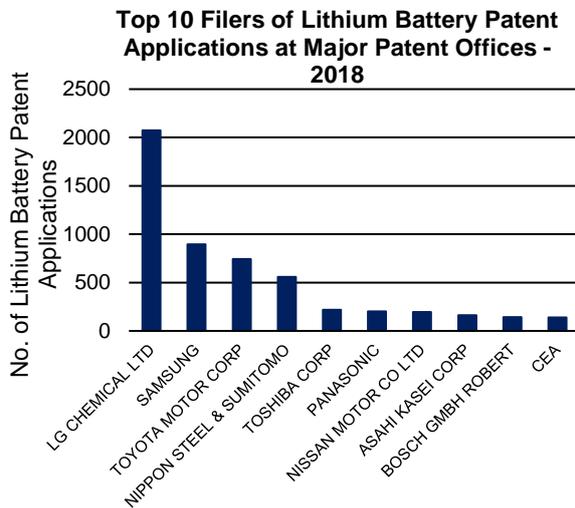


Figure 4.2.8. Top 10 filers of lithium battery patent applications at the Top 5 Patent Offices for 2018.

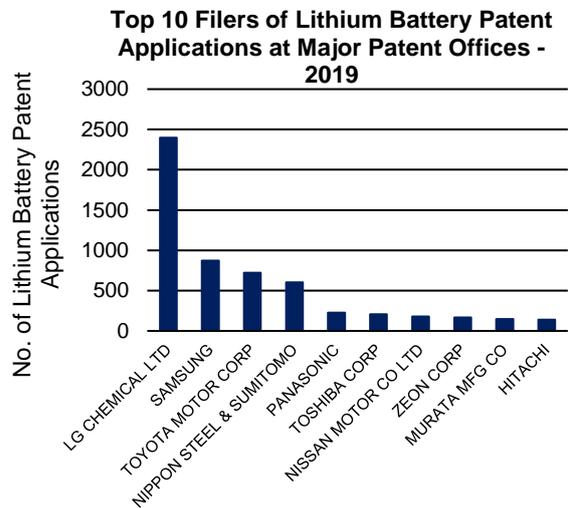


Figure 4.2.9. Top 10 filers of lithium battery patent applications at the Top 5 Offices for 2019.

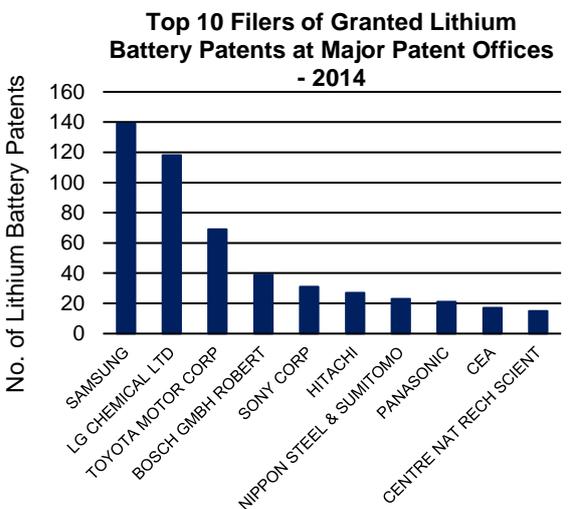
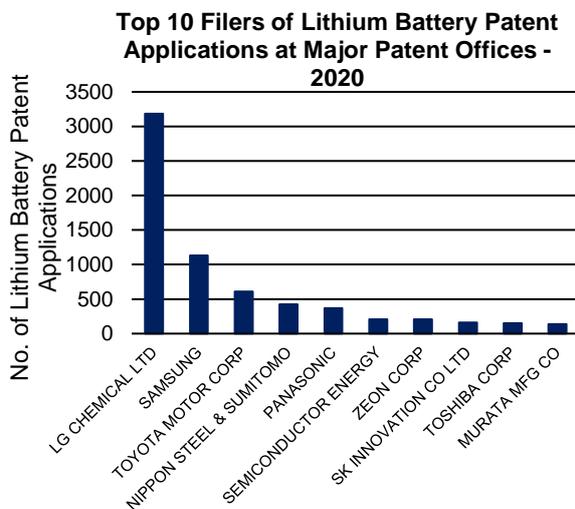


Figure 4.2.10. Top 10 filers of lithium battery patent at the Top 5 Patent Offices for 2020.

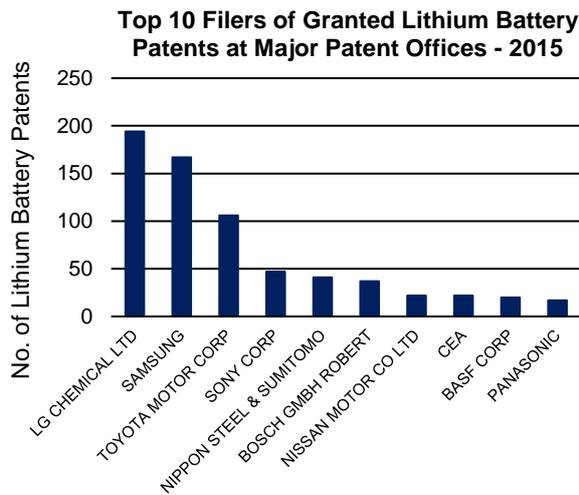


Figure 4.2.11. Top 10 filers of lithium battery patents applications at the Top 5 Offices for 2014.

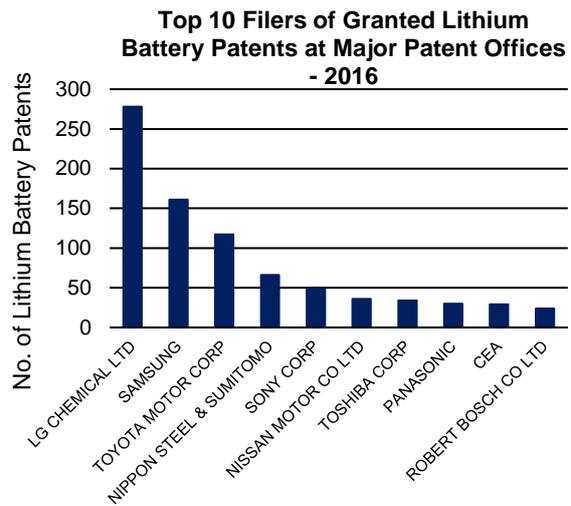


Figure 4.2.12. Top 10 filers of lithium battery patents at the Top 5 Patent Offices for 2015.

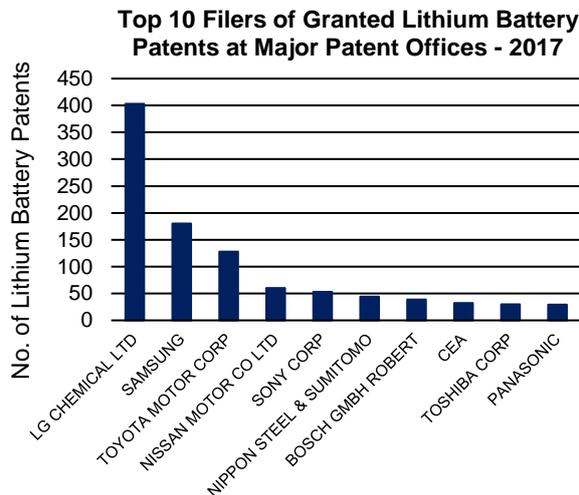


Figure 4.2.13. Top 10 filers of lithium battery patents at the Top 5 Offices for 2015.

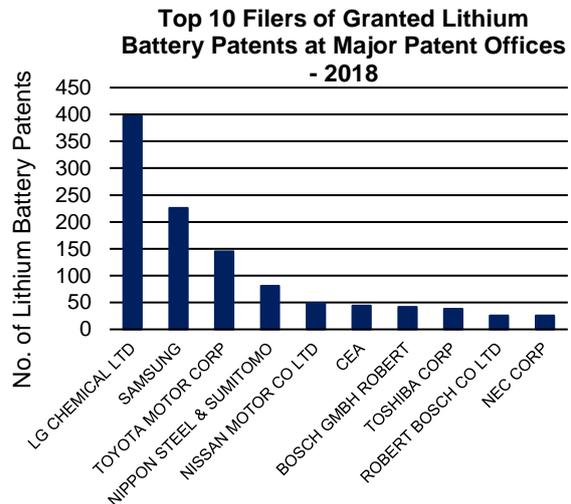


Figure 4.2.14. Top 10 filers of lithium battery patents at the Top 5 Patent Offices for 2017.

Figure 4.2.15. Top 10 filers of lithium battery patents at the Top 5 Offices for 2018.

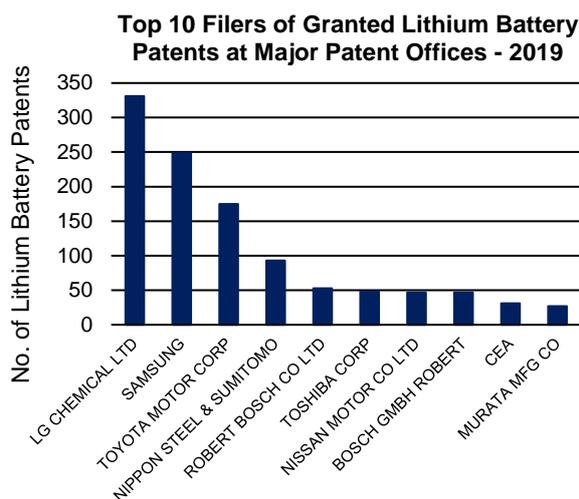


Figure 4.2.16. Top 10 filers of lithium battery patents at the Top 5 Patent Offices for 2019.

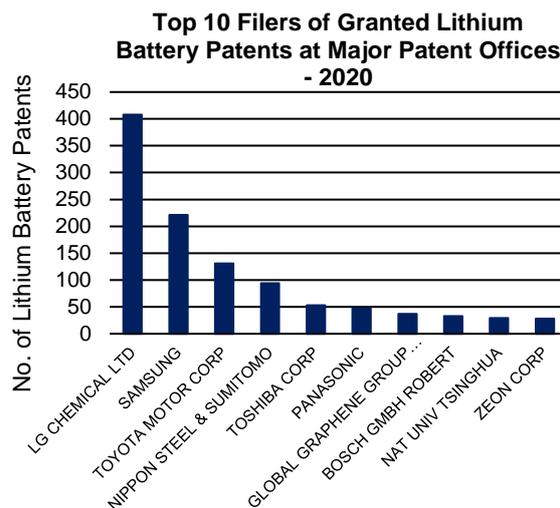
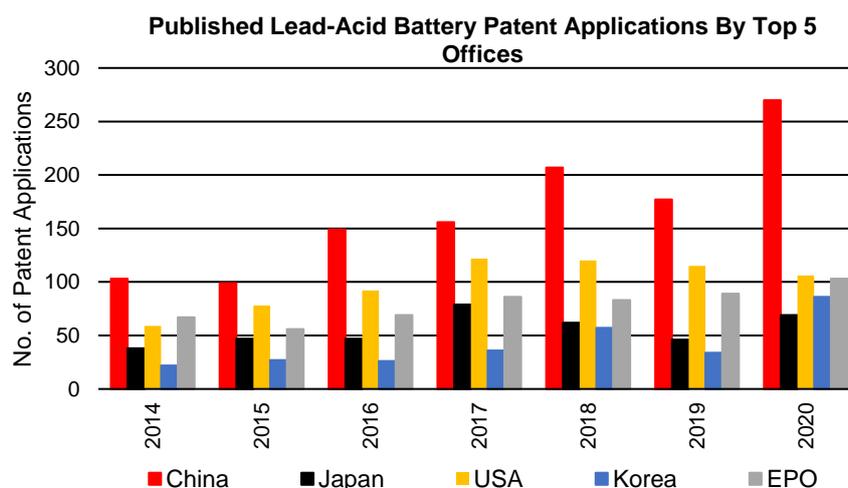


Figure 4.2.17. Top 10 filers of lithium battery patents at the Top 5 Offices for 2020.

4.2.2. Lead Acid Batteries

4.2.2.1. Filing Statistics

Figure 4.2.18 shows the total patent filings for lead-acid batteries across the top 5 patent offices.



4.2.18. Lead-acid battery patent applications for 2014 to 2020.

Figure 4.2.18 shows that China has become an increasingly important jurisdiction for filing lead-acid battery patent applications. Whilst Japan, Korea, the USA and the EPO show fluctuations in the number of patent applications filed in this area, the overall number of patent applications filed at the top 5 offices between 2014 and 2020 appears to be increasing.

Figure 4.2.19 shows the top 10 assignees of lead-acid battery patent applications for the top 5 offices over the period 2014 to 2020. The top five filers are GS Yuasa, Daramic, Hitachi, Johnson and Johnson and Panasonic.

Figure 4.2.20 shows the cumulative number of lead-acid battery patent applications published at the top 5 offices by the top 10 filers from 2014 to 2020. The data shows an increase in lead-acid battery patent application filings between 2014 and 2017, a decrease between 2017 and 2019 and a sharp increase between 2019 and 2020, leading to an overall increase in filings over the period.

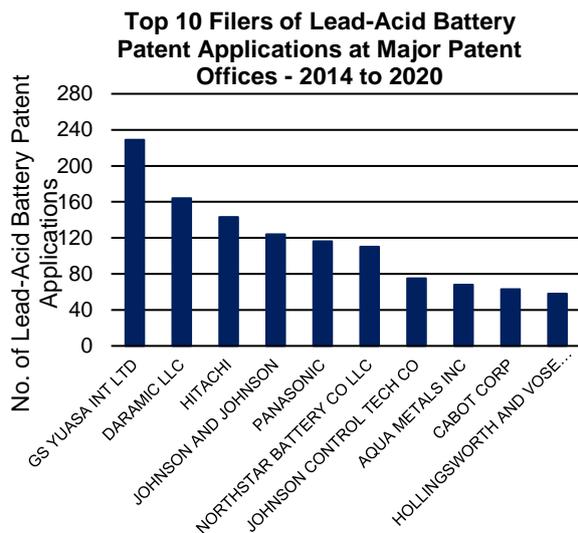


Figure 4.2.19. Top 10 filers of lead-acid battery patent applications at Top 5 Patent Offices for 2014 to 2020.

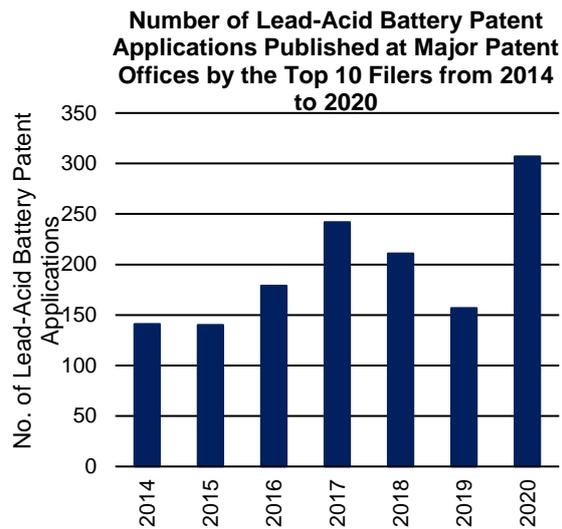


Figure 4.2.20. Number of lead-acid battery patent applications published by the top 10 filers for the years 2014 to 2020.

The data presented below shows the top 10 university filers of patent applications (Figures 4.2.21 to 4.2.27) in the area of lead-acid batteries recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

Whilst the top filers appear to vary over the period, the number of applications filed within the field of lead-acid batteries remains relatively low, in comparison to the number of lithium battery applications and granted patents.

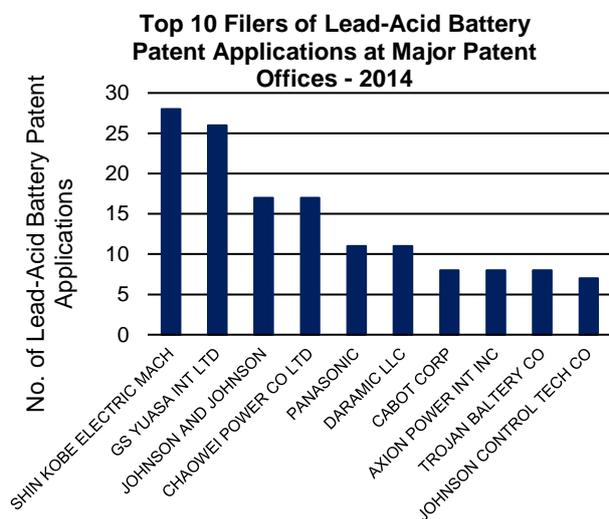


Figure 4.2.21. Top 10 filers of lead-acid battery patent applications at the Top 5 Patent Offices for 2014.

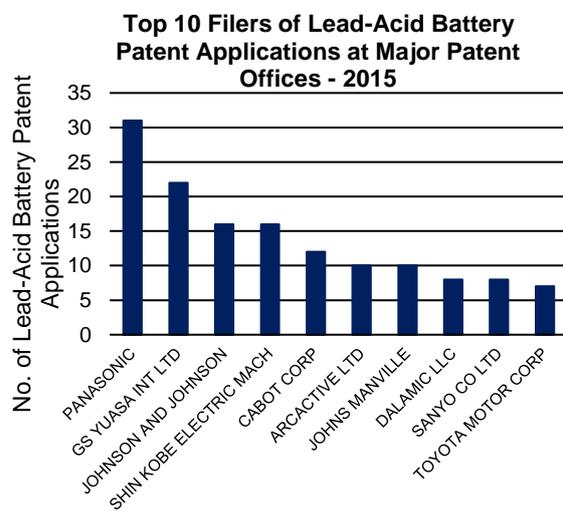


Figure 4.2.22. Top 10 filers of lead-acid battery patent applications at the Top 5 Offices for 2015.

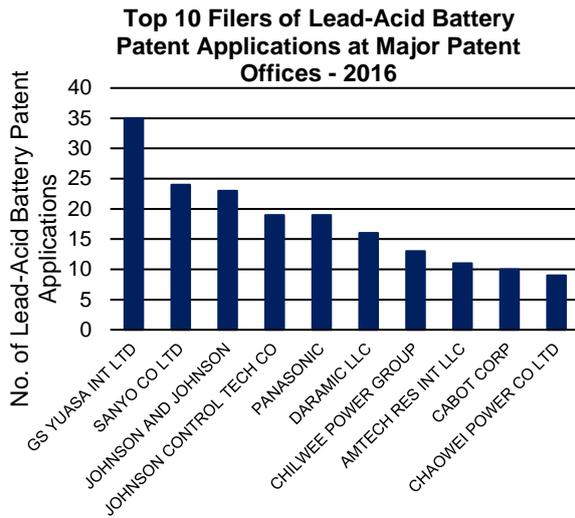


Figure 4.2.23. Top 10 filers of lead-acid battery patent applications at the Top 5 Patent Offices for 2016.

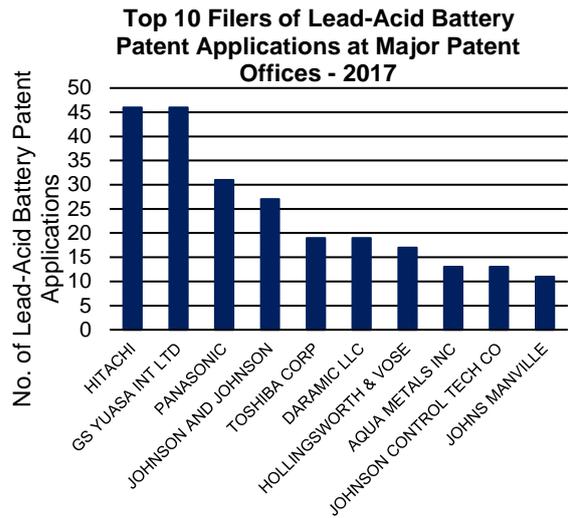


Figure 4.2.24. Top 10 filers of lead-acid battery patent applications at the Top 5 Offices for 2017.

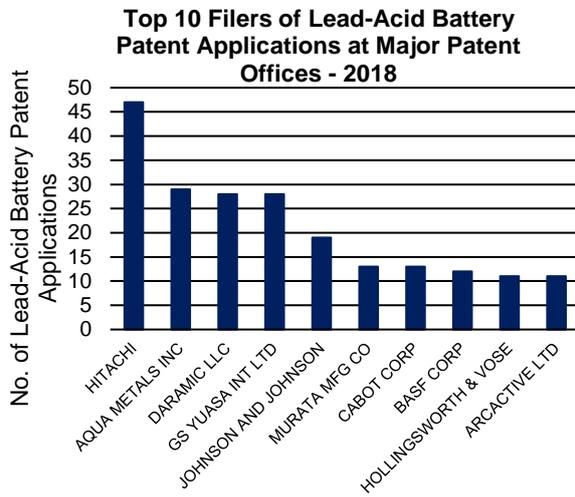


Figure 4.2.25. Top 10 filers of lead-acid battery patent applications at the Top 5 Patent Offices for 2018.

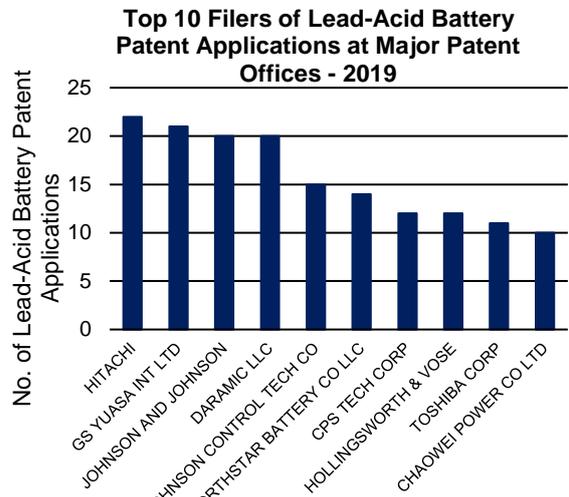


Figure 4.2.26. Top 10 filers of lead-acid battery patent applications at the Top 5 Offices for 2019.

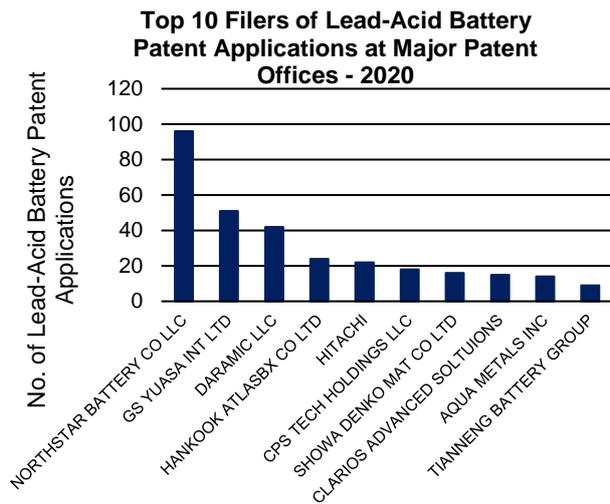
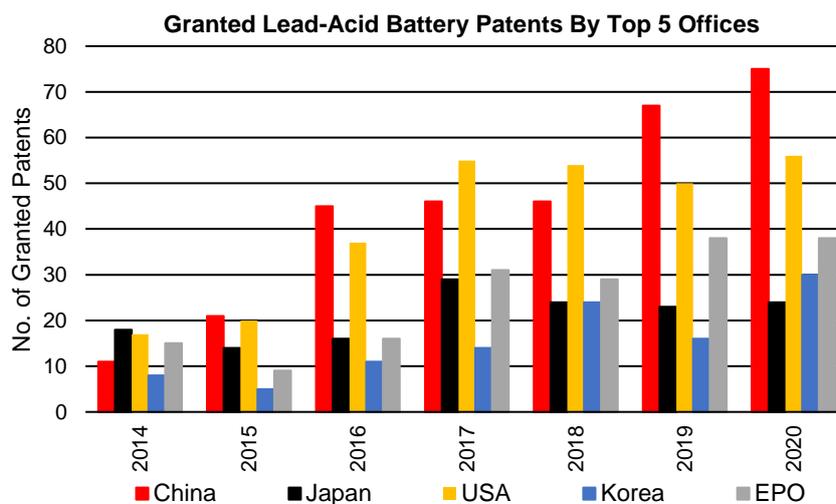


Figure 4.2.27. Top 10 filers of lead-acid battery patent applications at the Top 5 Patent Offices for 2020.

4.2.2.2. Granted Patents

Figure 4.2.28 shows the total number of granted lead-acid battery patents across the top 5 patent offices.



4.2.28. Granted lead-acid battery patents for 2014 to 2020.

Figure 4.2.28 shows that since 2016, China and the USA are the important jurisdictions in terms of the absolute number of patents granted in the area of lead-acid batteries. Whilst the remaining offices (Japan, Korea and the EPO) show fluctuations in the number of patents granted over the period, the overall trajectory appears to be increasing.

Figure 4.2.29 shows the top 10 assignees of granted lead-acid battery patents for the top 5 offices over the period 2014 to 2020. The top filers are GS Yuasa, Johnson Control Tech Co and Hitachi.

Figure 4.2.30 shows the cumulative number of lead-acid battery patents granted at the top 5 offices by the top 10. As observed with the cumulative number of published lead-acid battery applications, an increase in granted lead-acid battery patents is observed between 2014 and 2017. However, a more gradual decrease is observed between 2017 and 2019.

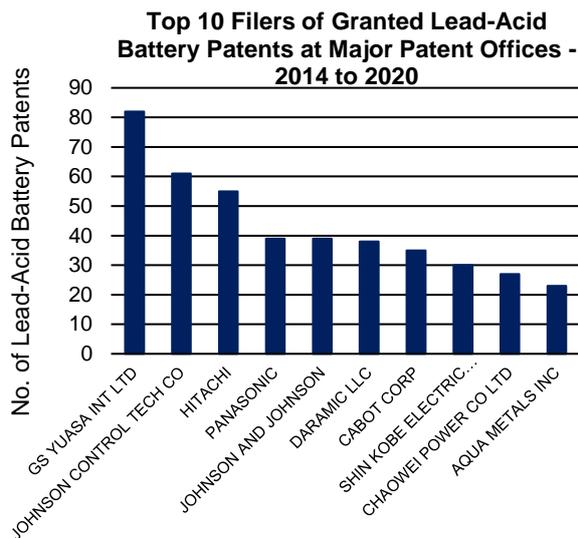


Figure 4.2.29. Top 10 filers of lead-acid battery patents granted at Top 5 Patent Offices for 2014 to 2020.

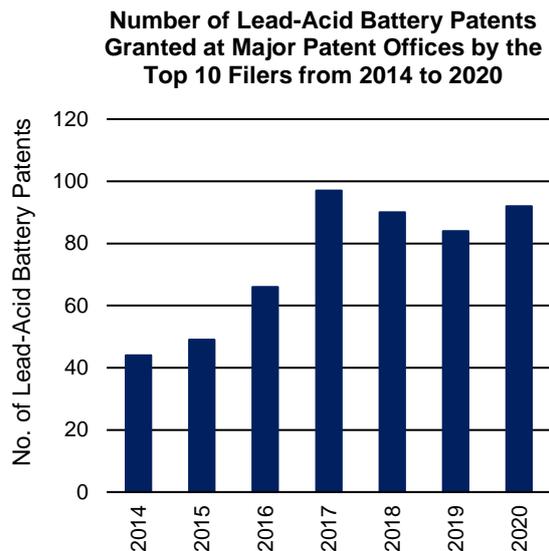


Figure 4.2.30. Number of lead-acid battery patents granted by the top 10 filers for the years 2014 to 2020.

The data presented below shows the top 10 university filers of granted patents (Figures 4.2.31 to 4.2.37) in the area of lead-acid batteries recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

Whilst the top filers appear to vary over the period, the number of patents granted within the field of lead-acid batteries remains relatively low, in comparison to the number of lithium battery applications and granted patents.

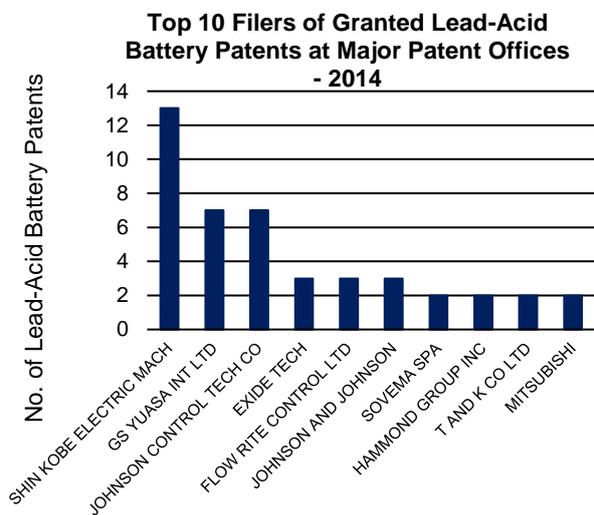


Figure 4.2.31. Top 10 filers of lead-acid battery patents at the Top 5 Offices for 2014.

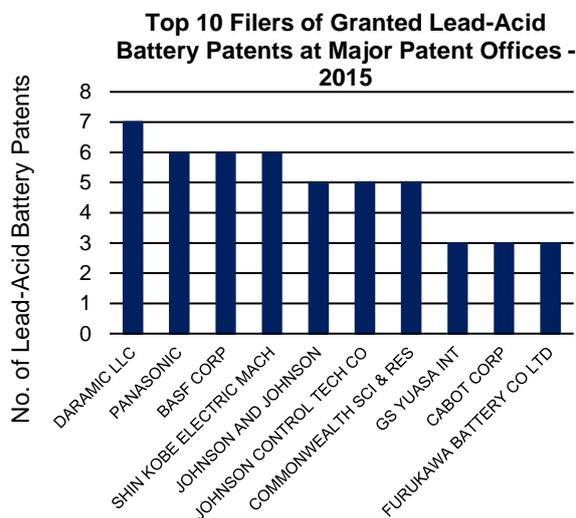


Figure 4.2.32. Top 10 filers of lead-acid battery patents at the Top 5 Patent Offices for 2015.

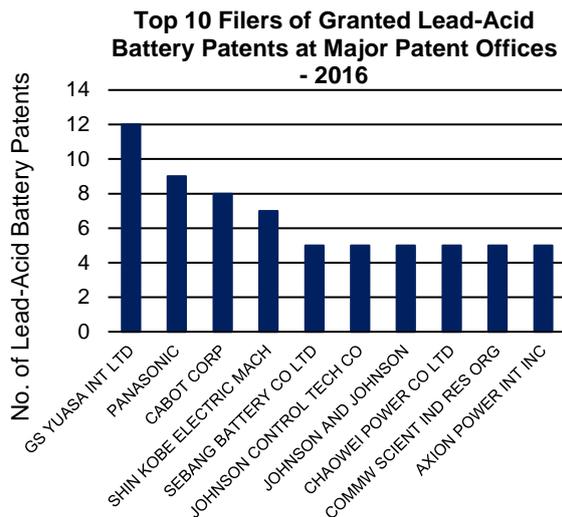


Figure 4.2.33. Top 10 filers of lead-acid battery patents at the Top 5 Offices for 2016.

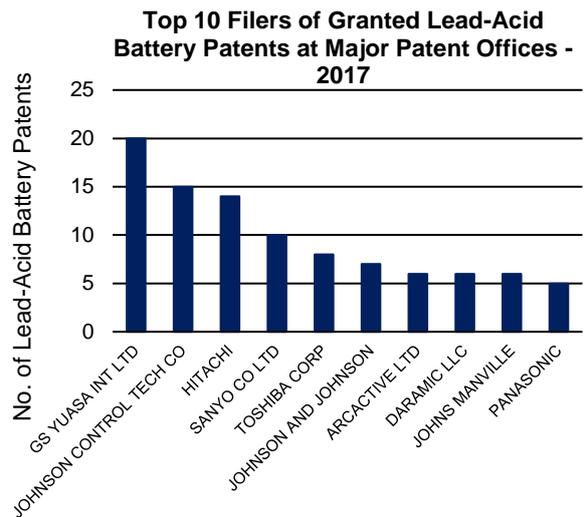


Figure 4.2.34. Top 10 filers of lead-acid battery patents at the Top 5 Patent Offices for 2017.

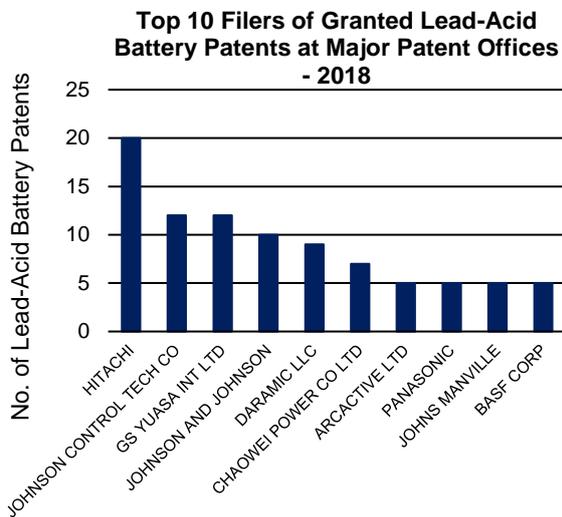


Figure 4.2.35. Top 10 filers of lead-acid battery patents at the Top 5 Offices for 2018.

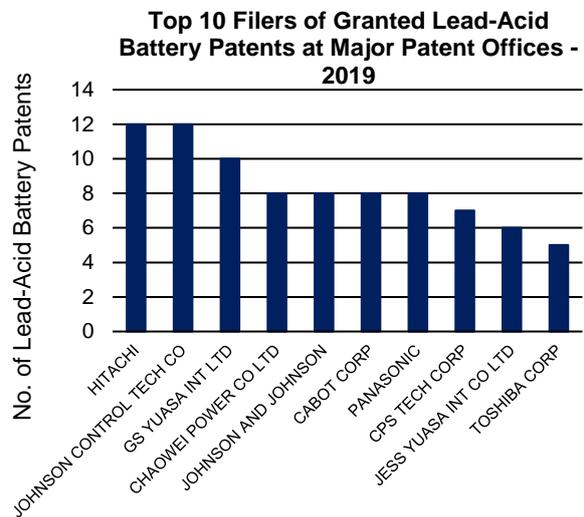


Figure 4.2.36. Top 10 filers of lead-acid battery patents at the Top 5 Patent Offices for 2019.

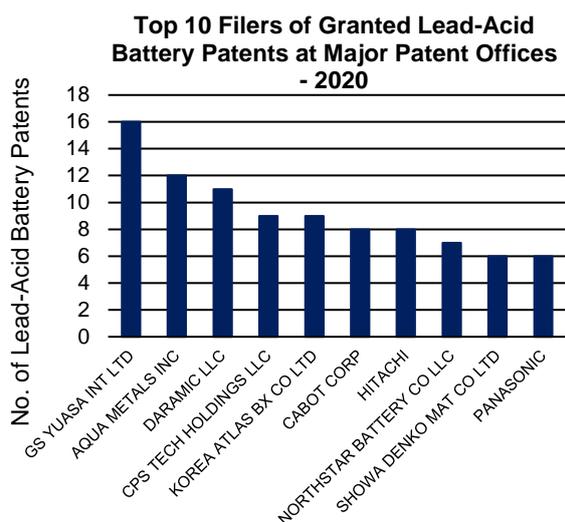


Figure 4.2.37. Top 10 filers of lead-acid battery patents at the Top 5 Offices for 2020.

4.3. Alternative Fuel Sources

4.3.1. Filing Statistics

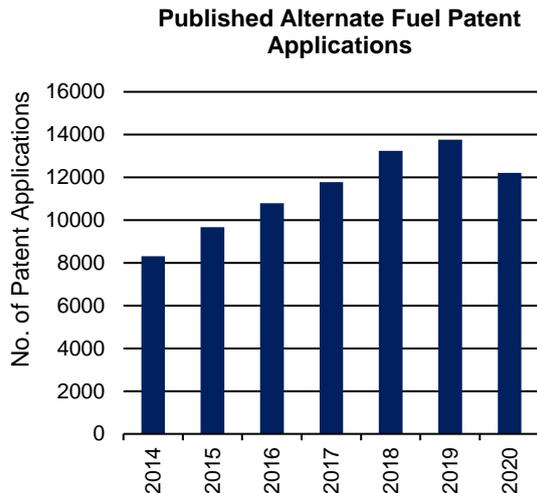
The number of alternative fuel (solar, wind and geothermal energy) patent applications published annually around the world has remained in excess of 8000 since 2014. The data shows an increasing trajectory in the number of published alternative fuel patent applications, with solar energy being the standout alternative. The USPTO and the Chinese office remain the most important territories for publishing alternative fuel patent applications, with the rise in those published at the Chinese office being the most significant.

If the current trend continues, the number of alternative fuel patent applications will likely outstrip the number of fuel cell patent applications in the near future.

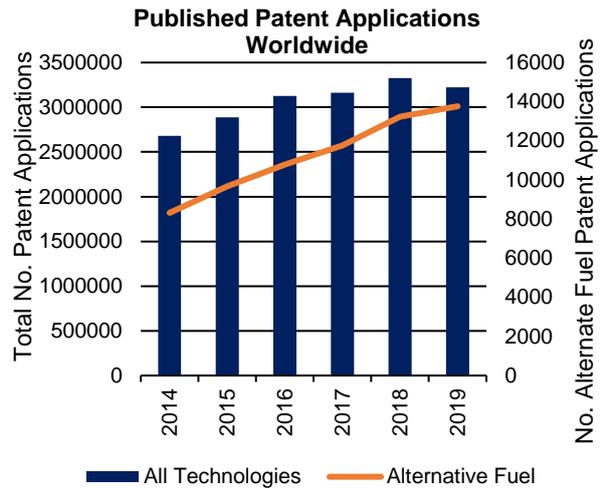
Table 4.3.1. List of classification codes searched for in alternative fuel sources.

Category	Classification Codes
Solar	E04D 1/30, E04D 13/18, F24J 2/00, F24J 2/02, F24J 2/04, F24J 2/05, F24J 2/06, F24J 2/07, F24J 2/08, F24J 2/10, F24J 2/12, F24J 2/13, F24J 2/14, F24J 2/15, F24J 2/16, F24J 2/18, F24J 2/23, F24J 2/24, F24J 2/36, F24J 2/38, F24J 2/42, F24J 2/46, F03G 6/06, G02B 5/10, H01L 31/052, H01L 31/04, H01L 31/042, H01L 31/18, G02F 1/136, G05F 1/67, H01L 25/00, H01L 31/00, H01L 31/048, H01L 33/00, H02J 7/35, H02N 6/00
Wind	F03D 1/00, F03D 3/00, F03D 5/00, F03D 7/00, F03D 9/00, F03D 11/00, B60L 8/00
Geothermal	F24J 3/08, F03G 4/00, F03G 7/05

Figure 4.3.1 shows worldwide patent statistics for the annual publication of patents in the area of alternative fuel sources.



4.3.1. Published alternative fuel patent applications for 2014 to 2020.



4.3.2. Published total patent applications vs. published alternative fuel patent applications for 2014 to 2019.

The data shows an increase in the number of alternative fuel patent applications being published between 2014 and 2019. A drop off in publication number is observed between 2019 and 2020⁸.

Figure 4.3.2 shows a comparison between the number of published alternative fuel patent applications and the total number of published patent applications between 2014 and 2019.

Both total patent applications (blue bars) and alternate fuel patent applications (orange line) show an incline in annual publication numbers between 2014 and 2019.

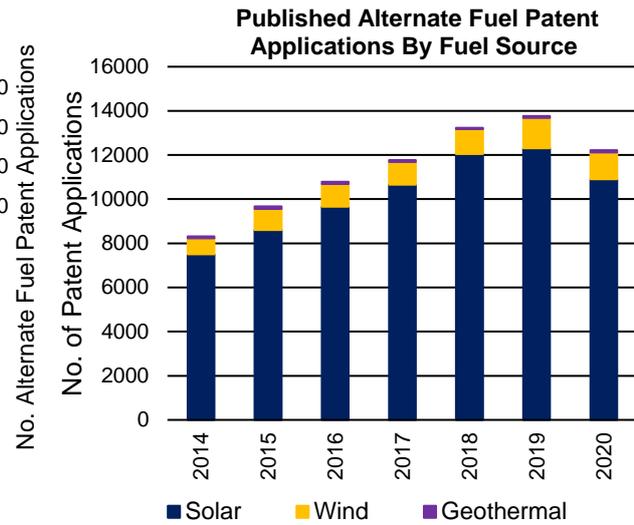
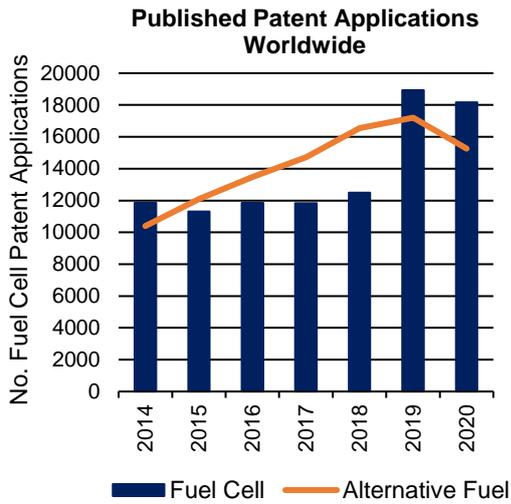
The marginal growth of +65% recorded between 2014 and 2019 for the publication of alternative fuel patent applications (orange line), is more than three times the growth reported for the total number of published patent applications (blue bars), with a marginal growth of +20%.

This clearly shows that patent applications relating to alternative fuels are an increasingly important component of the overall patent filing picture and that an increasing amount of research activity is being undertaken in these fields as compared to technology in general.

Figure 4.3.3 shows a comparison between the number of published alternative fuel patent applications and the number of published fuel cell patent applications.

Whilst an overall increase in publication number is observed between 2014 and 2018 for both the number of fuel cell patent applications (blue bars, LH scale) and alternative fuel patent applications (orange line, RH scale), the number of alternative fuel patent applications seems to be growing at a much higher rate with the number of fuel cell patent applications being relatively flat. However, a sharp increase in the number of fuel cell patent applications is observed between 2018 and 2019.

⁸ As previously explained, the numbers presented for 2020 may be subject to change and may therefore not be a true representation of the filing statistics for that year.



4.3.3. Published fuel cell patent applications vs. published alternative fuel patent applications for 2014 to 2020.

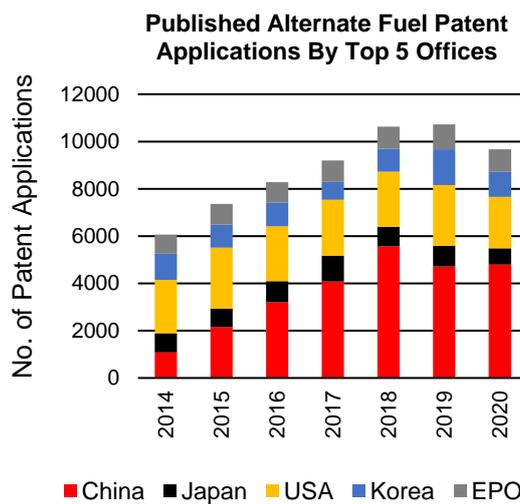
4.3.4. Published alternative fuel patent applications by fuel source for 2014 to 2020.

Figure 4.3.4 shows the overall number of published alternative fuel patent applications according to the alternative fuel source.

Over 89% of the published alternative fuel patent applications are in the field of solar energy, with the remaining 11% relating to the areas of wind (10%) and geothermal (1%) energy.

Figure 4.3.5 shows the overall number of published alternative fuel patent applications according to the geographical split of the top 5 patent offices.

The data reflects that of the overall number of alternative fuel patent applications published worldwide (Figure 4.3.1).

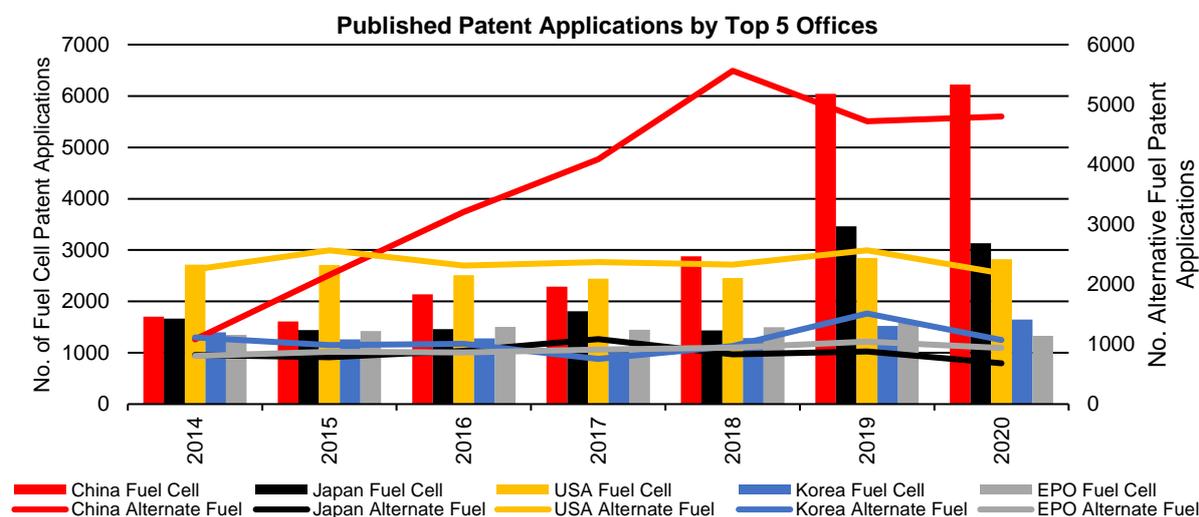


4.3.5. Published alternative fuel patent applications at the Top 5 Patent Offices for 2014 to 2020.

The data shows a marked incline in the number of alternative fuel patent applications published at the top 5 patent offices between 2014 and 2019.

The Chinese office and the USPTO are clear leaders in the publication of alternative fuel patent applications, with the Chinese office overtaking the USPTO in terms of absolute numbers in 2016. The number of filings in Europe appears to be fairly stable.

Figure 4.3.6 shows the number of published alternative fuel patent applications in comparison to the number of published fuel cell patent applications, according to the geographical split of the top 5 patent offices.



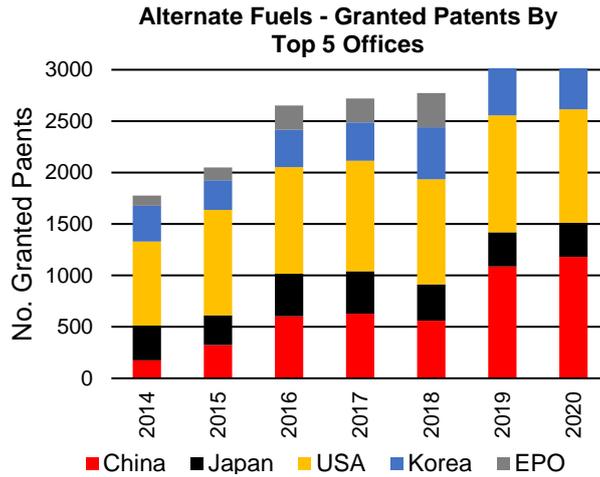
4.3.6. Published fuel cell patent applications vs. published alternative fuel patent applications at the Top 5 Patent Offices for 2014 to 2020.

The number of alternate fuel cell patent applications being published in each of the top 5 offices appears to reflect the same trend observed with the publication of fuel cell patent applications. Most notably, the data shows a significant increase in the number of alternative fuel patent applications published at the Chinese office. In comparison to the Chinese office, the trend at the remaining 4 major patent offices, although showing fluctuations, remain relatively stable in terms of publication numbers.

4.3.2. Granted Alternative Fuel Patents

The number of alternative fuel cell patents granted annually, in the top 5 offices, has remained in excess of 1700 since 2014. The data shows a marked increase in the number of granted alternative fuel patents between 2014 and 2016 which is then followed by a period of stability before a further between 2018 and 2019. The USPTO remains the single most important territory for granting alternate fuel patents. Businesses wishing to commercialise their alternate fuel technology world-wide must continue to consider their patent position in the USA.

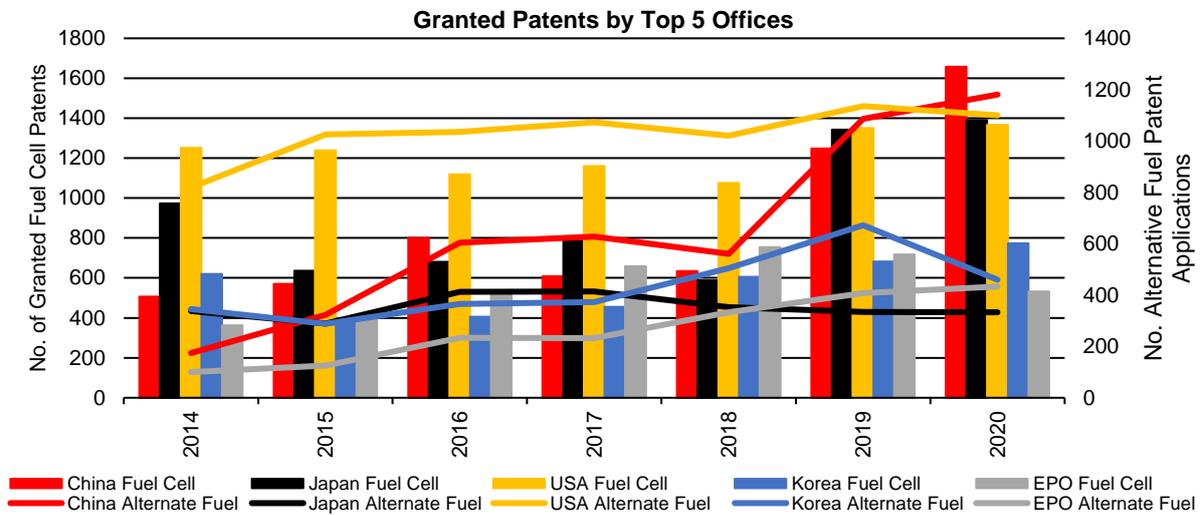
Figure 4.3.7 shows the annual number of granted alternative fuel patents for the top 5 offices.



4.3.7. Granted alternate fuel patents for the Top 5 Patent Offices for 2014 to 2020.

With the exception of Japan, each of the top 5 offices has observed an increased marginal growth in the number of granted alternate fuel patents between 2014 and 2020, with those of the Chinese office and the EPO being the most significant (579% and 333% respectively). However, it is the USPTO that remains by far the most significant authority for granting patents in the area of alternative fuels.

Figure 4.3.8 shows a comparison between the annual number of granted alternative fuel patents and the number of granted fuel cell patents for the top 5 offices. The trend in the number of granted alternative fuel patents appear to mirror those of the granted fuel cell patents.



4.3.8. Granted fuel cell patents vs. granted alternative fuel patents at the Top 5 Patent Offices for 2014 to 2020.

5. Conclusions

Fuel cells offer an interesting prospect in times where there is drive towards use of climate friendly energy technologies. When assessing the state of the industry it is important to consider many of the contributing factors. This report looks at trends in patent activity for businesses and research and academic organisations.

It is clear that there are many companies currently manufacturing and distributing fuel cells. Our report focuses on world's largest patent offices which account for approximately 75% of global patent filings. Of the major businesses involved in filing patent applications in the fuel cell space the leaders in terms of numbers appear to be based in Asia, more specifically, in Japan and South Korea and are dominated by the large automotive companies.

China appears to be by far the most dominant country for academic filings of fuel cell patents.

From the patent analysis, it appears that patent activity within the sector of fuel cells is in flux. The number of fuel cell patent applications published annually around the world has remained in excess of 11,000 since 2014 and the overall trajectory appears to be increasing.

The USPTO and the Chinese patent office remain the most important territories for publishing fuel cell patents.

Whilst the absolute number of applications is robust, the mix of those patent applications appears to be changing with decreasing amounts of patent applications being filed for inventions which are categorised in specific fuel cell types.

Fuel cells for vehicles remain one of the most high-profile applications of fuel cells, with a large majority of the top ranked companies coming from the automotive sector.

Within the hydrogen sector the number of hydrogen production patent applications are greater than those of both hydrogen storage and hydrogen distribution. This indicates that research and innovation in this area is continuing to develop, albeit at a slower rate than heretofore.

Within the comparable technology sector of batteries, there is shown an overall increasing trajectory in terms of the total numbers of patent applications being filed and those being granted.

From this report it is clear that research and development in the global fuel cell industry is fairly stable, and if anything, increasing. Whilst the filing statistics are dominated by a few large players the patent filings are relatively diverse with many businesses actively filing patent applications.

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6. Contributors

6.1. About the Authors

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6.2. About HGF

HGF is a leading firm of Intellectual Property Specialists. HGF has its headquarters in the United Kingdom and has 22 offices throughout Europe.

HGF is one of the largest intellectual property firms in Europe with over 200 attorneys spanning patent, trade mark and IP solicitor disciplines.

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Chapter 5

2021 Patent Report Appendix

July 2021



Disclaimer

This is an appendix to the Fuel Cell and Hydrogen Deployment Patent Overview 2021. The data was gathered as part of the Fuel Cells and Hydrogen Observatory for the period up to 31 December 2020. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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This Appendix was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from <https://www.fchobservatory.eu/>

The Fuel Cells and Hydrogen Observatory has been prepared for the FCH 2 JU under a public procurement contract.

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1. Patent Analysis

1.1. Fuel Cell Patent Activity

1.1.1. Filing and Grant Statistics

Figure A1.1.1 shows the number of published fuel cell patent applications in comparison to the number of total published patent applications according to the geographical split amongst the top 5 patent offices.

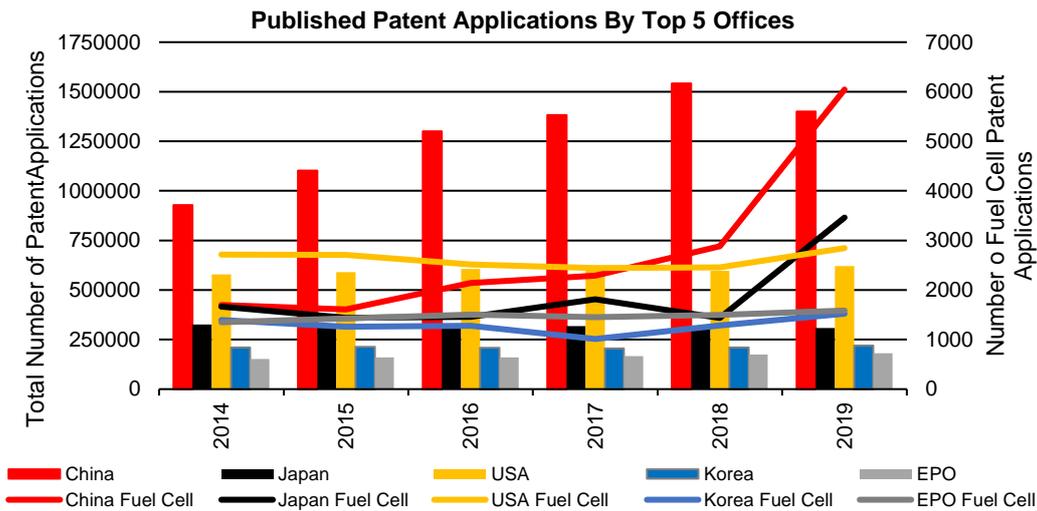


Figure A 1.1.1.1 Published fuel cell patent applications vs. total patent applications for 2014 to 2019 at Top 5 Patent Offices.

In terms of the relative rankings of the top 5 offices, the USPTO has the largest number of published fuel cell patent applications between 2014 and 2017, with China recording the greatest number of filings in 2018 and 2019. China are consistently the leading filer of overall patent applications over the period, with the number of filings increasing annually between 2014 and 2018.

Figures A1.1.2 and A1.1.3 show how the overall number of published fuel cell applications (Figure A1.1.2) and granted fuel cell patents (Figure A1.1.3), at the top 5 offices, is relatively constant year-on-year between 2014 and 2018. A significant incline is observed in the number of fuel cell patent applications published and fuel cell patents granted between 2018 and 2019, with filings in China and Japan recording the biggest increases.

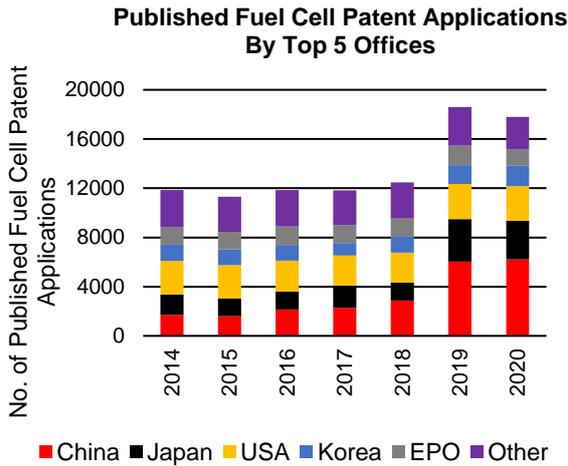


Figure A1.1.2. Annual publications of fuel cell patent applications for 2014 to 2020.

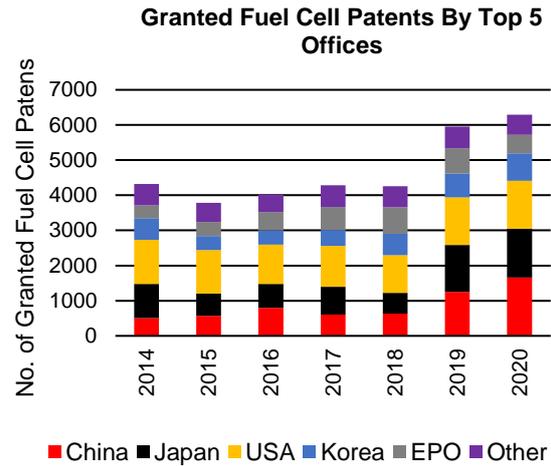


Figure A1.1.3. Annual publications of granted fuel cell for 2014 to 2020.

1.1.2. Assignee Data

The data presented below shows the top 10 filers of patent applications (Figures A1.1.4 to A1.1.10) and granted patents (Figures A1.1.11 to A1.1.18) in the area of fuel cells recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

The top 10 filers for both the published fuel cell applications and the granted fuel cell patents predominantly comprise the same entities. The top 10 lists are dominated by large Japanese corporations, with Toyota steadily in the leading position, with second place typically being taken by Hyundai or Nissan. This demonstrates that south east Asian automotive businesses are consistently leading the way in patent filings and, it would be imagined, in fuel cell R&D activity.

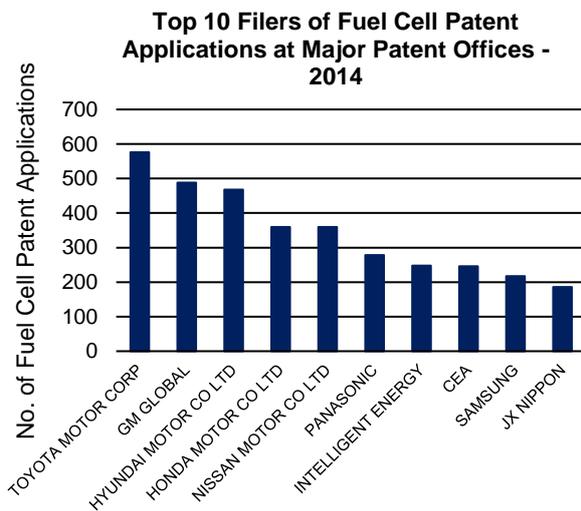


Figure A1.1.4. Top ten filers of fuel cell patent applications at the Top 5 Patent Offices for 2014.

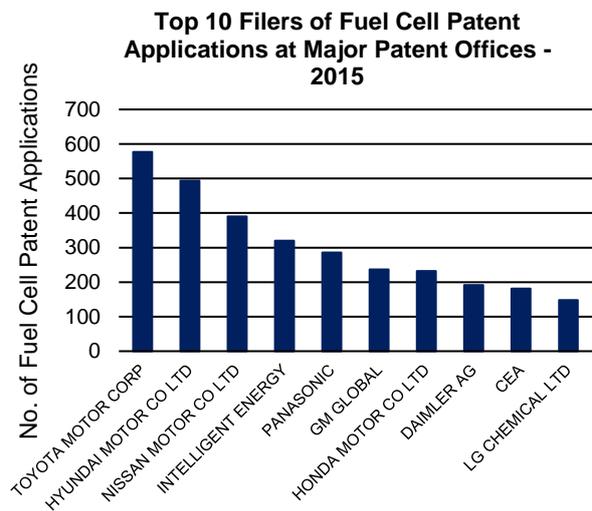


Figure A1.1.5. Top 10 filers of fuel cell patent applications at the Top 5 Offices for 2015.

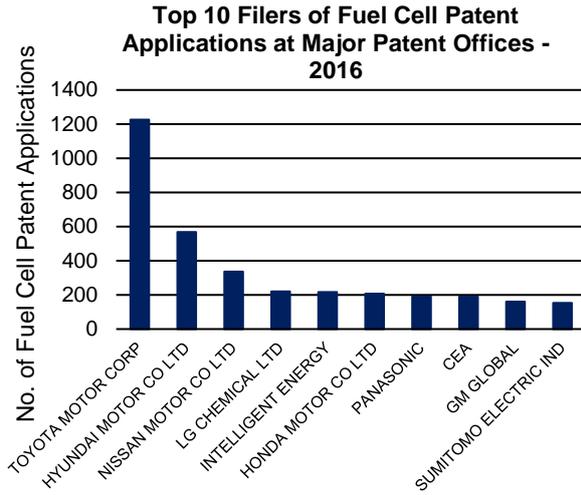


Figure A1.1.6. Top ten filers of fuel cell patent applications at the Top 5 Patent Offices for 2016.

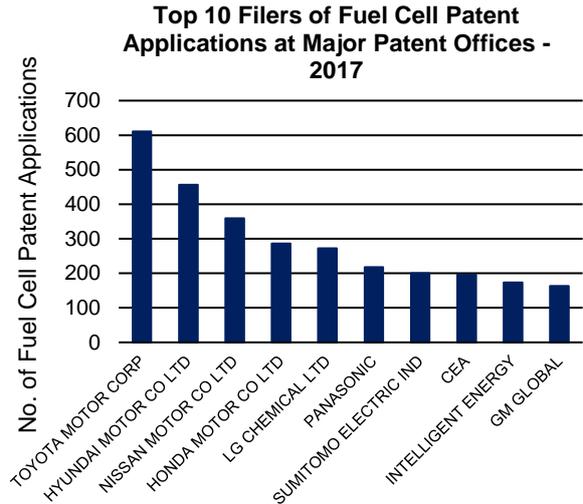


Figure A1.1.7. Top 10 filers of fuel cell patent applications at the Top 5 Offices for 2017.

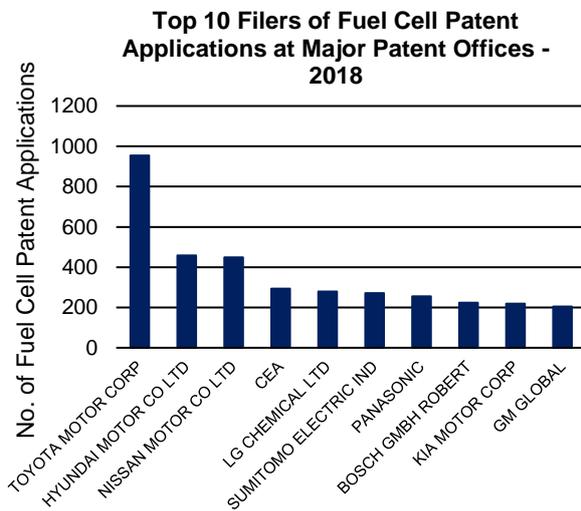


Figure A1.1.8. Top ten filers of fuel cell patent applications at the Top 5 Patent Offices for 2018.

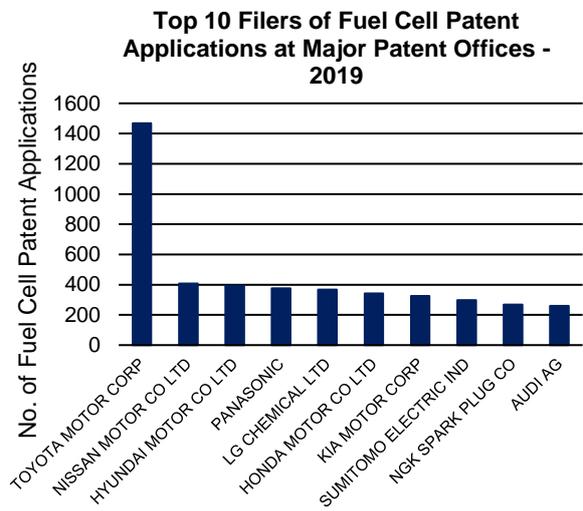


Figure A1.1.9. Top 10 filers of fuel cell patent applications at the Top 5 Offices for 2019.

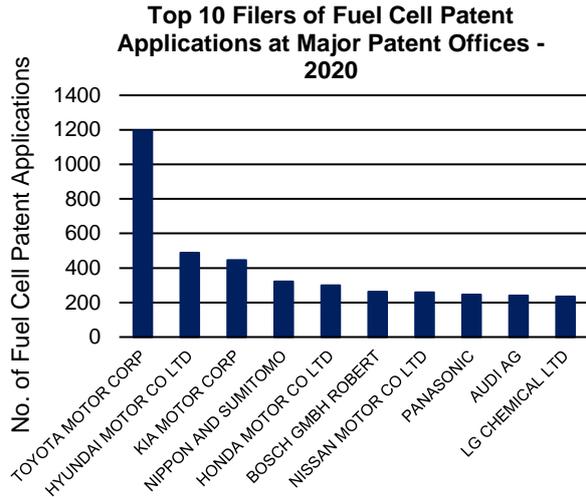


Figure A1.1.10. Top ten filers of fuel cell patent applications at the Top 5 Patent Offices for 2020.

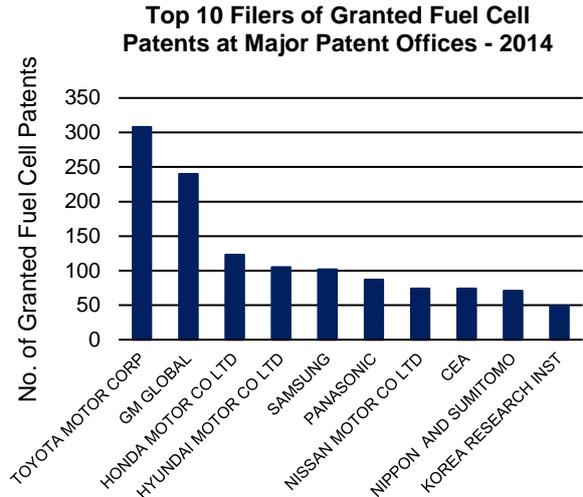


Figure 1.1.12. Top ten filers of granted fuel cell patents at the Top 5 Offices for 2014.

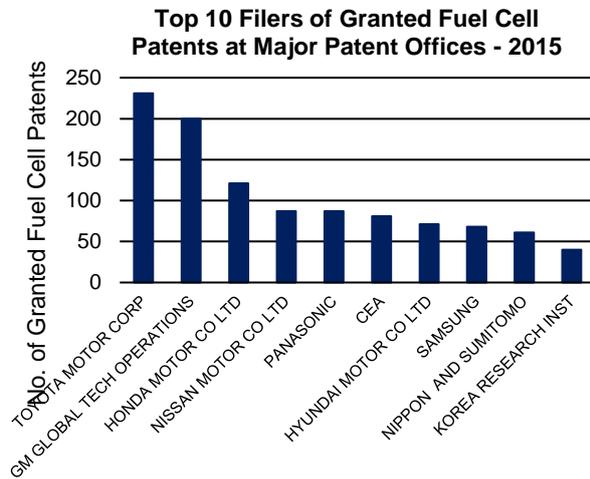


Figure A1.1.13. Top ten filers of granted fuel cell patents at the Top 5 Patent Offices for 2015.

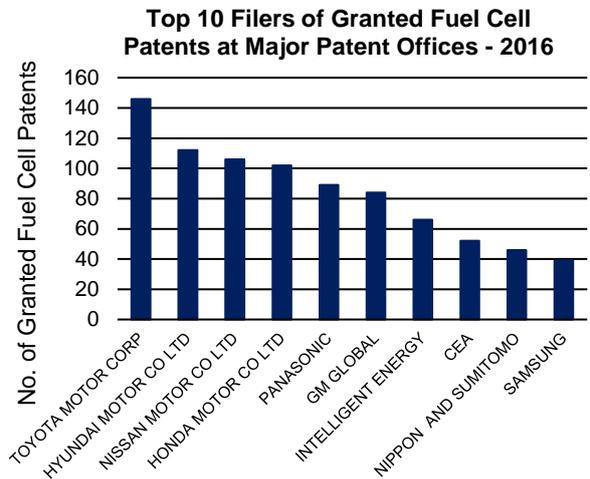


Figure A1.1.14. Top 10 filers of granted fuel cell patents at the Top 5 Offices for 2016.

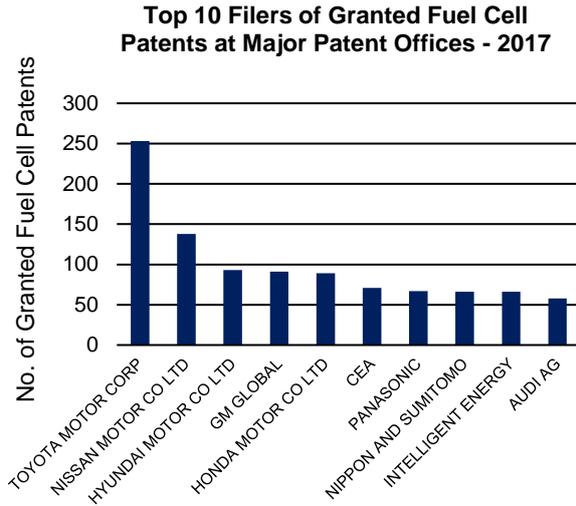


Figure A1.1.15. Top ten filers of granted fuel cell patents at the Top 5 Patent Offices for 2017.

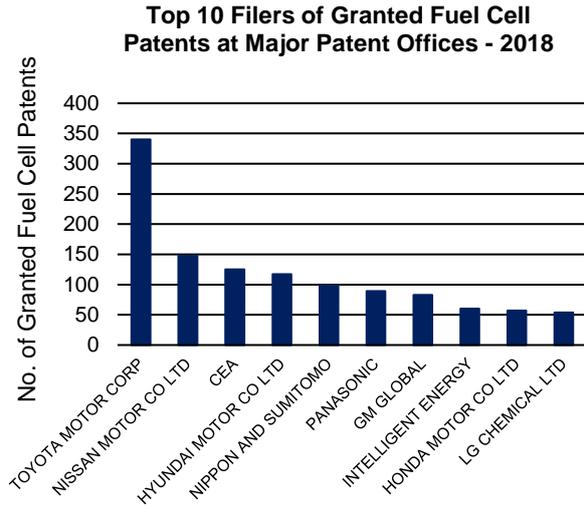


Figure A1.1.16. Top 10 filers of granted fuel cell patents at the Top 5 Offices for 2018.

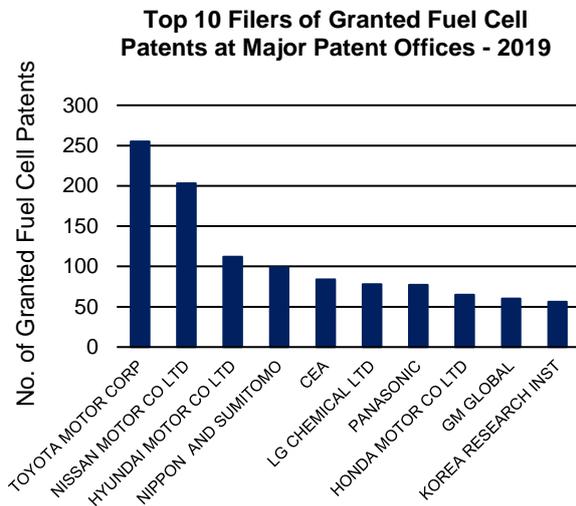


Figure A1.1.17. Top ten filers of granted fuel cell patents at the Top 5 Patent Offices for 2019.

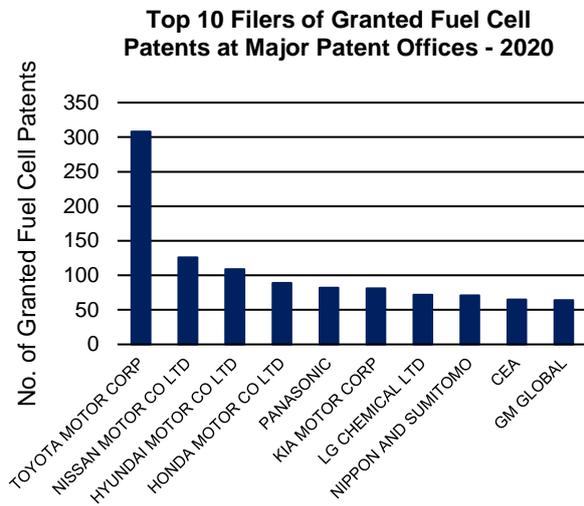


Figure A1.1.18. Top 10 filers of granted fuel cell patents at the Top 5 Offices for 2020.

Automotive companies dominate the filing statistics, followed by electronics companies. Intelligent Energy is the only dedicated fuel cell business featured amongst the top ten patentees

The trend in statistics relating to the number of granted fuel cell patents of the top 10 filers largely reflects that of the published patent applications. Unsurprisingly, given the filing statistics, Toyota, Nissan, Hyundai, GM, Panasonic, CEA and Honda feature in the top 10 patentees annually.

1.1.3. Academic Patent Filers

The data presented below shows the top 10 university filers of patent applications (Figures A1.1.19 to A1.1.25) and granted patents (Figures A1.1.26 to A1.1.32) in the area of fuel cells recorded annually from 2014 to 2020 at the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

The top 10 academic filers are dominated by Chinese and Japanese universities. The National University of Tsinghua features in the top two university filers annually from 2014 to 2020.

Whilst fluctuations in the numbers of granted fuel cell patents are observed, the National University of Tsinghua remains a prominent entity, featuring in the top four university filers of granted fuel cell patents annually, except for 2019 when it featured in the top 9 university filers.

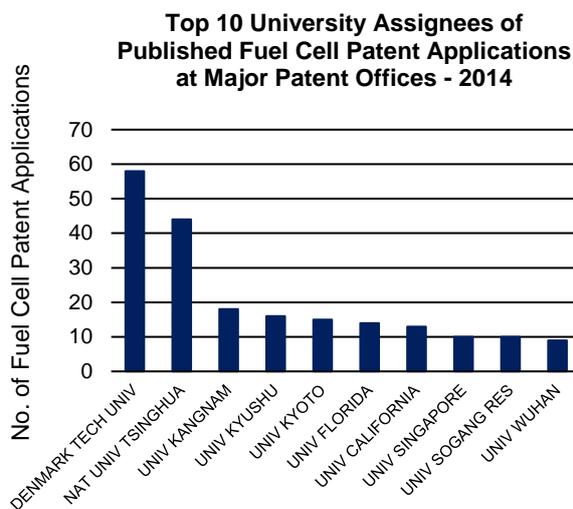


Figure A1.1.19. Top ten university filers of fuel cell patent applications at the Top 5 Patent Offices for 2014.

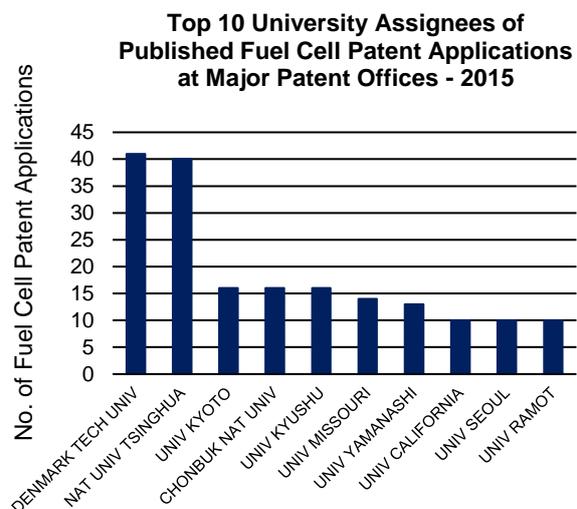


Figure A1.1.20. Top 10 university filers of fuel cell patent applications at the Top 5 Offices for 2015.

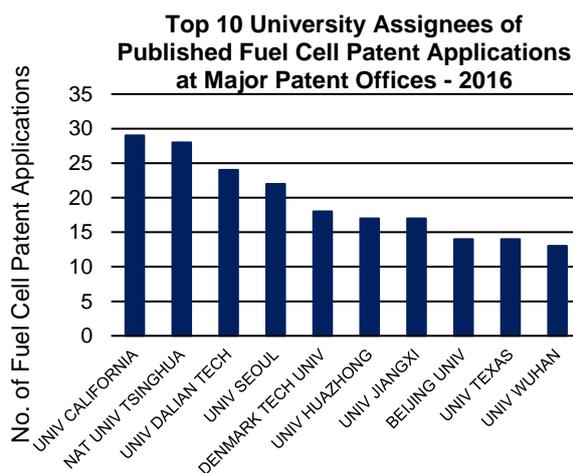


Figure A1.1.21. Top ten university filers of fuel cell patent applications at the Top 5 Patent Offices for 2016.

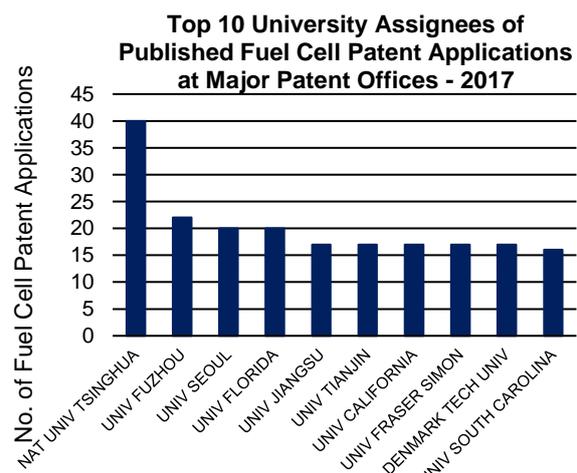


Figure A1.1.22. Top 10 university filers of fuel cell patent applications at the Top 5 Offices for 2017.

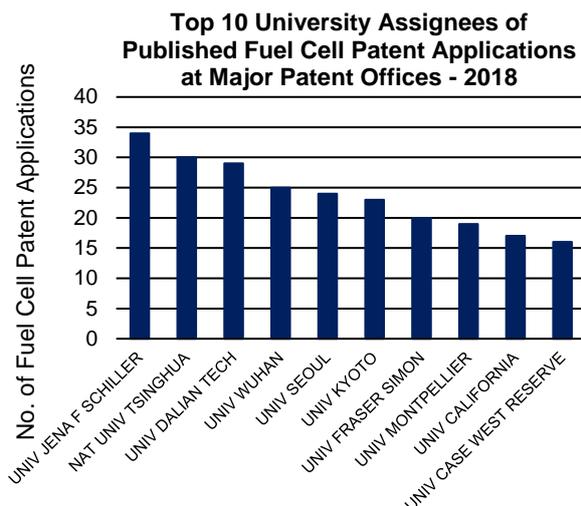


Figure A1.1.23. Top ten university filers of fuel cell patent applications at the Top 5 Patent Offices for 2018.

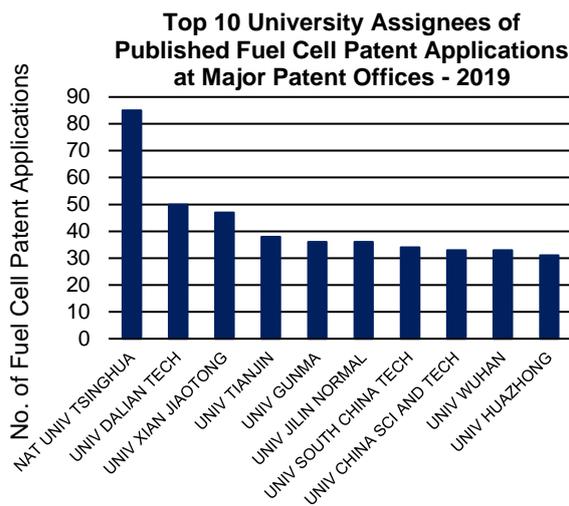


Figure A1.1.24. Top 10 university filers of fuel cell patent applications at the Top 5 Offices for 2019.

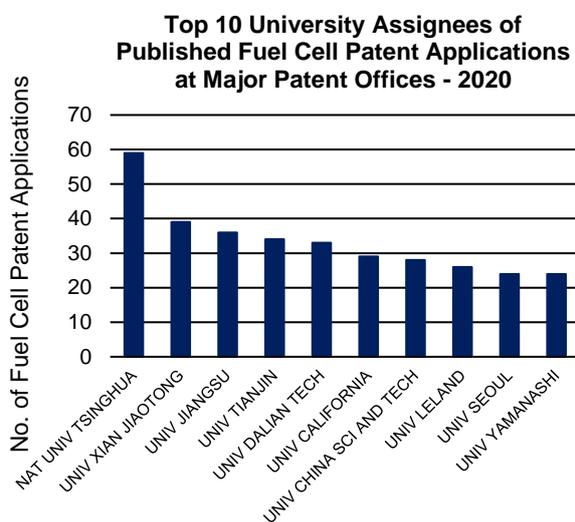


Figure A1.1.25. Top ten university filers of fuel cell patent applications at the Top 5 Patent Offices for 2020.

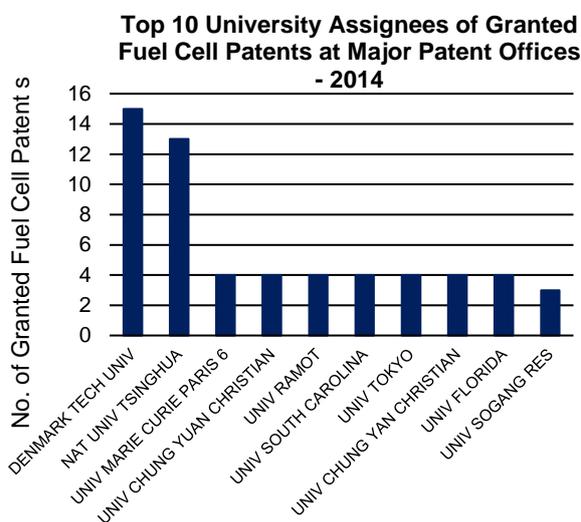


Figure A1.1.26. Top 10 university filers of granted fuel cell patents at the Top 5 Offices for 2014.

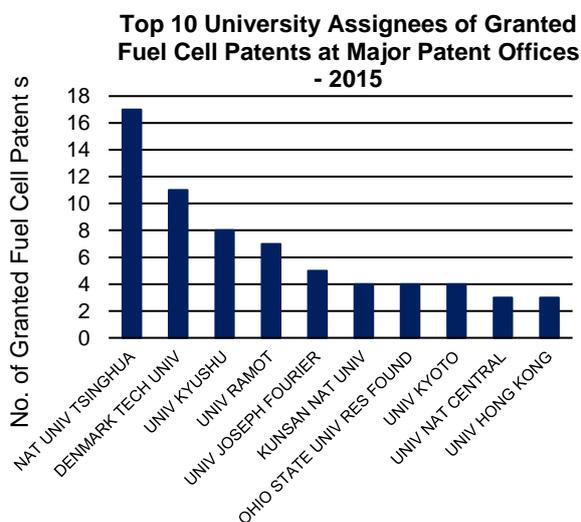


Figure A1.1.27. Top ten university filers of granted fuel cell patents at the Top 5 Patent Offices for 2015.

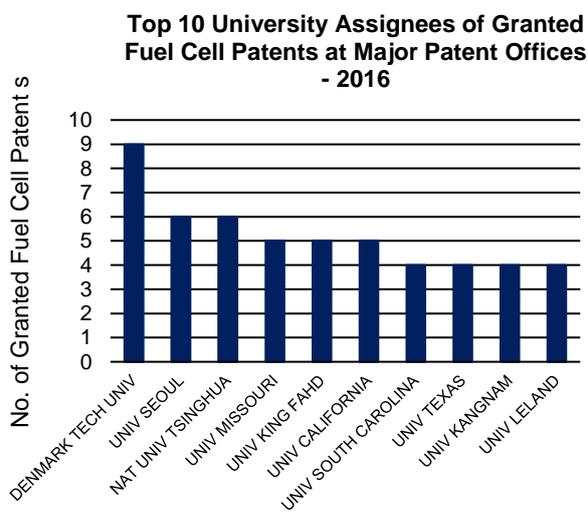


Figure A1.1.28. Top 10 university filers of granted fuel cell patents at the Top 5 Offices for 2016.

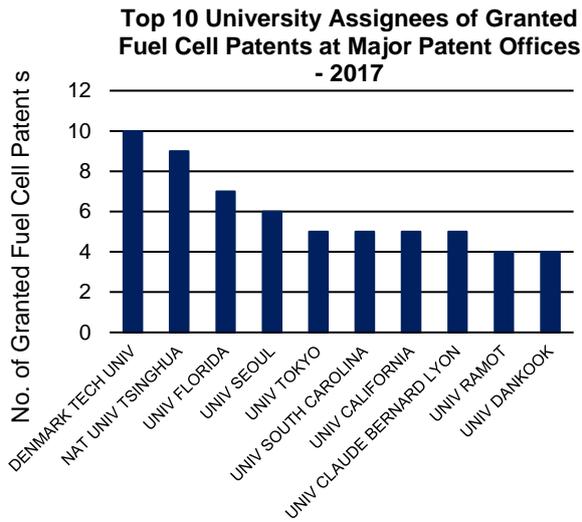


Figure A1.1.29. Top ten university filers of granted fuel cell patents at the Top 5 Patent Offices for 2017.

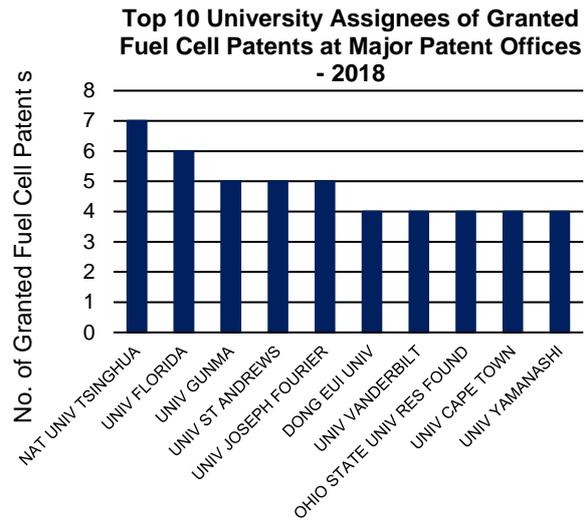


Figure A1.1.30. Top 10 university filers of granted fuel cell patents at the Top 5 Offices for 2018.

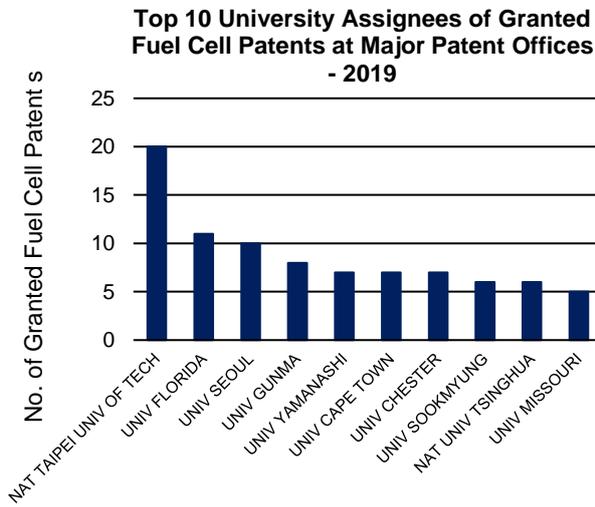


Figure A1.1.31. Top ten university filers of granted fuel cell patents at the Top 5 Patent Offices for 2019.

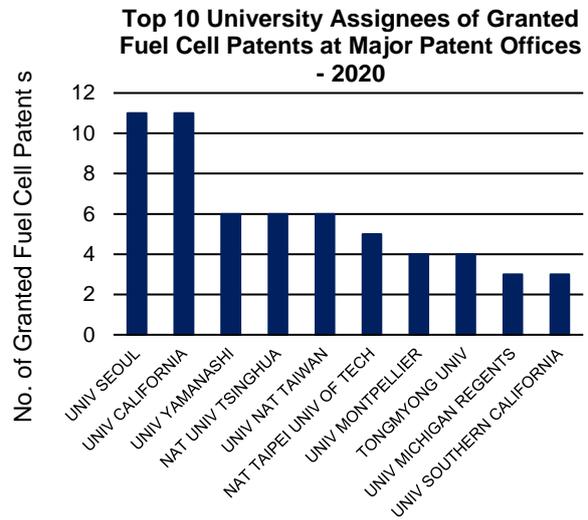


Figure A1.1.32. Top 10 university filers of granted fuel cell patents at the Top 5 Offices for 2020.

1.2. Fuel Cell Chemistry

The data presented below shows the top 10 filers of patent applications for each of the individual fuel cell chemistries, for the years 2014 to 2019, for each of the top 5 patent offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

1.2.1. Direct Alcohol Fuel Cells

Figures 1.2.1 to 1.2.7 show the top 10 assignees of direct alcohol fuel cell (DAFC) patent applications, e.g. direct methanol fuel cells (DMFCs), for the top 5 offices.

The top filers appear to vary over the period.

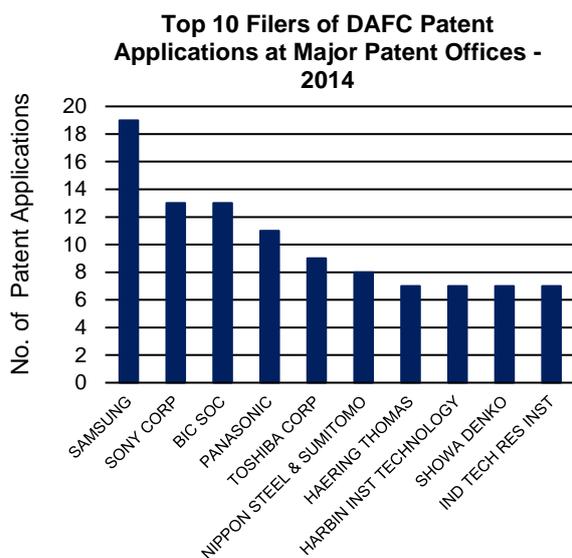


Figure A1.2.1. Top ten filers of DAFC patent applications at the Top 5 Patent Offices for 2014.

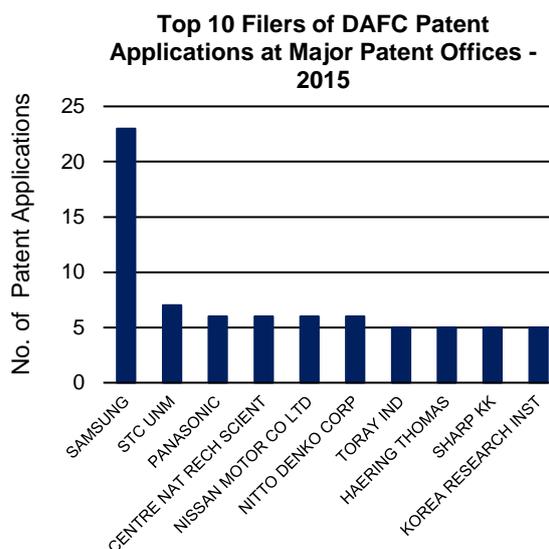


Figure A1.2.2. Top 10 filers of DAFC patent applications at the Top 5 Offices for 2015.

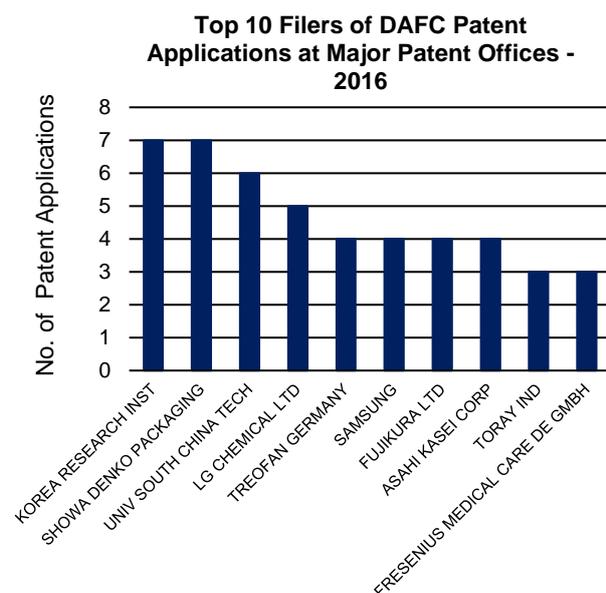


Figure A1.2.3. Top ten filers of DAFC patent applications at the Top 5 Patent Offices for 2016.

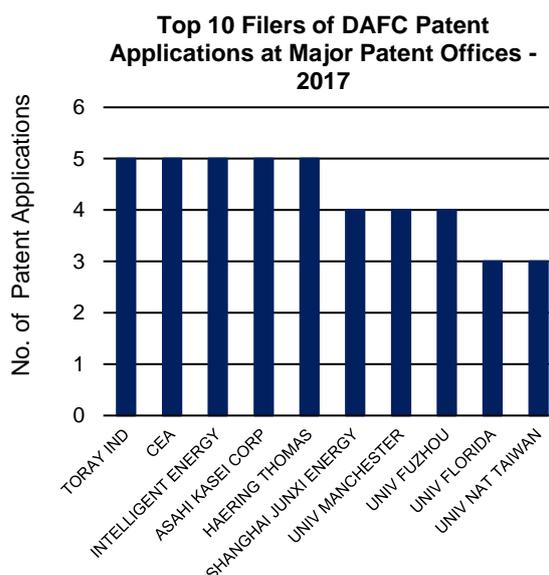


Figure A1.2.4. Top 10 filers of DAFC patent applications at the Top 5 Offices for 2017.

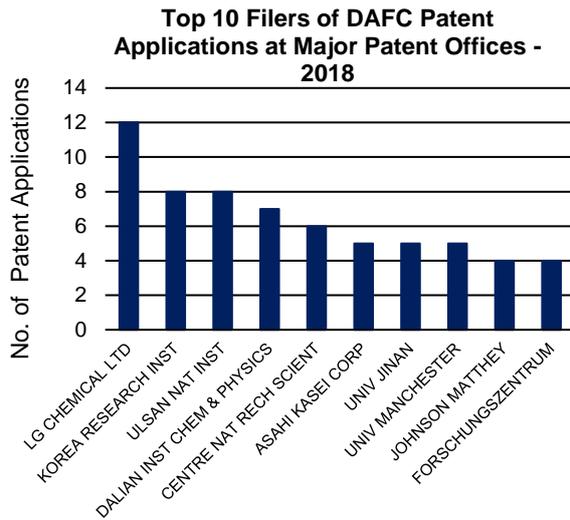


Figure A1.2.5. Top ten filers of DAFC patent applications at the Top 5 Patent Offices for 2018.

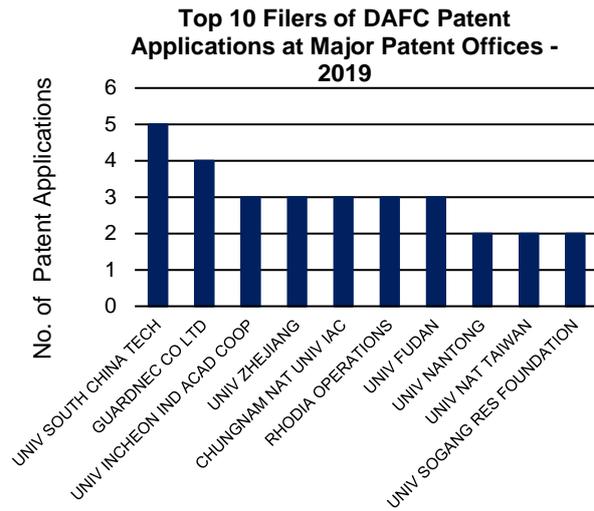


Figure A1.2.6. Top 10 filers of DAFC patent applications at the Top 5 Offices for 2019.

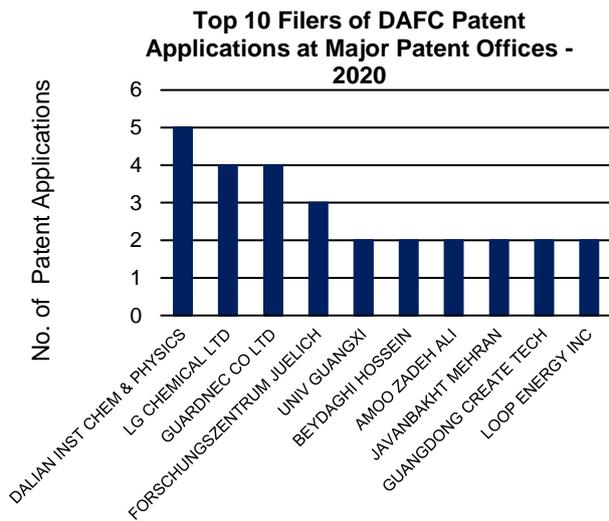


Figure A1.2.7. Top ten filers of DAFC patent applications at the Top 5 Patent Offices for 2020.

Figure 1.2.8 provides a technical comparison between patents filed for DAFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure 1.2.8 shows that the technical fields in which DAFC patent applications are related has altered over time. For both periods (2005 to 2009 and 2014 to 2019) the electrical engineering aspects dominate but over time chemical aspects such as surface technology and macromolecular chemistry appear to become relatively more important.

The major blue bar in each case represents ‘Electrical apparatus, machinery and energy’ and the minor purple bars represent ‘Chemical Engineering’ and ‘Macromolecular Chemistry’. The major green bar is ‘Mechanical Engineering’ in both cases. Overall the technological map indicates that in the period 2014-19 research in this space continues along similar lines, compared with 2005-09, with perhaps a minor shift towards chemical research.

It should be noted that the size of the dataset for each respective period is not the same (2014/19< 2005/09) and so this graph provides information about relative changes between the periods.

Technological Breakdown for DAFC Patent Applications 2005 – 2009



Technological Breakdown for DAFC Patent Applications 2014 - 2019



Figure A1.2.8. Technological breakdown for DAFC patent applications in comparison with 2005-2009 (PI).

Figure 1.2.9 provides data to show how applicant location has varied over a ten-year window. The data shows a concentration of research activity in USA, Europe (France, Germany, UK) and China with continued activity in Japan. It also shows the emergence of China, and to a lesser degree France, Germany and UK, as important locations for patent applicants.

Applicant location for worldwide DAFC patent applications 2005 – 2009



Applicant location for worldwide DAFC patent applications 2014 – 2019

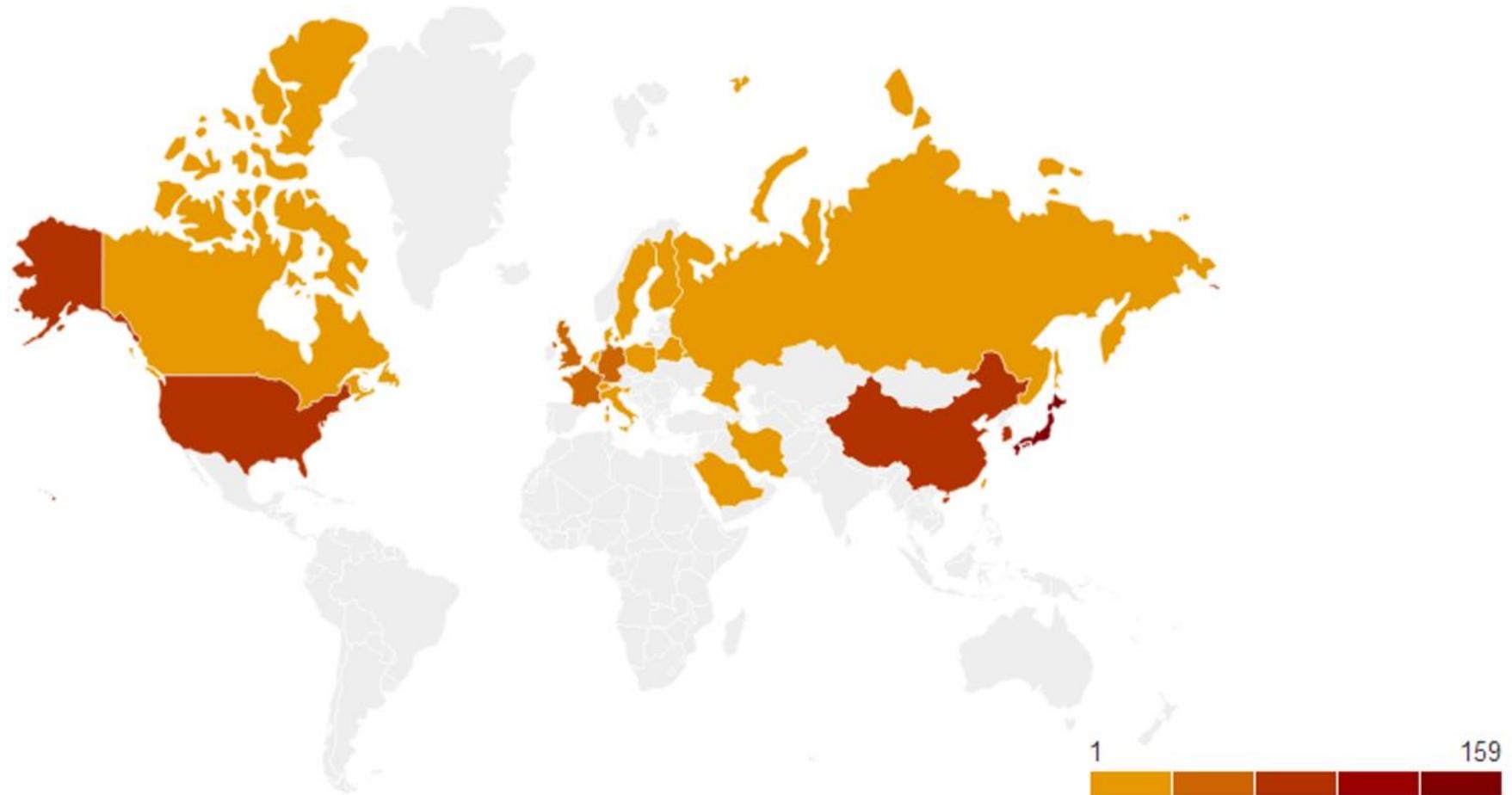


Figure A1.2.9. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.2.2. Molten Carbonate Fuel Cells

Figures 1.2.10 to 1.2.16 show the top 10 assignees of molten carbonate fuel cell (MCFC) patent applications, for the top 5 offices.

Exxon Mobil are the leading filer of MCFC patent applications, featuring in the top two annually from 2014 to 2020.

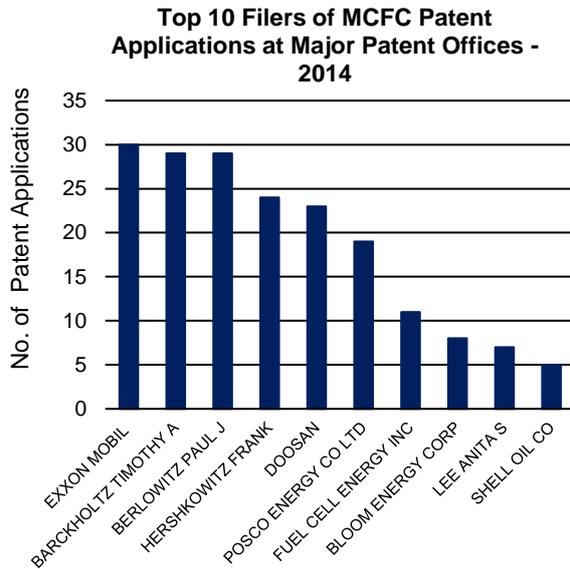


Figure A1.2.10. Top ten filers of MCFC patent applications at the Top 5 Patent Offices for 2014.

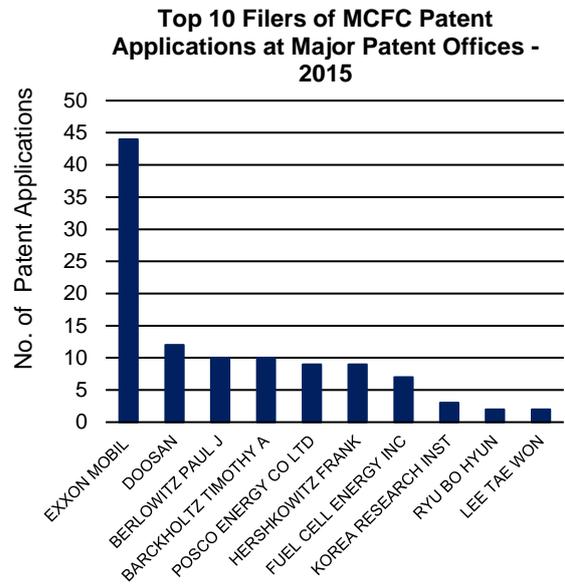


Figure A1.2.11. Top 10 filers of MCFC patent applications at the Top 5 Offices for 2015.

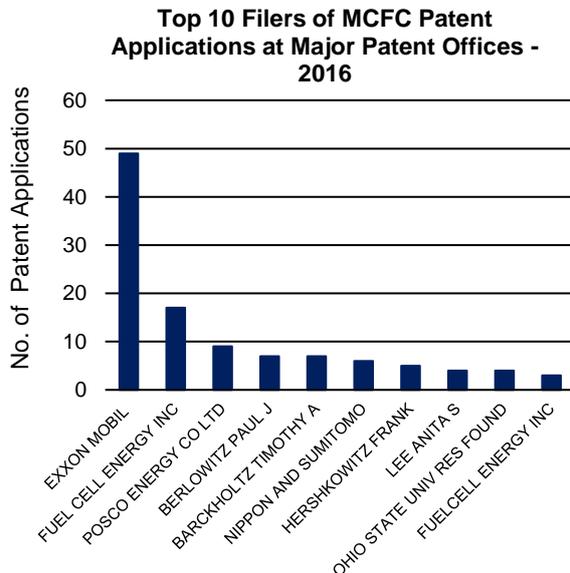


Figure A1.2.12. Top ten filers of MCFC patent applications at the Top 5 Patent Offices for 2016.

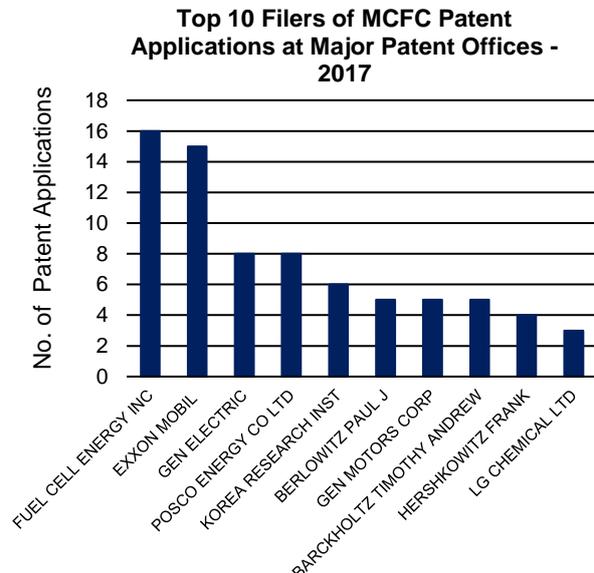


Figure A1.2.13. Top 10 filers of MCFC patent applications at the Top 5 Offices for 2017.

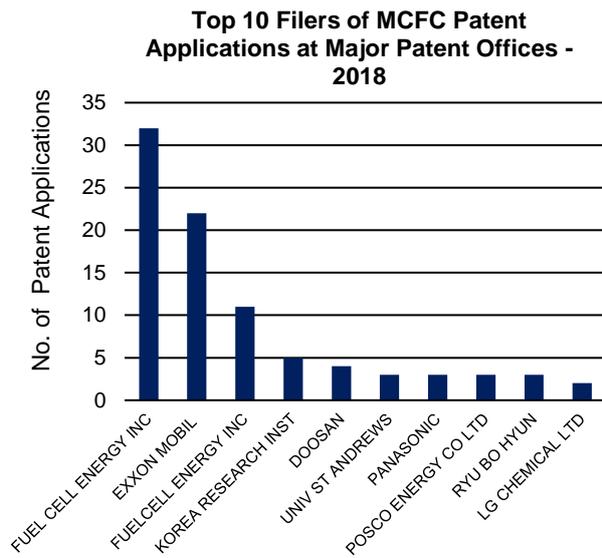


Figure A1.2.14. Top ten filers of MCFC patent applications at the Top 5 Patent Offices for 2018.

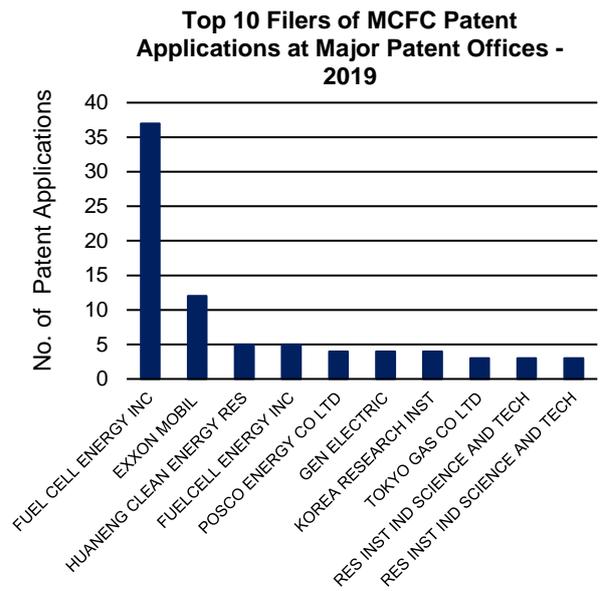


Figure A1.2.15. Top 10 filers of MCFC patent applications at the Top 5 Offices for 2019.

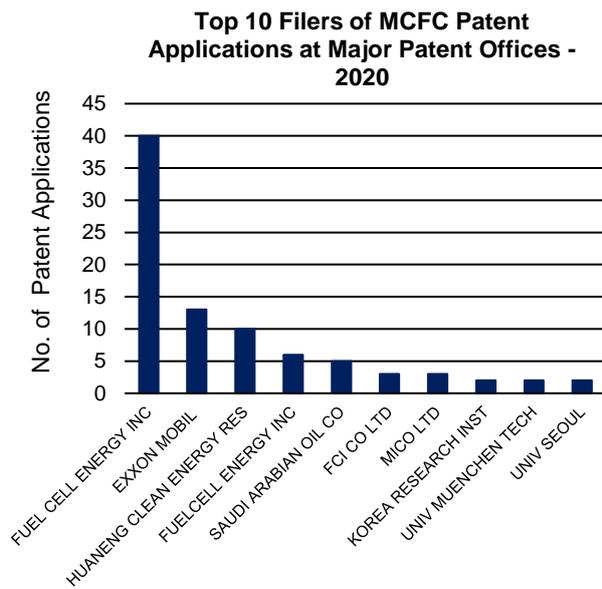


Figure A1.2.16. Top ten filers of MCFC patent applications at the Top 5 Patent Offices for 2020.

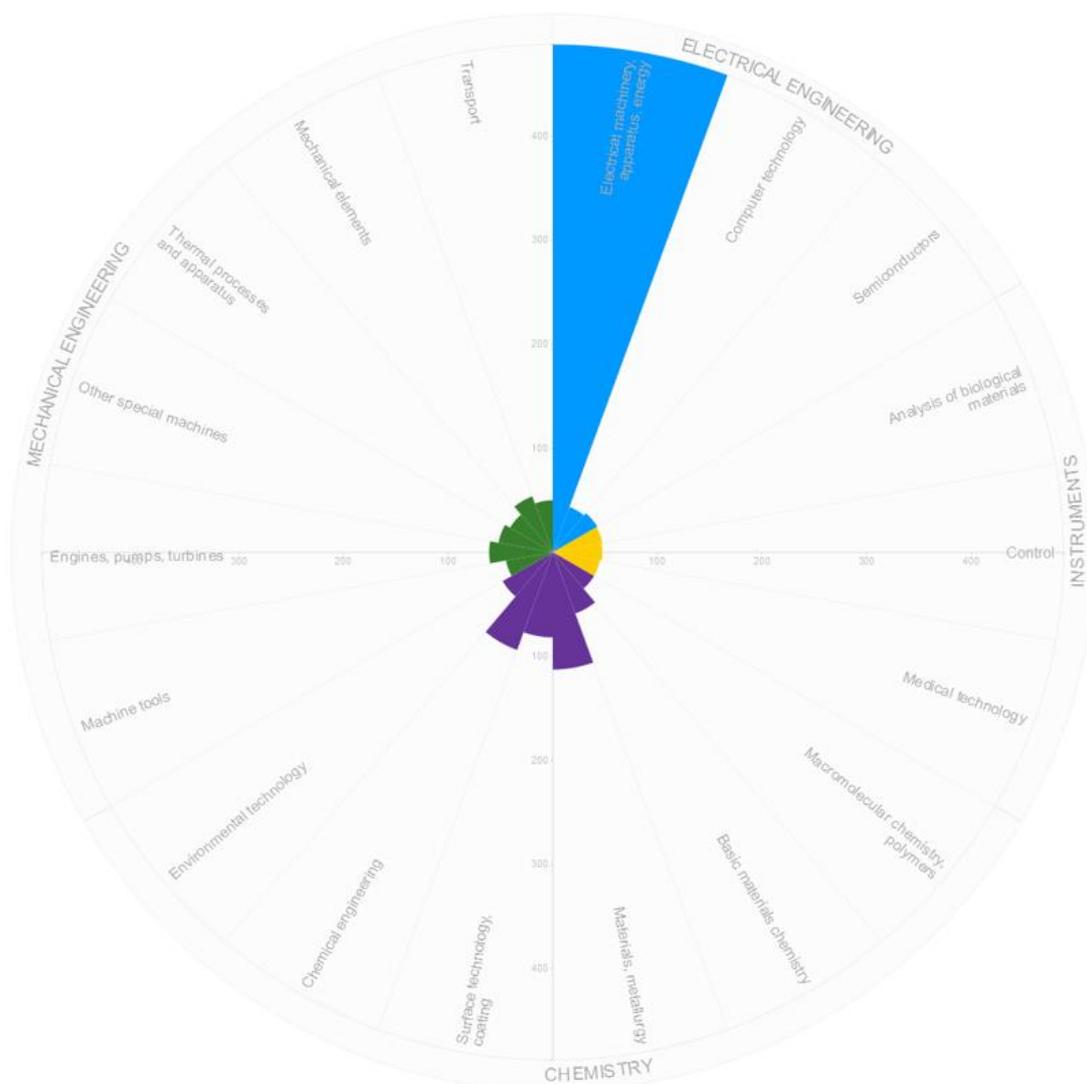
Figure A1.2.17 provides a technical comparison between patents filed for MCFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.2.17 shows that materials are becoming less of a relative focus from the first period to the second.

The major blue bar in each case represents 'Electrical apparatus, machinery and energy'. The data appears to show a significant increase in 'Materials, Metallurgy' (major purple bar) for the later period as compared to the earlier. Indeed, it appears as if more chemical research (purple bars is being conducted) during the later period. The major green bars in each case relate to 'Thermal Processes' and 'Pumps' is 'Mechanical Engineering' in both cases.

It should be noted that the size of the dataset for each respective period is broadly similar (2005/09>2014/19).

Technological Breakdown for MCFC Patent Applications 2005 – 2009



Technological Breakdown for MCFC Patent Applications 2014 – 2019



A1.2.17. Technological breakdown for MCFC patent applications in comparison with 2005-2009 (PI).

Figure A1.2.18 provides data to show how applicant location has varied over a ten-year window.

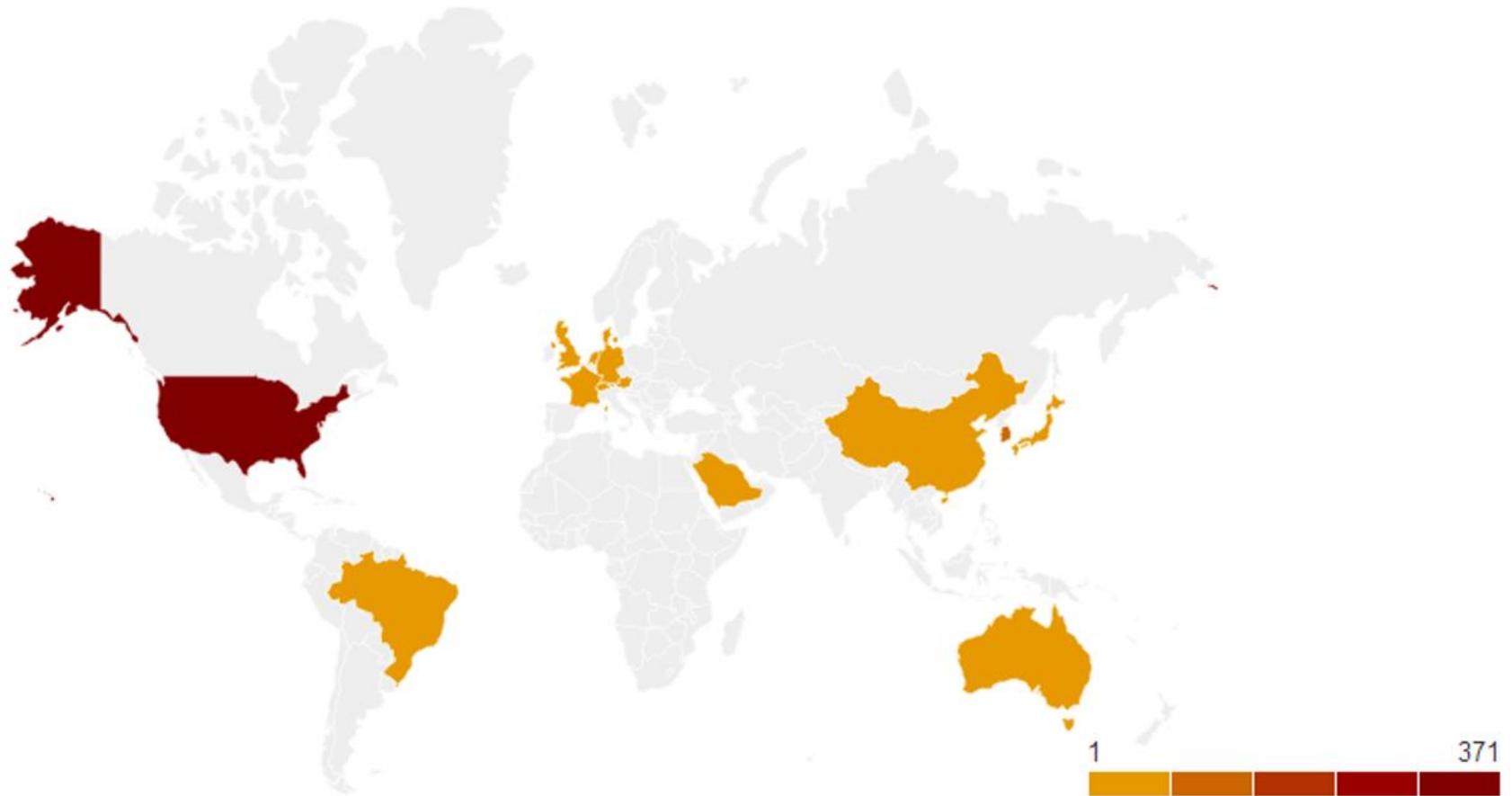
Figure A1.2.18 shows that the USA is becoming the dominant location for patent applicants in this space with countries in Europe, Australia and Brazil also maintaining their positions.

This shows a clear concentration in USA, Australia, Europe and China with Brazil also emerging.

Applicant location for worldwide MCFC patent applications 2005 – 2009



Applicant location for worldwide MCFC patent applications 2014 – 2019



A1.2.18. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.2.3. Alkaline Fuel Cells

Figures A1.2.19 to A1.2.15 show the top 10 assignees of alkaline fuel cell (AFC) patent applications, for the top 5 offices.

The top filers appear to vary over the period.

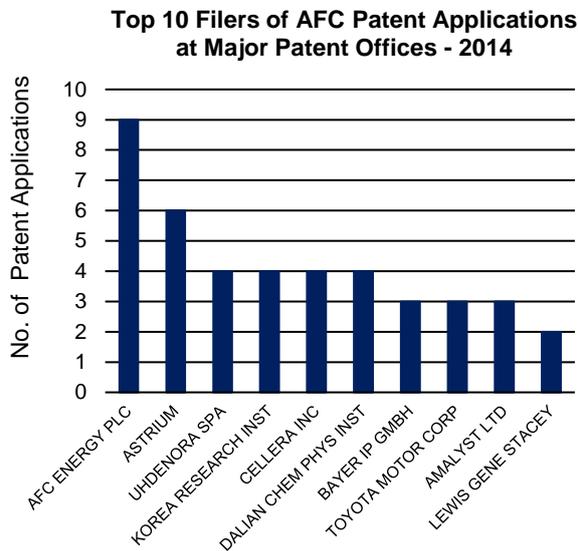


Figure A1.2.19. Top ten filers of AFC patent applications at the Top 5 Patent Offices for 2014.

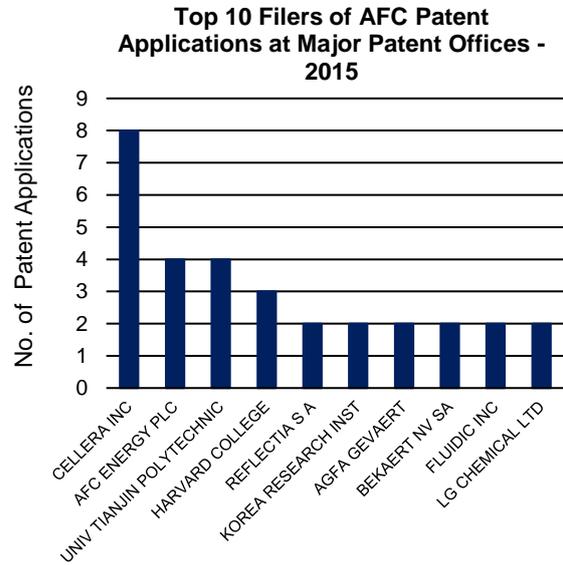


Figure A1.2.20. Top 10 filers of AFC patent applications at the Top 5 Offices for 2015.

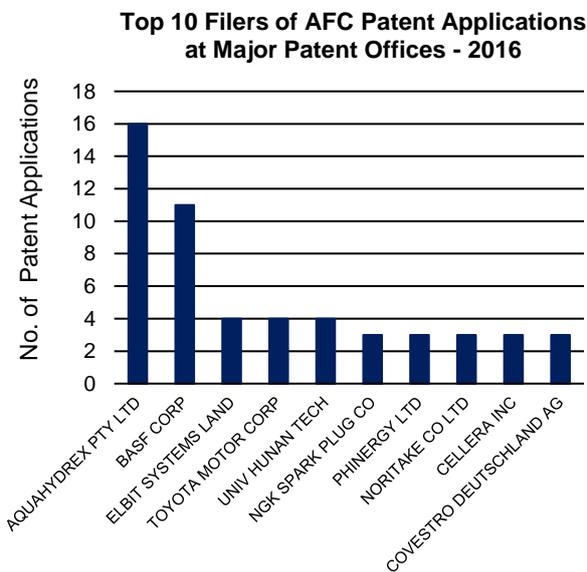


Figure A1.2.21. Top ten filers of AFC patent applications at the Top 5 Patent Offices for 2016.

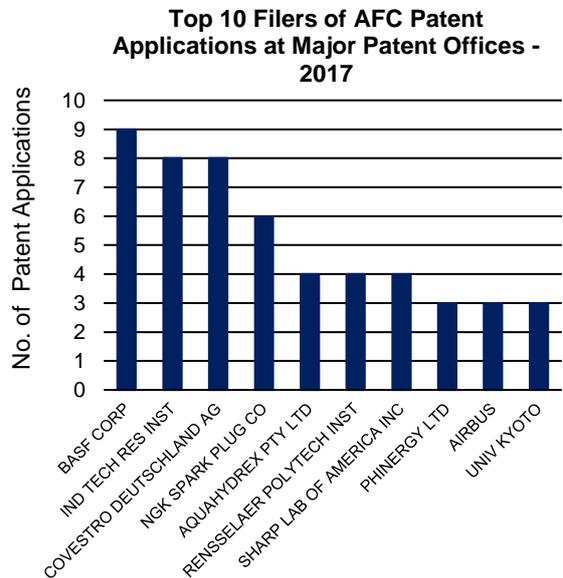


Figure A1.2.22. Top 10 filers of AFC patent applications at the Top 5 Offices for 2017.

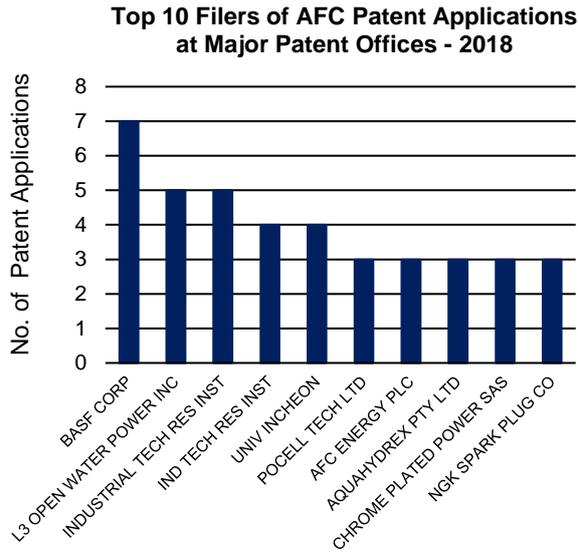


Figure A1.2.23. Top ten filers of AFC patent applications at the Top 5 Patent Offices for 2018.

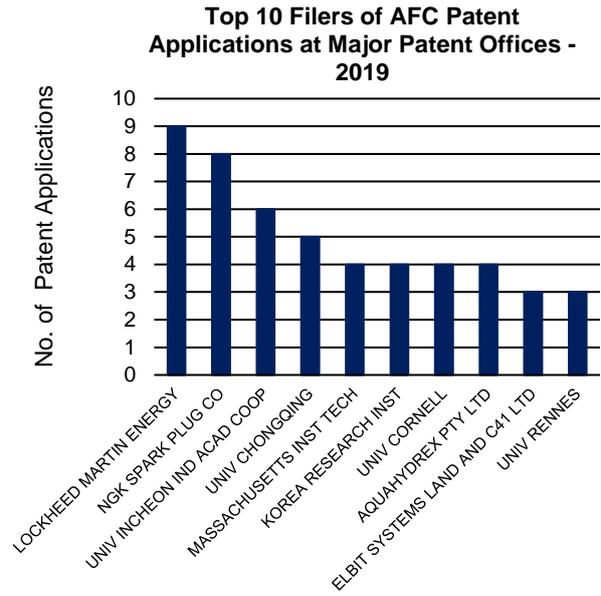


Figure A1.2.24. Top 10 filers of AFC patent applications at the Top 5 Offices for 2019.

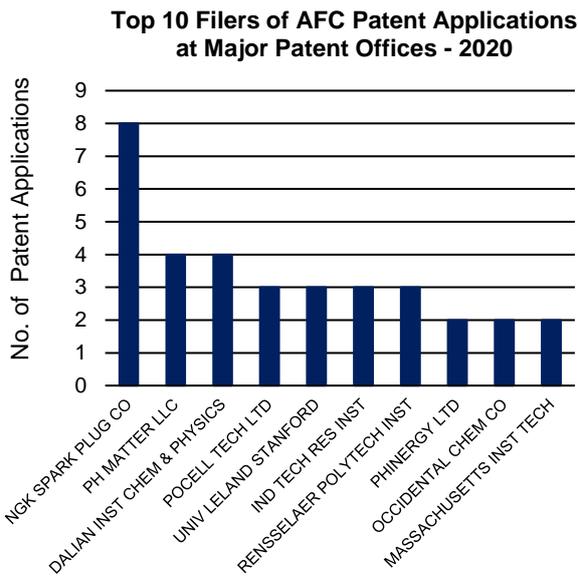


Figure A1.2.25. Top ten filers of AFC patent applications at the Top 5 Patent Offices for 2020.

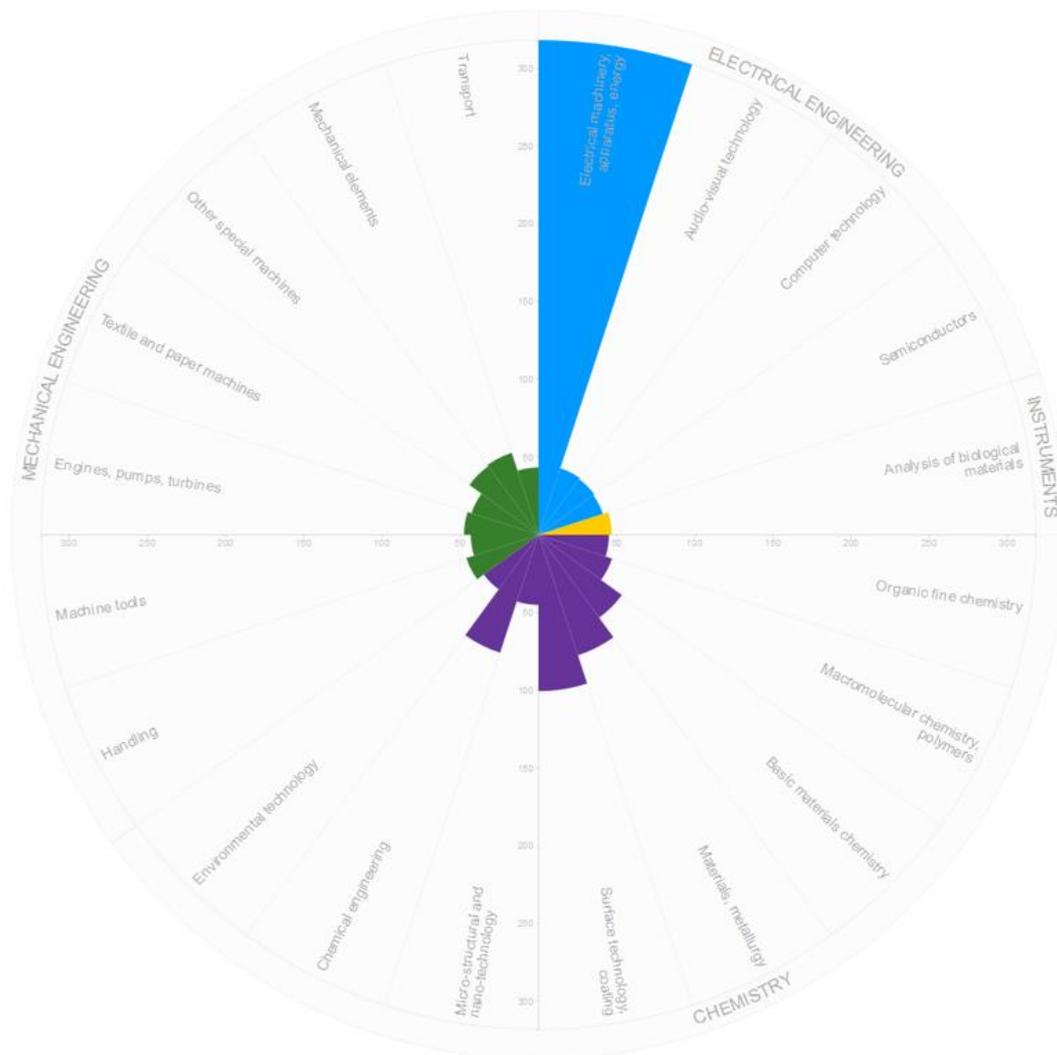
Figure A1.2.26 provides a technical comparison between patents filed for AFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.2.26 clearly shows that surface chemistry and coating technologies are becoming increasingly important in the period 2014/19.

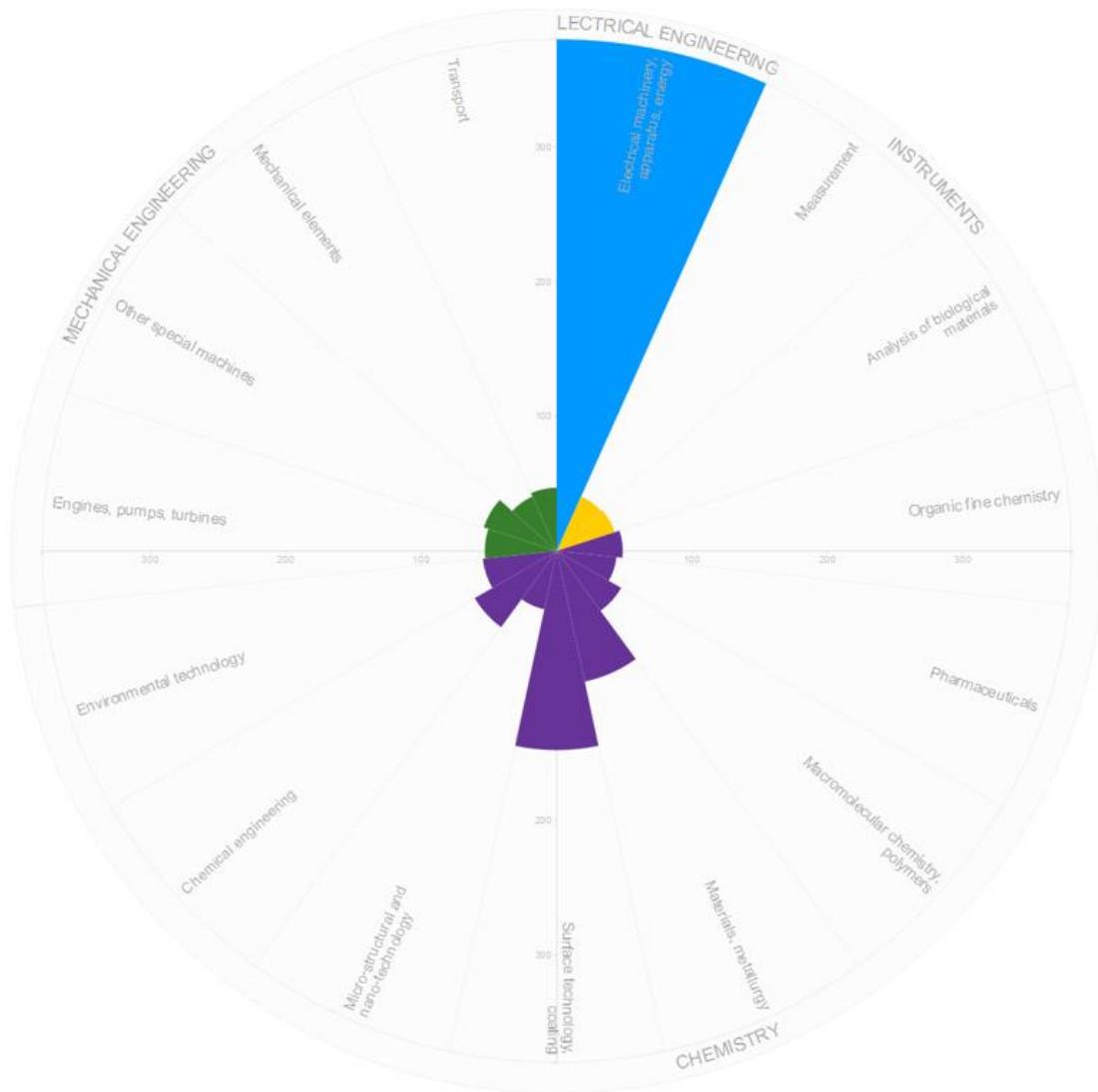
The overall technology picture in the later period is remarkably similar to that of the earlier period with the exception of surface chemistry technologies becoming more important relatively.

It should be noted that the size of the dataset for each respective period are similar (2014/19>2005/09).

Technological Breakdown for AFC Patent Applications 2005 – 2009



Technological Breakdown for AFC Patent Applications 2014 – 2019

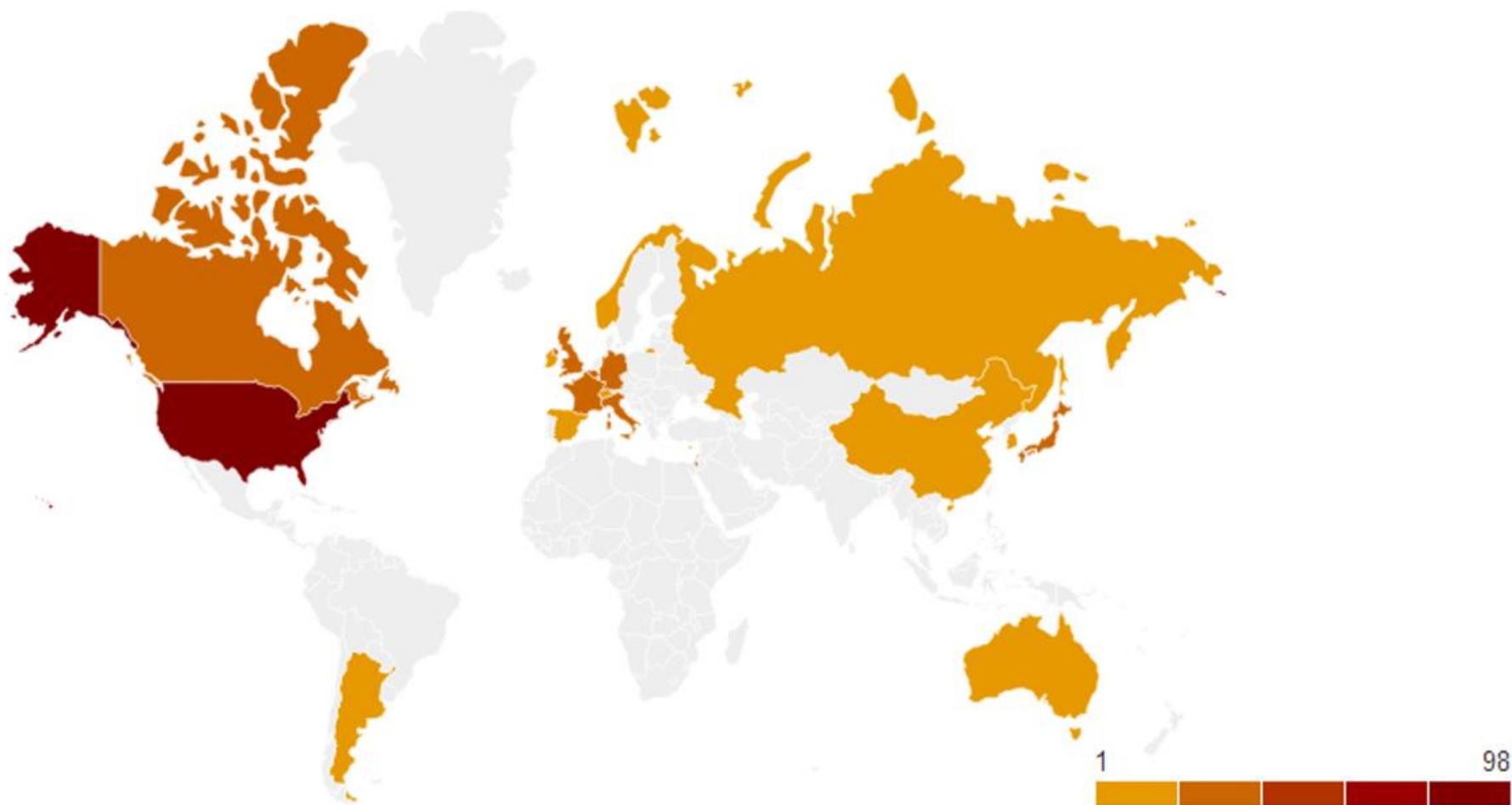


A1.2.26. Technological breakdown for AFC patent applications in comparison with 2005-2009 (PI).

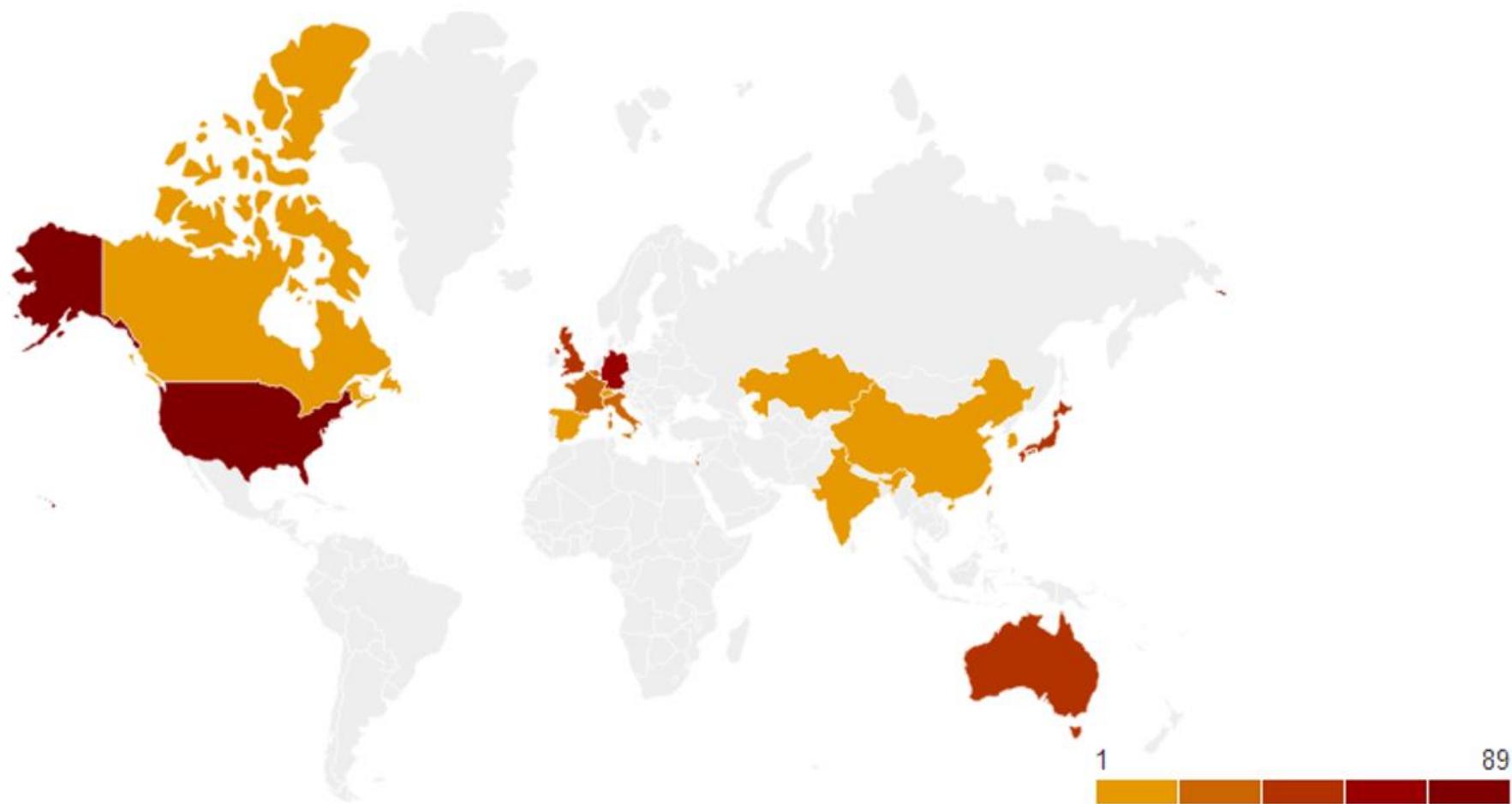
Figure A1.2.27 provides data to show how applicant location has varied over a ten-year window.

Figure A1.2.27 shows that applicants are increasingly found in fewer states with the USA maintaining its dominant position as the principal location for applicants.

Applicant location for worldwide AFC patent applications 2005 – 2009



Applicant location for worldwide AFC patent applications 2014 – 2019



A1.2.27. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.2.4. Phosphoric Acid Fuel Cells

Figures A1.2.28 to A1.2.34 show the top 10 assignees of phosphoric acid fuel cell (PAFC) patent applications, for the top 5 offices.

Doosan are consistently the top filers of PAFC patent applications annually between 2015 and 2020.

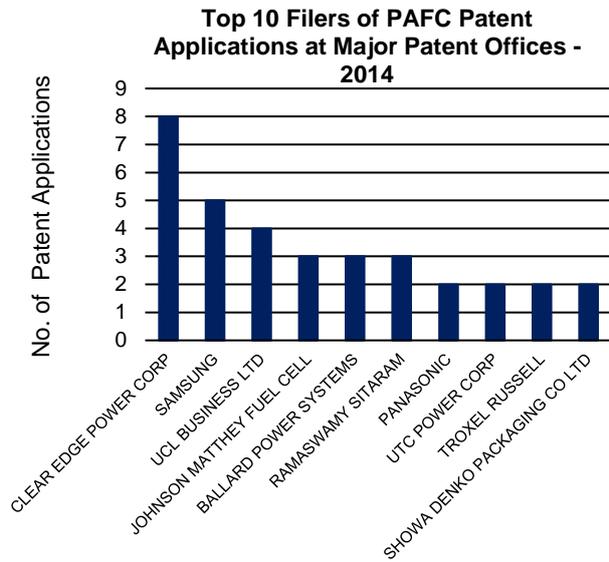


Figure A1.2.28. Top ten filers of PAFC patent applications at the Top 5 Patent Offices for 2014.

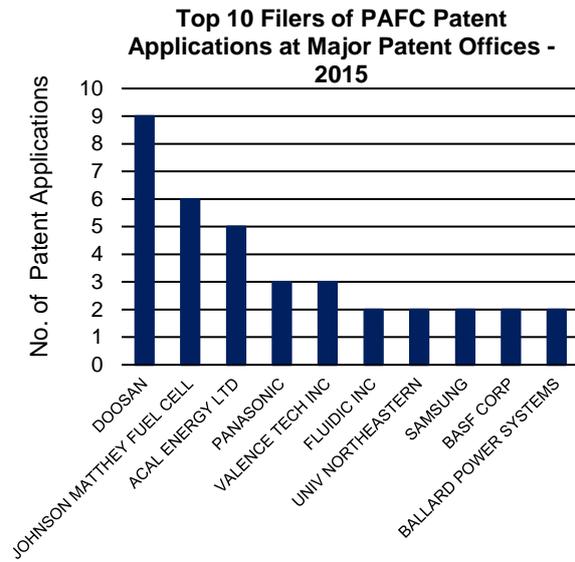


Figure A1.2.29. Top 10 filers of PAFC patent applications at the Top 5 Offices for 2015.

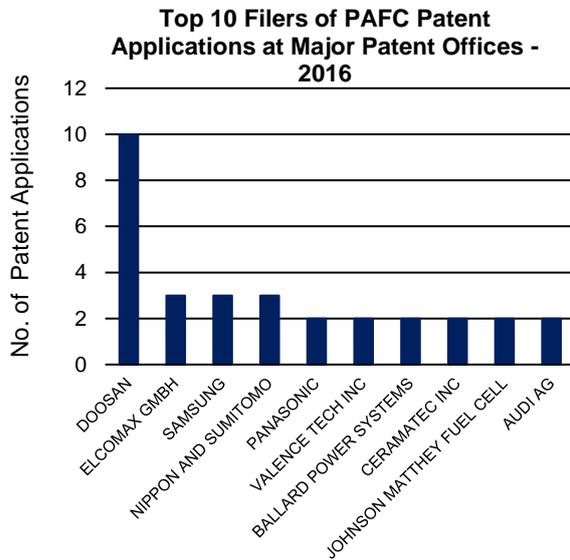


Figure A1.2.30. Top ten filers of PAFC patent applications at the Top 5 Patent Offices for 2016.

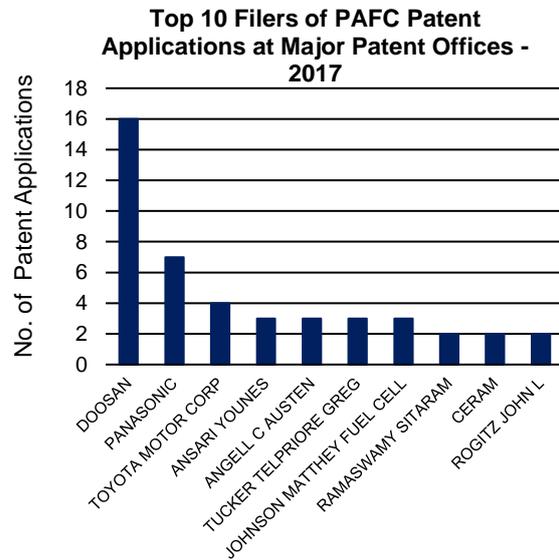


Figure A1.2.31. Top 10 filers of PAFC patent applications at the Top 5 Offices for 2017.

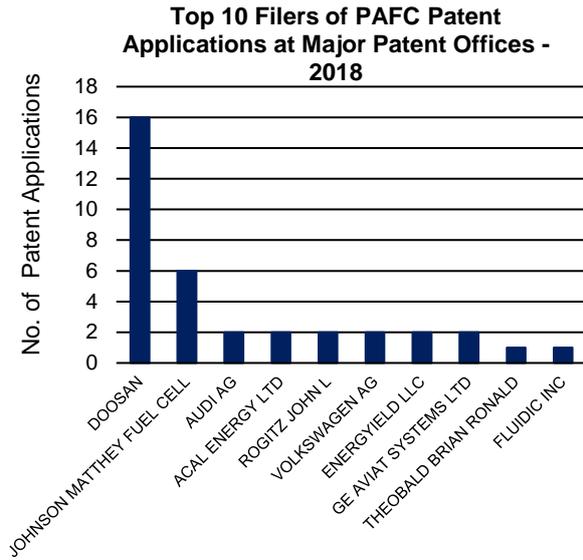


Figure A1.2.32. Top ten filers of PAFC patent applications at the Top 5 Patent Offices for 2018.

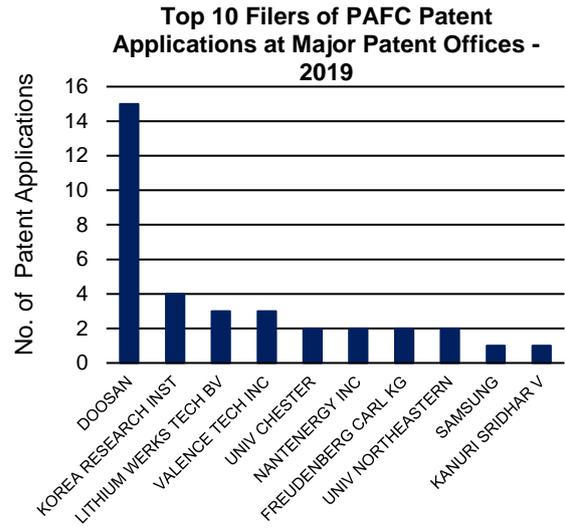


Figure A1.2.33. Top 10 filers of PAFC patent applications at the Top 5 Offices for 2019.

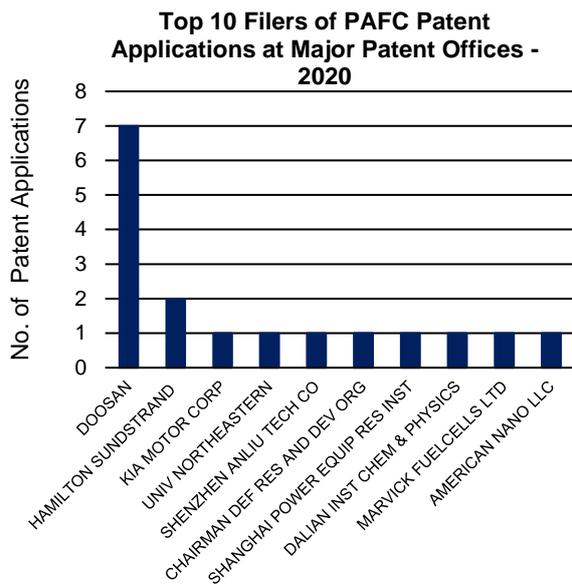


Figure A1.2.34. Top ten filers of PAFC patent applications at the Top 5 Patent Offices for 2020.

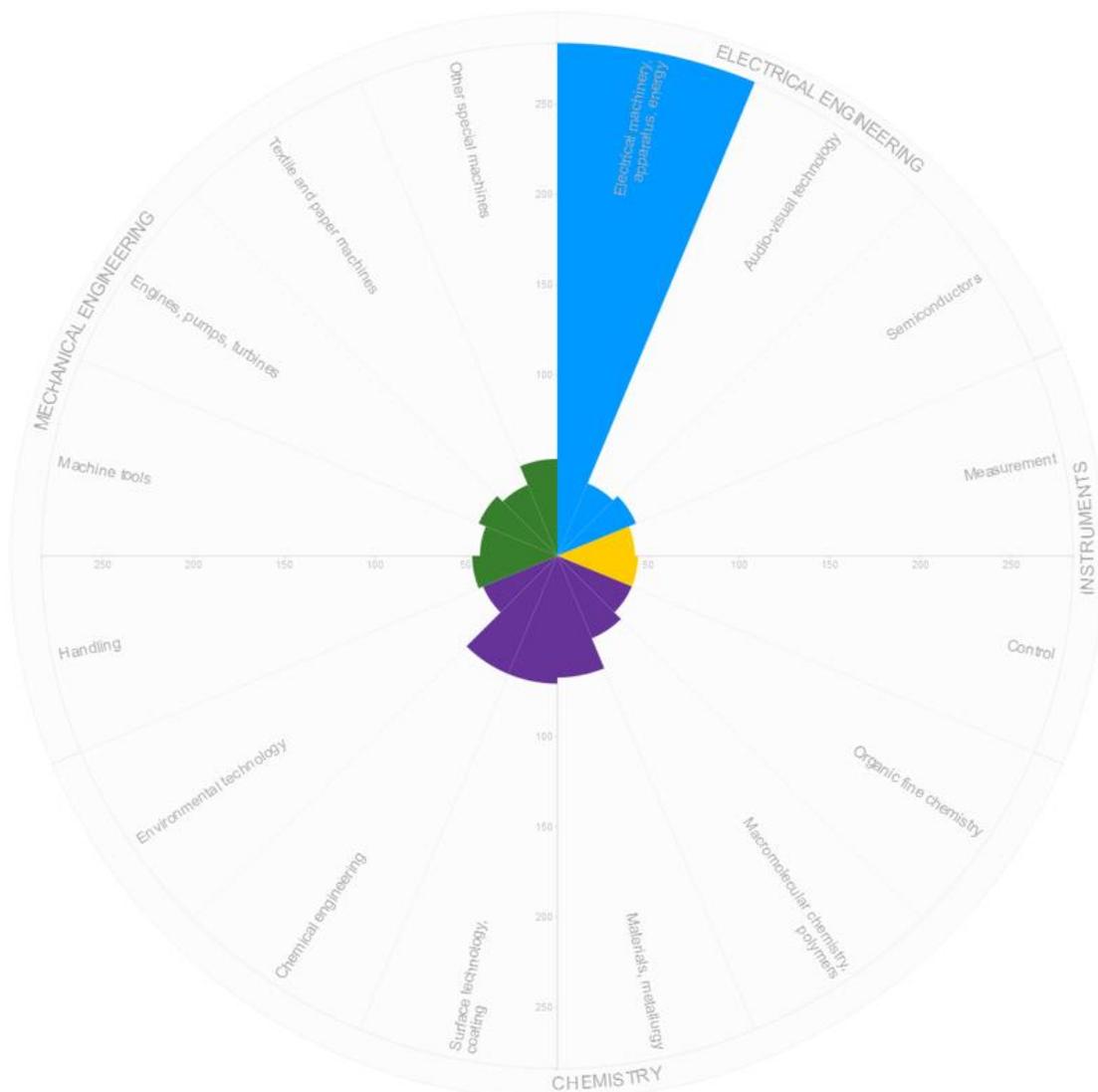
Figure A1.2.35 provides a technical comparison between patents filed for PAFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.2.35 shows that surface technologies have become less relatively important, but the overall technology spread remained fairly constant.

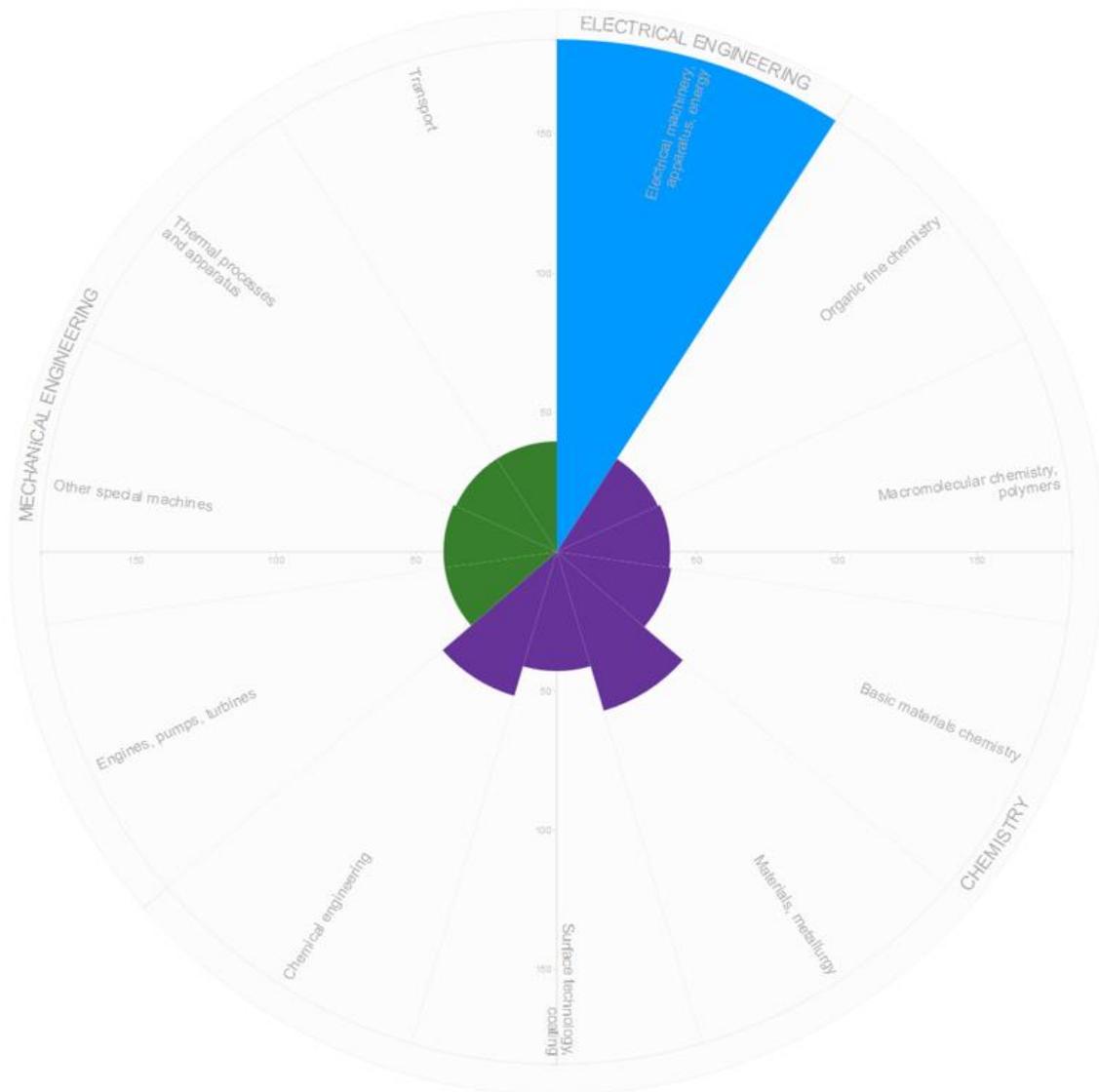
The overall picture is remarkably similar between the two periods. Notably, surface chemistry technology appears to have relatively decreased over time, as have “Measurement Techniques” (yellow bars in earlier period).

It should be noted that the size of the dataset for 2005/09 is larger than that for 2014/19.

Technological Breakdown for PAFC Patent Applications 2005 – 2009



Technological Breakdown for PAFC Patent Applications 2014 – 2019



A1.2.35. Technological breakdown for PAFC patent applications in comparison with 2005-2009 (PI).

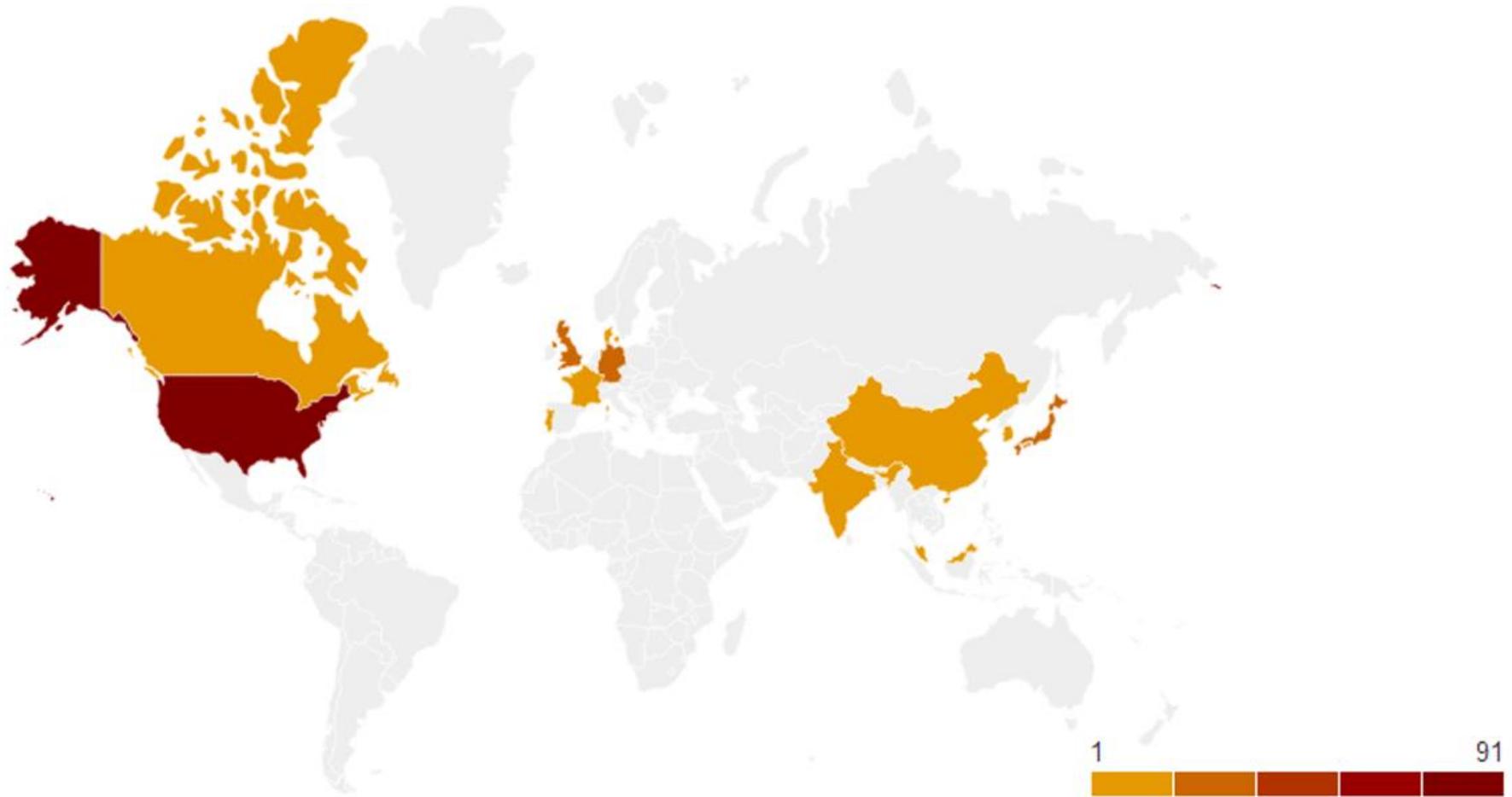
Figure A1.2.36 provides data to show how applicant location has varied over a ten-year window.

Figure A1.2.36 shows that the USA remains as the dominant location for patent filers. The data also shows that the UK, France and Germany have increased in importance.

Applicant location for worldwide PAFc patent applications 2005 – 2009



Applicant location for worldwide PAFI patent applications 2014 – 2019



A1.2.36. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.2.5. Proton Exchange Membrane Fuel Cell

Figures A1.2.37 to A1.2.43 show the top 10 assignees of proton exchange membrane fuel cell (PEMFC) patent applications, for the top 5 offices.

Many of the top 10 filers come from the automotive sector.

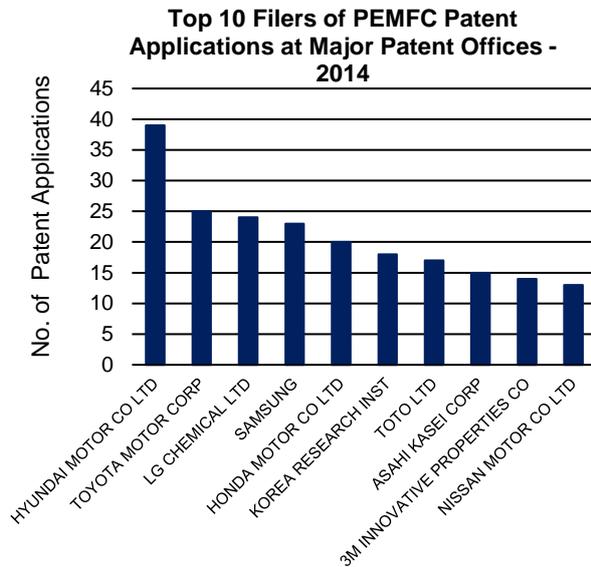


Figure A1.2.37. Top ten filers of PEMFC patent applications at the Top 5 Patent Offices for 2014.

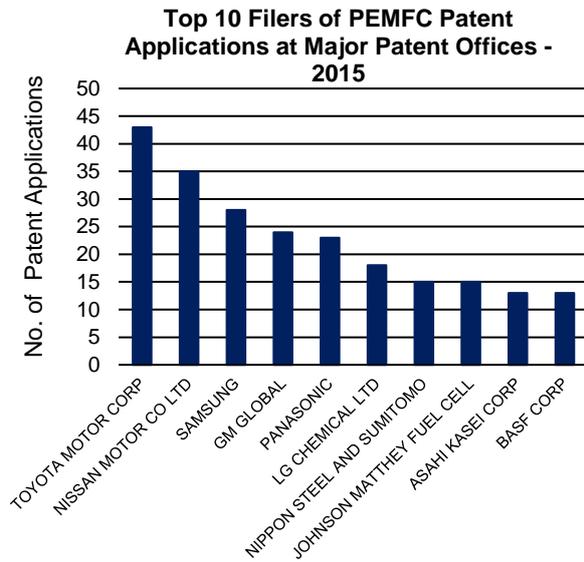


Figure A1.2.38. Top 10 filers of PEMFC patent applications at the Top 5 Offices for 2015.

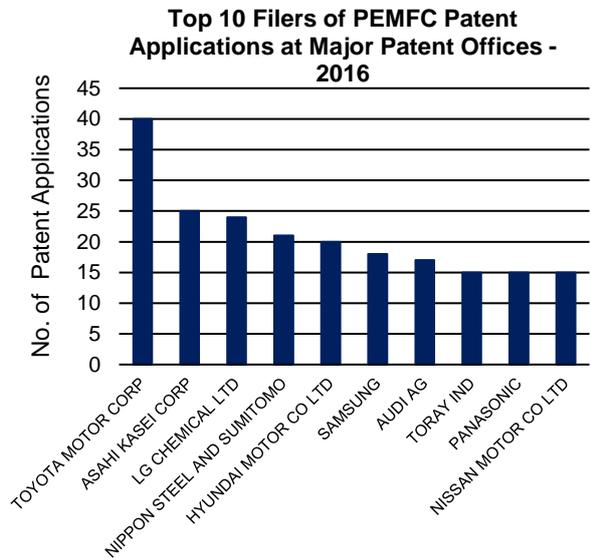


Figure A1.2.39. Top ten filers of PEMFC patent applications at the Top 5 Patent Offices for 2016.

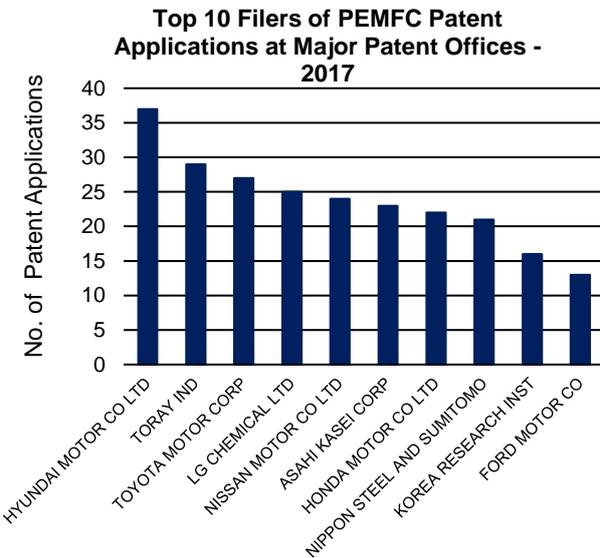


Figure A1.2.40. Top 10 filers of PEMFC patent applications at the Top 5 Offices for 2017.

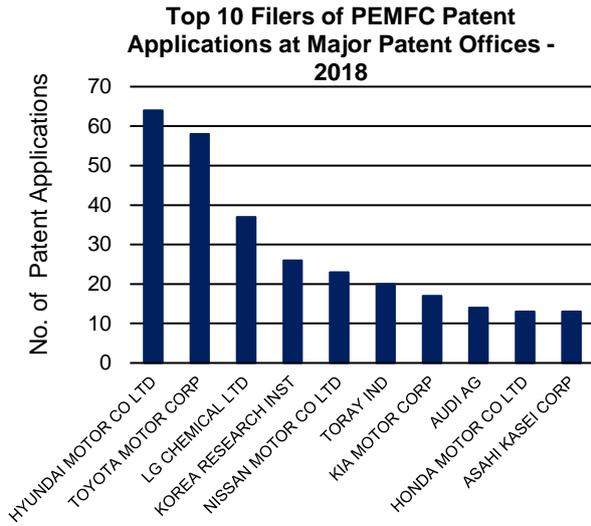


Figure A1.2.41. Top ten filers of PEMFC patent applications at the Top 5 Patent Offices for 2018.

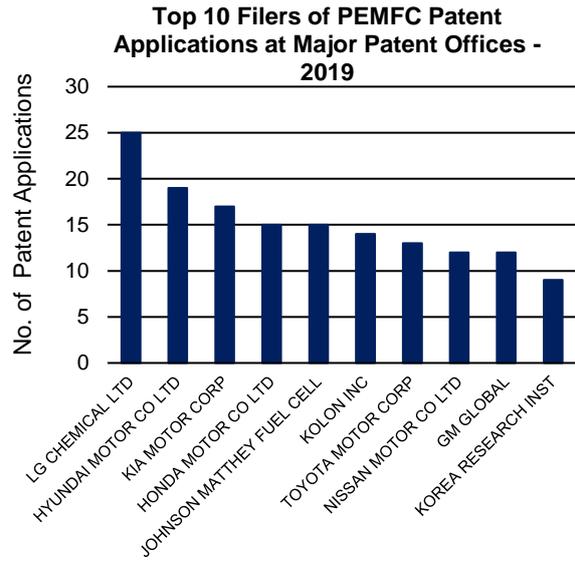


Figure A1.2.42. Top 10 filers of PEMFC patent applications at the Top 5 Offices for 2019.

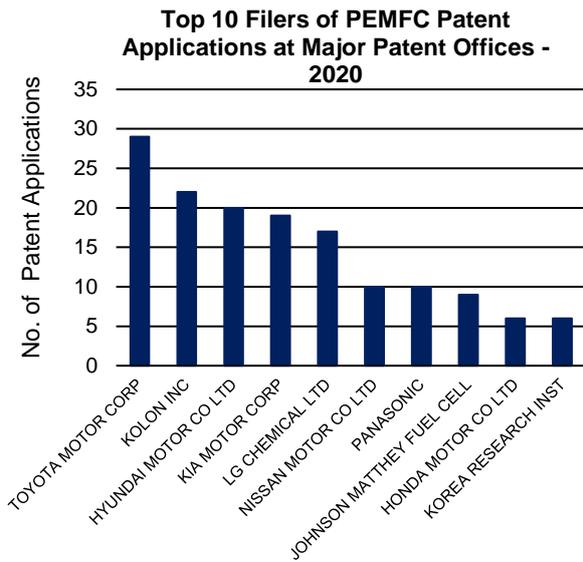


Figure A1.2.43. Top ten filers of PEMFC patent applications at the Top 5 Patent Offices for 2020.

Figure A1.2.44 provides a technical comparison between patents filed for PEMFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.2.44 shows that the technical spread has broadened over the period, with surface technologies becoming more important.

The overall technological picture appears similar over time with the only notable change being the emergence of “Surface Technology and Coating” during the later period.

It should be noted that the size of the dataset for each respective period are not the same (2014/19< 2005/09) and so this graph provides information about relative changes between the periods.

Technological Breakdown for PEMFC Patent Applications 2005 – 2009



Technological Breakdown for PEMFC Patent Applications 2014 – 2019



A1.2.44 Technological breakdown for PEMFC patent applications in comparison with 2005-2009 (PI).

Figure A.1.2.45 provides data to show how applicant location has varied over a ten-year window.

Figure A1.2.45 shows that the USA has become increasingly dominant, with the UK Germany and Japan being important locations.

Applicant location for worldwide PEMFC patent applications 2005 – 2009



Applicant location for worldwide PEMFC patent applications 2014 – 2019



A1.2.45. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.2.6. Solid Oxide Fuel Cells

Figures 3.3.46 to 3.3.52 show the top 10 assignees of solid oxide fuel cell (SOFC) patent applications, for the top 5 offices.

The top filers are LG (China), NGK (Japan and Europe), Bloom Energy (USA) and the Korean Research Institute (Korea).

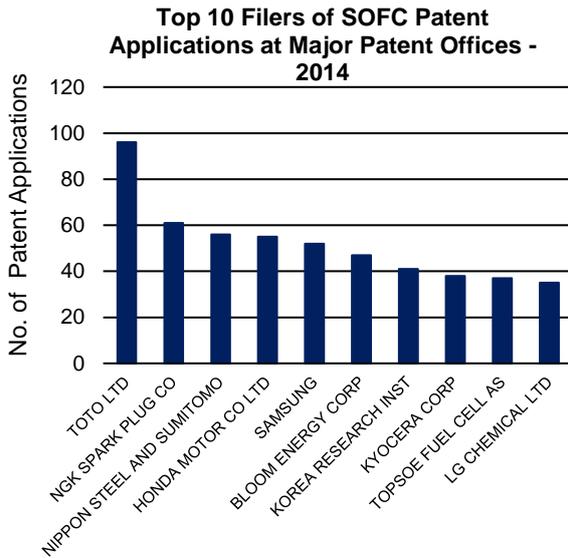


Figure A1.2.46. Top ten filers of SOFC patent applications at the Top 5 Patent Offices for 2014.

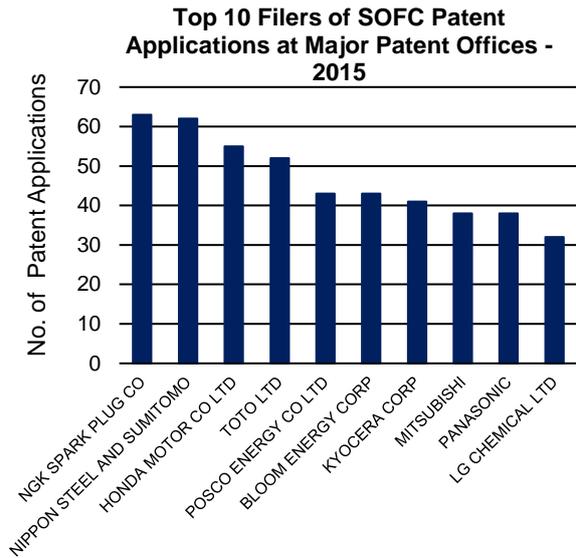


Figure A1.2.47. Top 10 filers of SOFC patent applications at the Top 5 Offices for 2015.

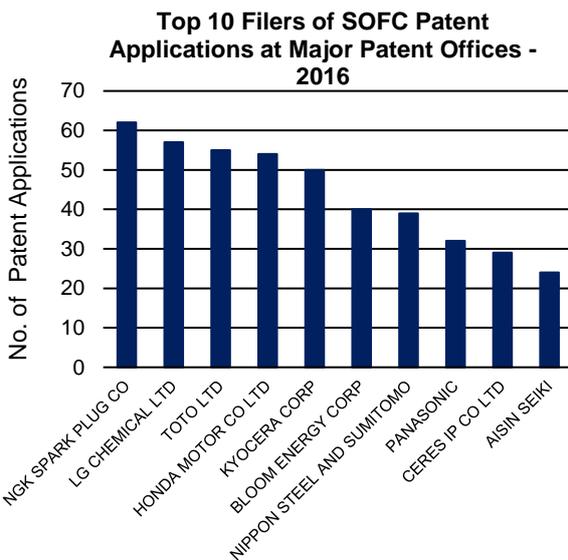


Figure A1.2.48. Top ten filers of SOFC patent applications at the Top 5 Patent Offices for 2016.

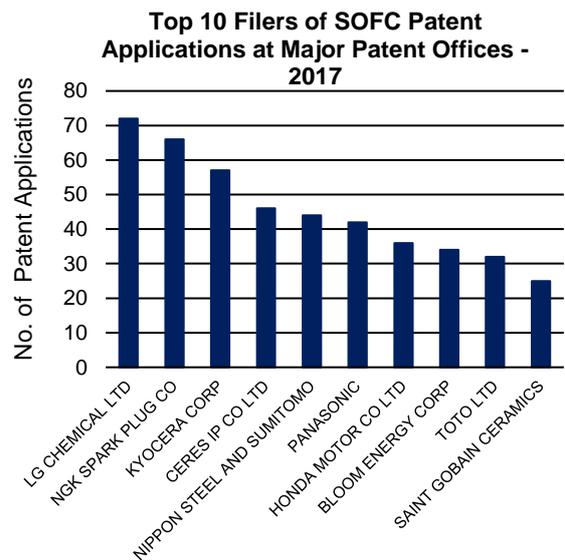


Figure A1.2.49. Top 10 filers of SOFC patent applications at the Top 5 Offices for 2017.

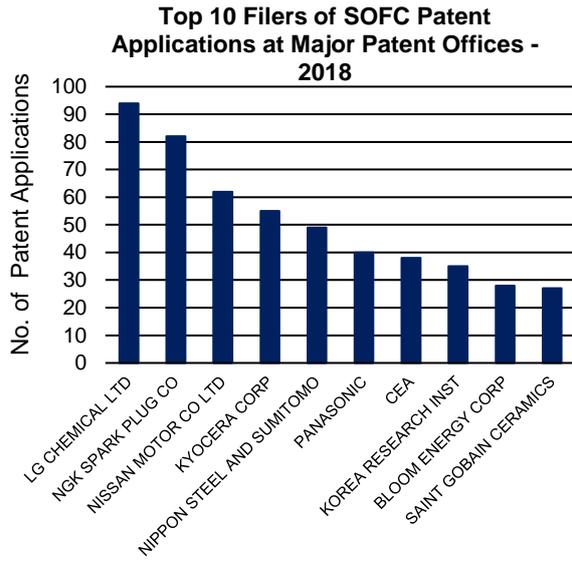


Figure A1.2.50. Top ten filers of SOFC patent applications at the Top 5 Patent Offices for 2018.

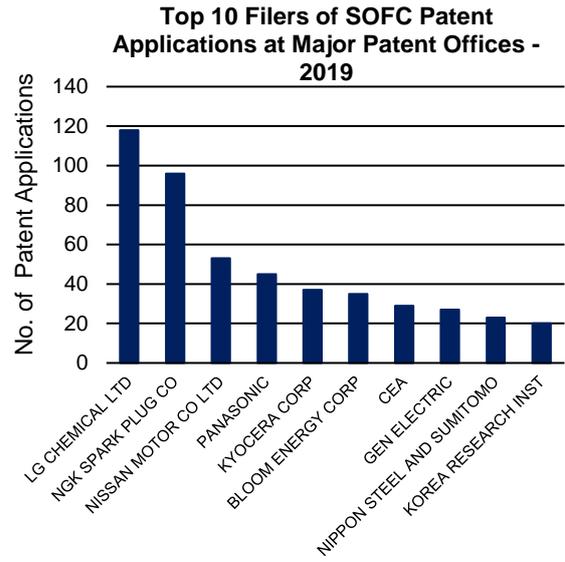


Figure A1.2.51. Top 10 filers of SOFC patent applications at the Top 5 Offices for 2019.

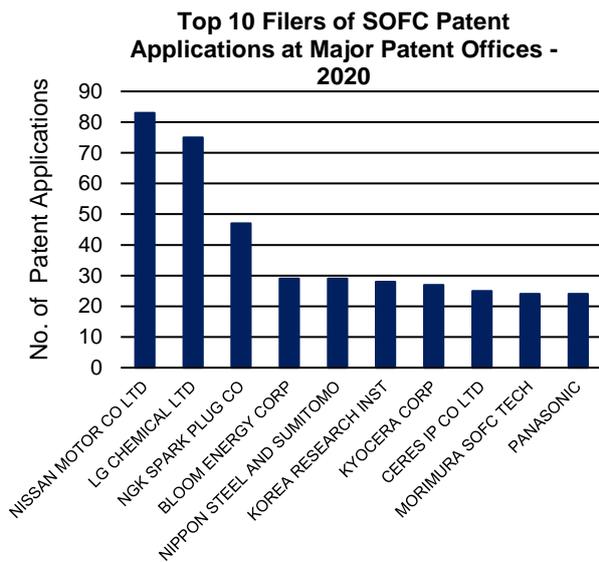


Figure A1.2.52. Top ten filers of SOFC patent applications at the Top 5 Patent Offices for 2020.

Figure A1.2.53 provides a technical comparison between patents filed for SOFCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.2.53 shows a similar technological spread over time.

The technological spread appears to be remarkably consistent over time.

It should be noted that the size of the dataset for each respective period are broadly similar (2014/19 < 2005/09).

Technological Breakdown for SOFC Patent Applications 2005 – 2009



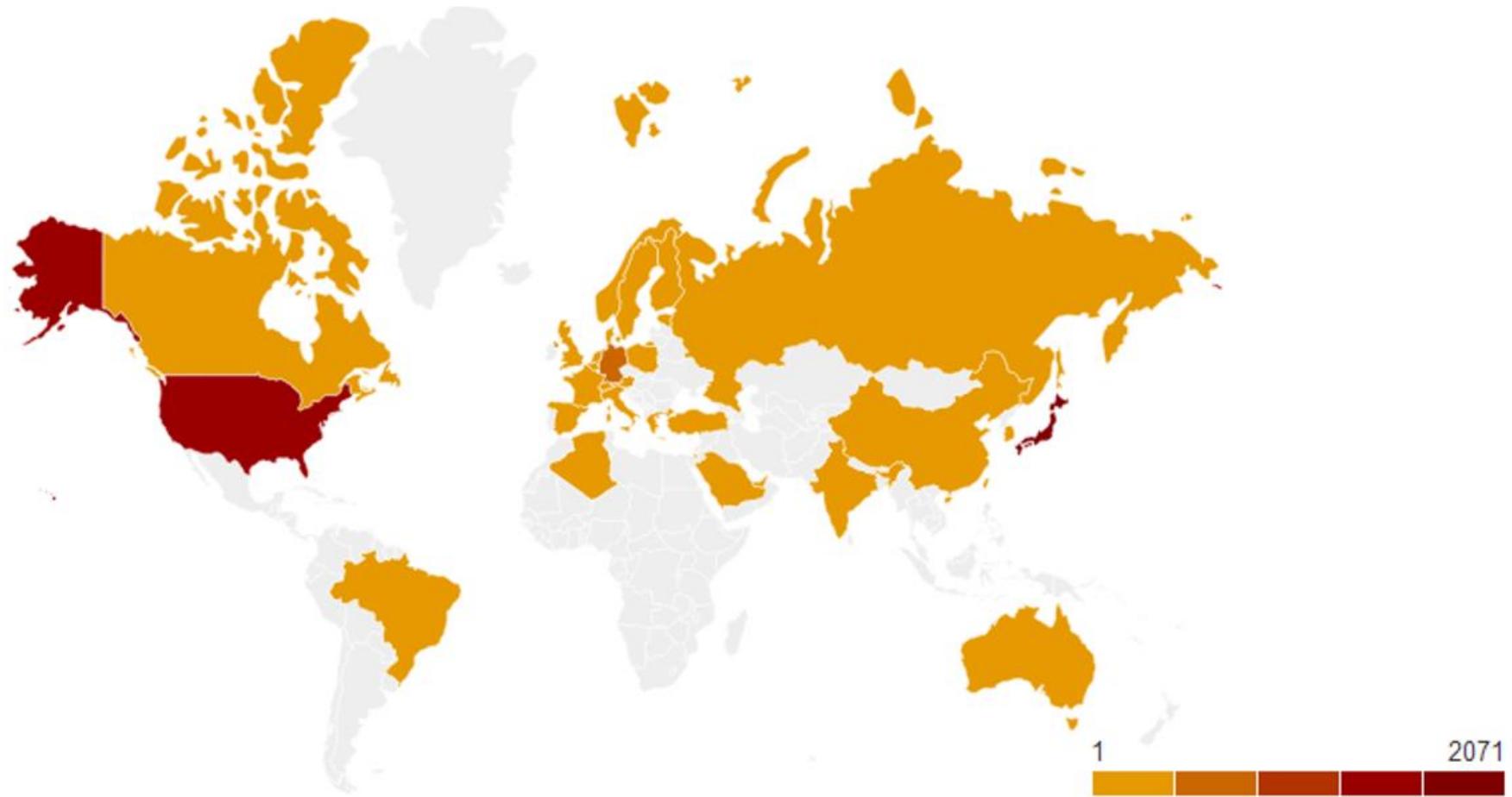
Technological Breakdown for SOFC Patent Applications 2014 – 2019



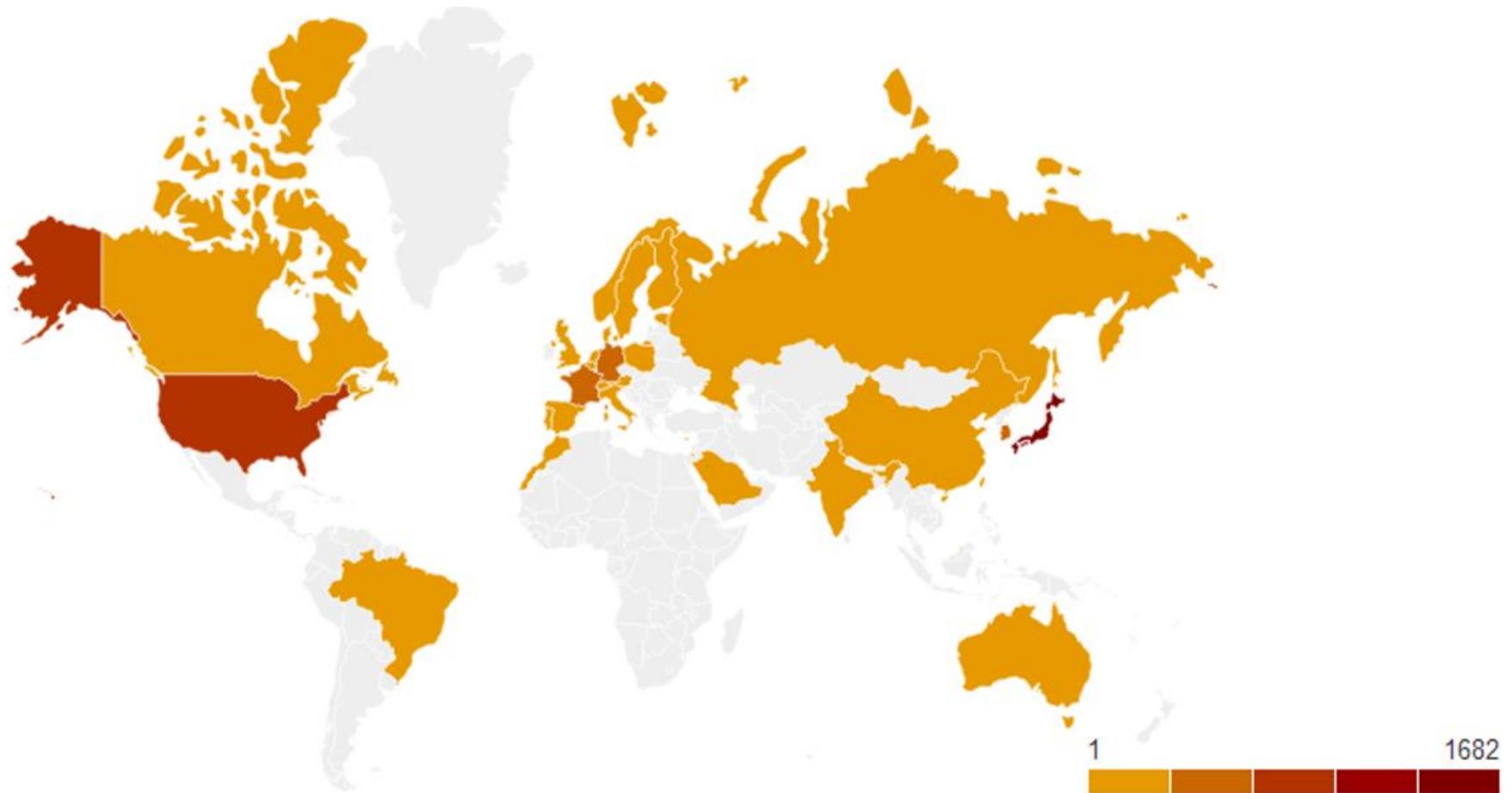
A1.2.53. Technological breakdown for SOFC patent applications in comparison with 2005-2009 (PI).

Figure A1.2.54 provides data to show how applicant location has varied over a ten-year window. Figure A1.2.54 shows that the location of patent applicants has remained very similar over time, except France emerging as a more important location and the USA slightly falling back.

Applicant location for worldwide SOFC patent applications 2005 – 2009



Applicant location for worldwide SOFC patent applications 2014 – 2019



A1.2.54. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.3. Fuel Cell Deployment

The data presented below shows the top 10 filers of patent applications for mobile, stationary and portable fuel cells, for the years 2014 to 2019, for each of the top 5 offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

1.3.1. Mobile Fuel Cells

Figures A1.3.1 to A1.3.7 show the top 10 assignees of mobile fuel cell patent applications for the top 5 offices.

The top 10 assignees are unsurprisingly dominated by automotive companies.

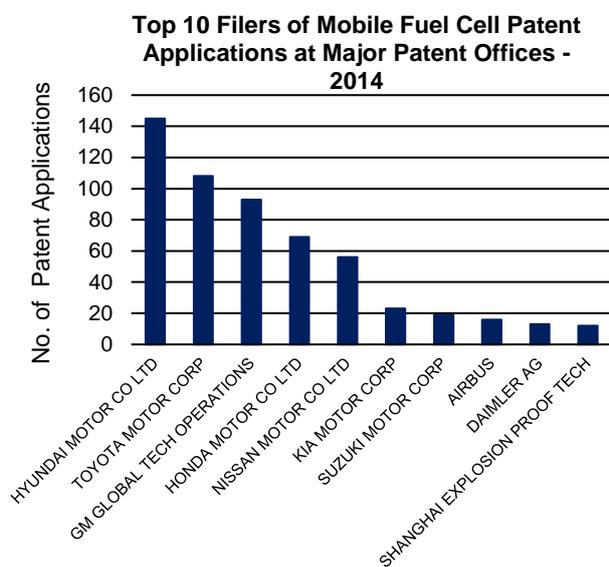


Figure A1.3.1. Top ten filers of mobile fuel cell patent applications at the Top 5 Patent Offices for 2014.

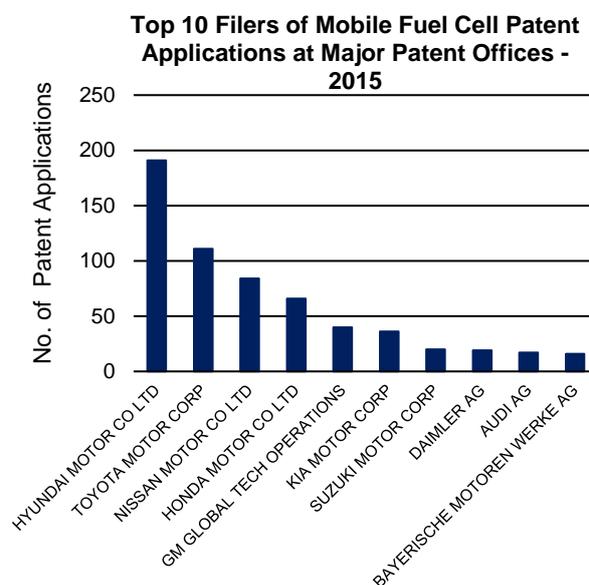


Figure A1.3.2. Top 10 filers of mobile fuel cell patent applications at the Top 5 Offices for 2015.

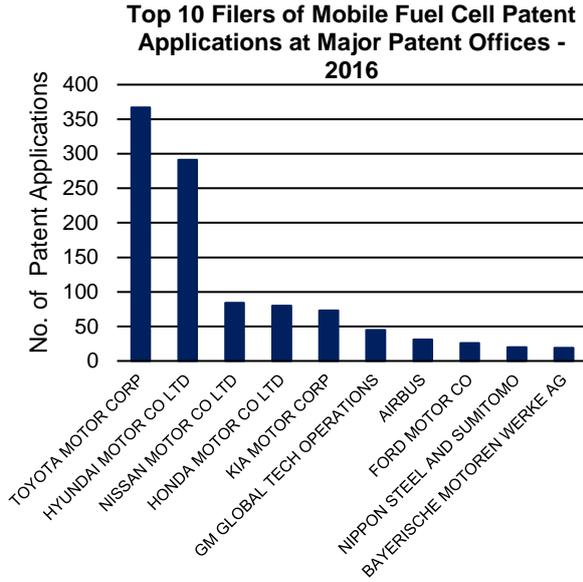


Figure A1.3.3. Top ten filers of mobile fuel cell patent applications at the Top 5 Patent Offices for 2016.

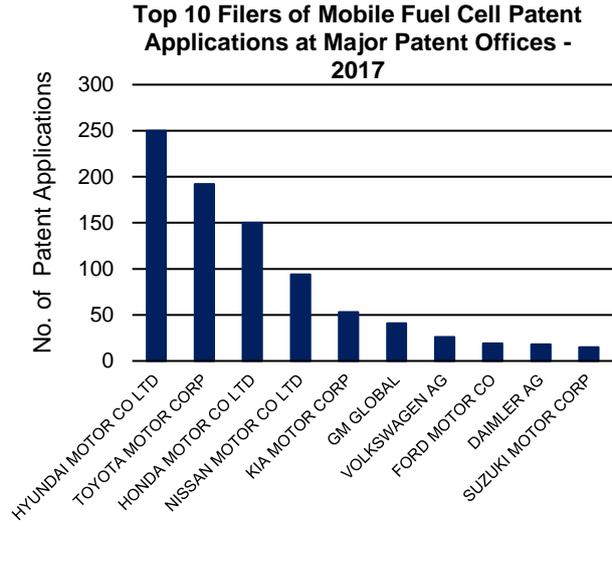


Figure A1.3.4. Top 10 filers of mobile fuel cell patent applications at the Top 5 Offices for 2017.

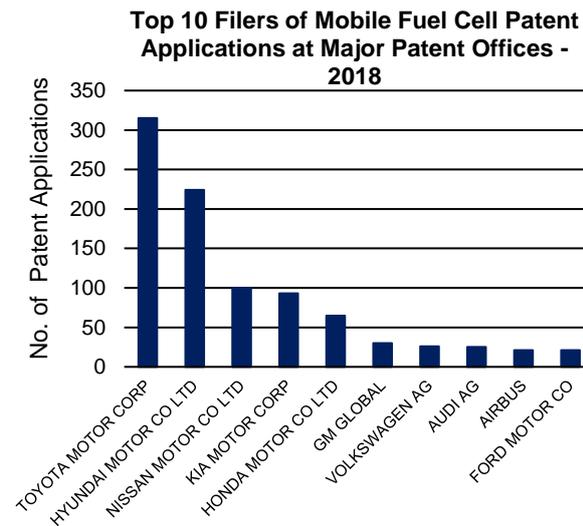


Figure A1.3.5. Top ten filers of mobile fuel cell patent applications at the Top 5 Patent Offices for 2018.

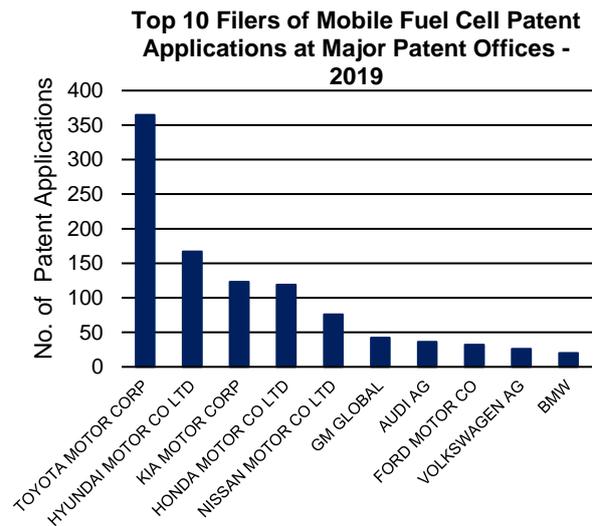


Figure A1.3.6. Top 10 filers of mobile fuel cell patent applications at the Top 5 Offices for 2019.

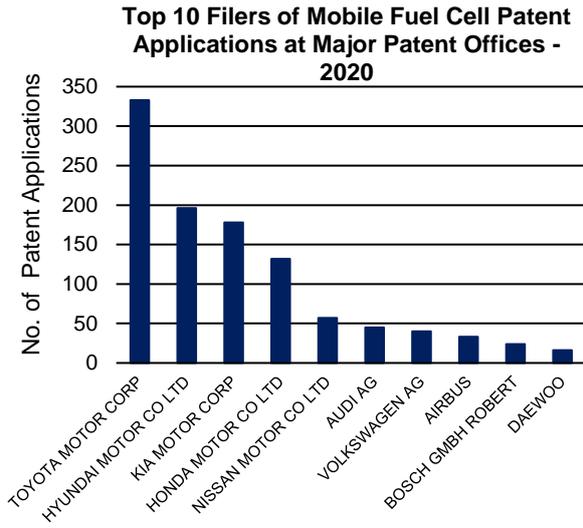


Figure A1.3.7. Top ten filers of mobile fuel cell patent applications at the Top 5 Patent Offices for 2020.

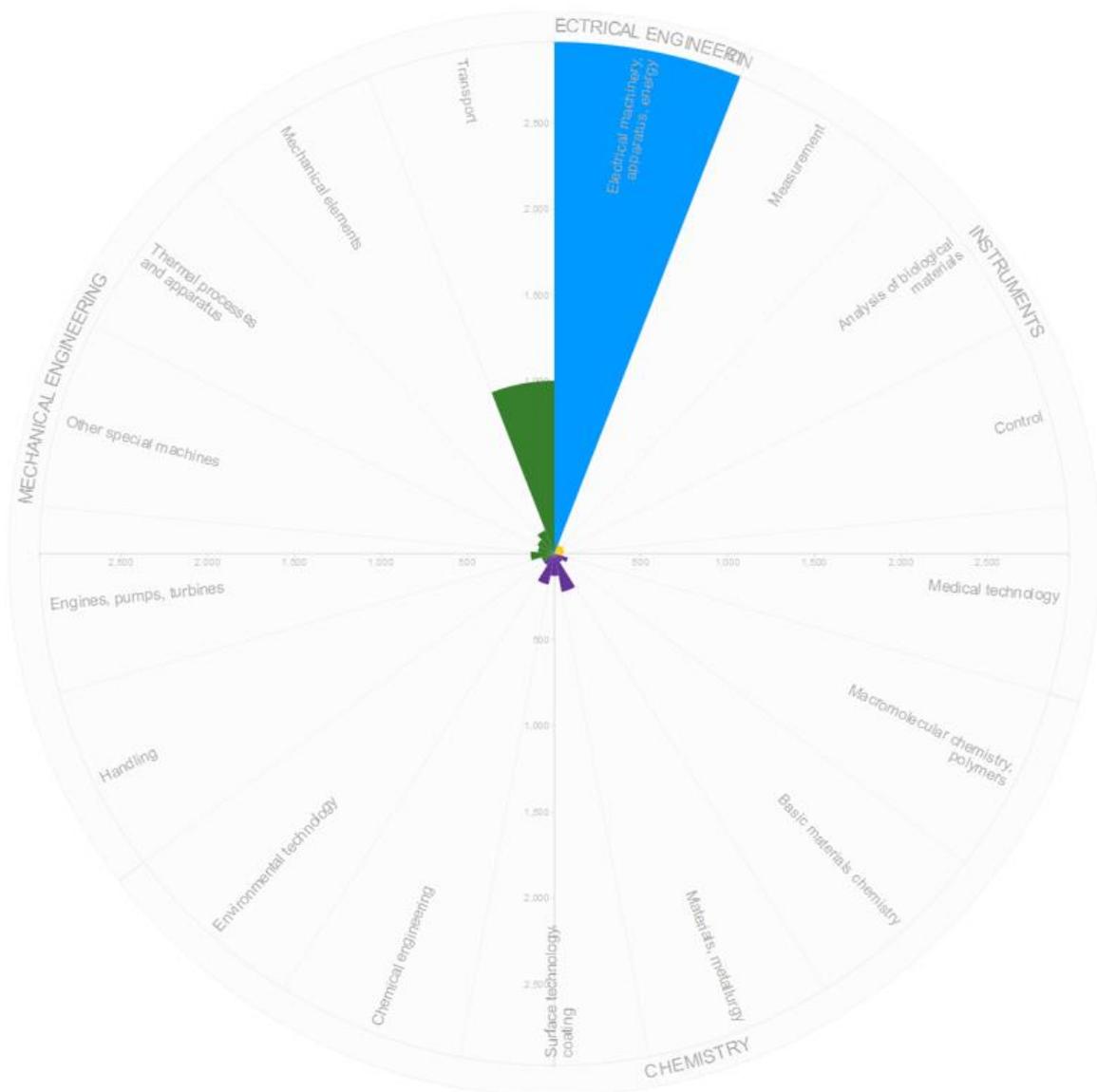
Figure A1.3.8 provides a technical comparison between patents filed for Mobile FCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.3.8 shows that chemical technologies appear to have become relatively less relevant.

The relative decrease in the size of the purple bars indicates that chemical technologies have become relative less important over the period.

It should be noted that the size of the dataset for each respective period are very similar.

Technological Breakdown for Mobile FC Patent Applications 2005 – 2009



Technological Breakdown for Mobile FC Patent Applications 2014 – 2019

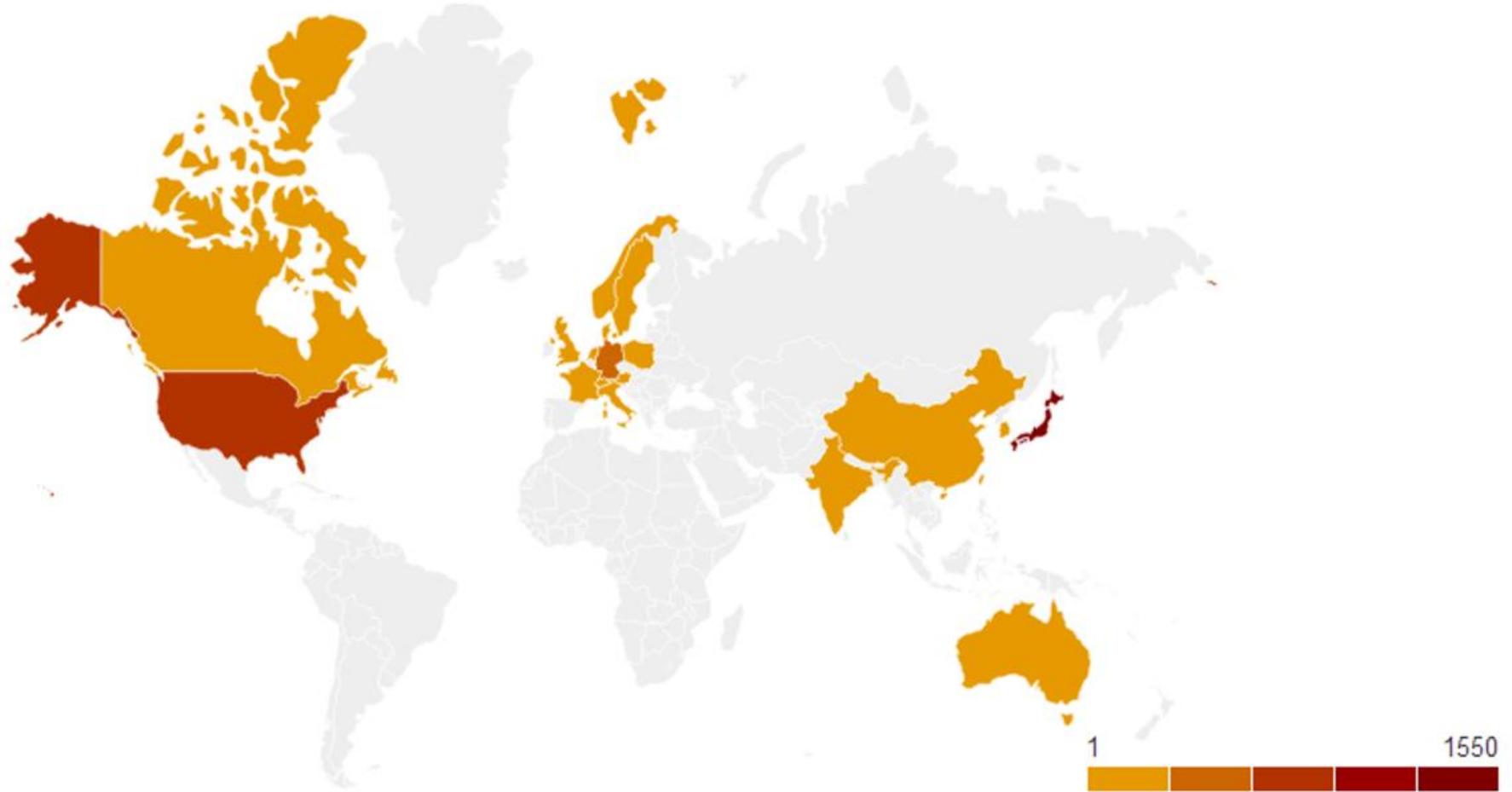


A1.3.8. Technological breakdown for Mobile FC patent applications in comparison with 2005-2009 (PI).

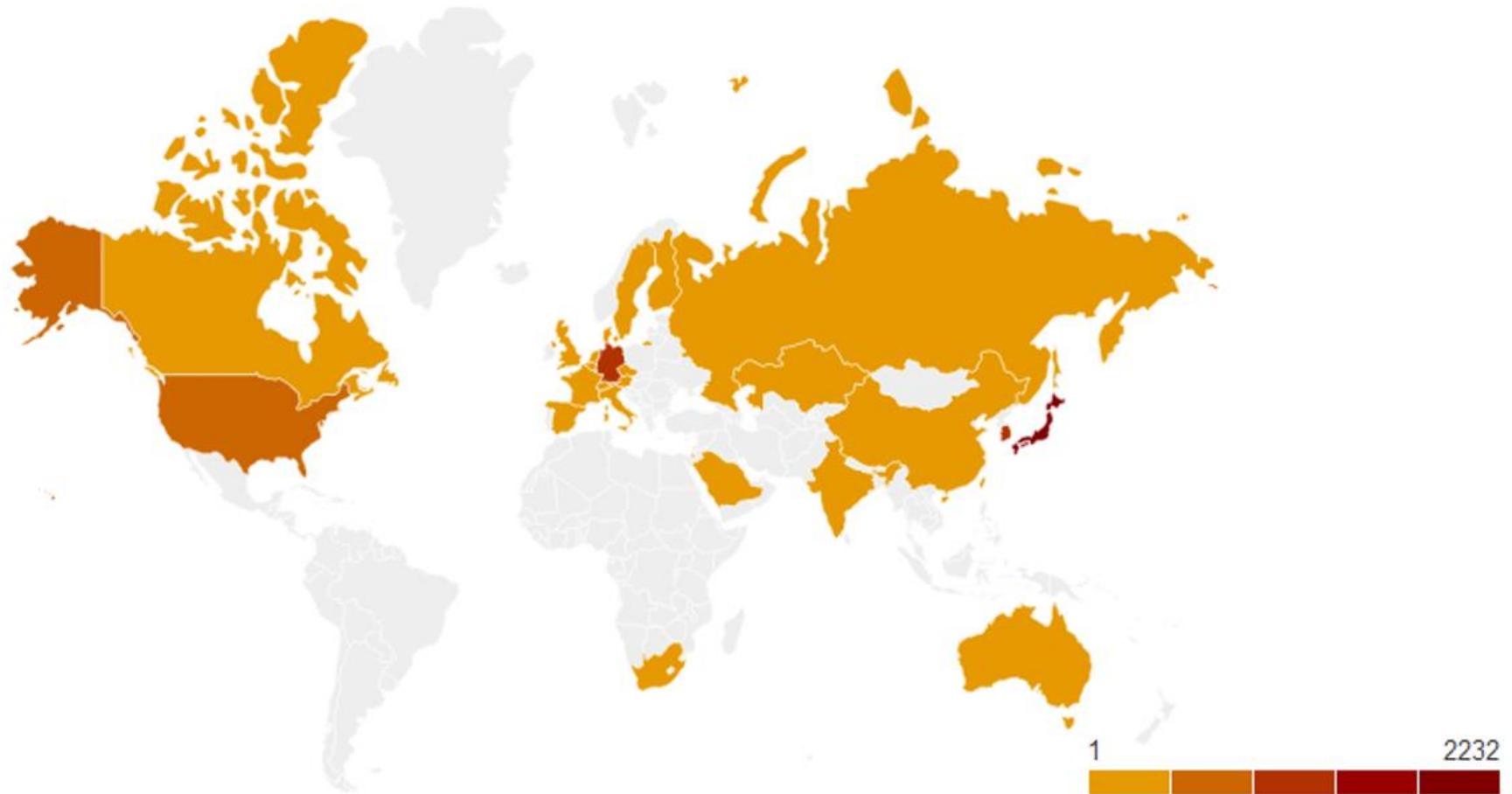
Figure A1.3.9 provides data to show how applicant location has varied over a ten-year window.

Figure A1.3.9 appears to show that there has been more diversification in the location of patent applicants in this space.

Applicant location for worldwide Mobile FC patent applications 2005 – 2009



Applicant location for worldwide Mobile FC patent applications 2014 – 2019



A1.3.9. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.3.2. Stationary Fuel Cells

Figures A1.3.10 to A1.3.16 show the top 10 assignees of stationary fuel cell patent applications for the top 5 offices.

The top filers appear to vary over the period.

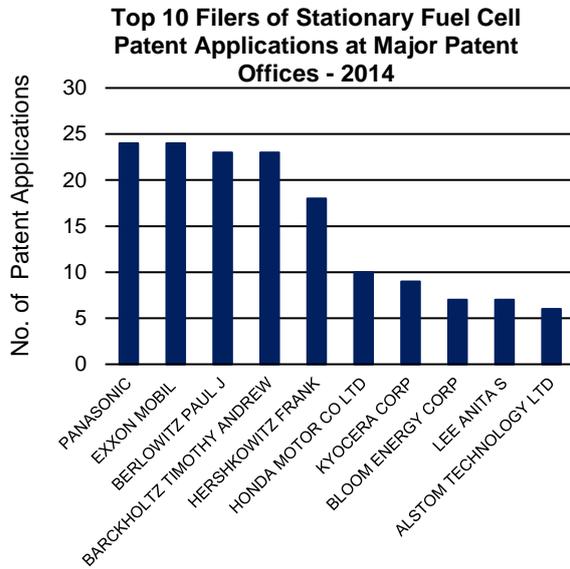


Figure A1.3.10. Top ten filers of stationary fuel cell patent applications at the Top 5 Patent Offices for 2014.

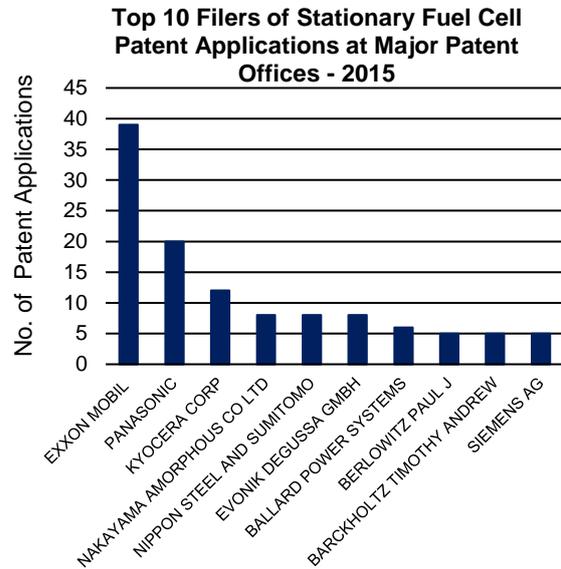


Figure A1.3.11. Top 10 filers of stationary fuel cell patent applications at the Top 5 Offices for 2015.

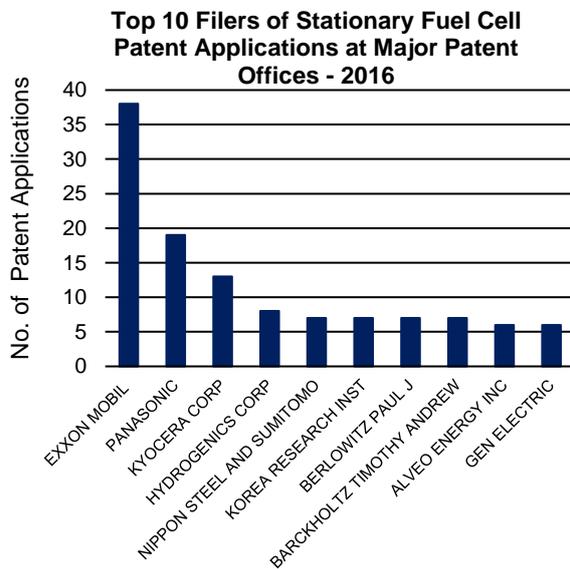


Figure A1.3.12. Top ten filers of stationary fuel cell patent applications at the Top 5 Patent Offices for 2016.

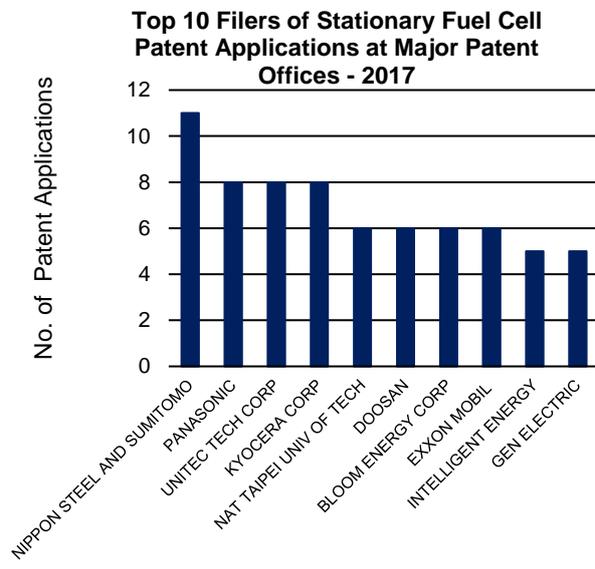


Figure A1.3.13. Top 10 filers of stationary fuel cell patent applications at the Top 5 Offices for 2017.

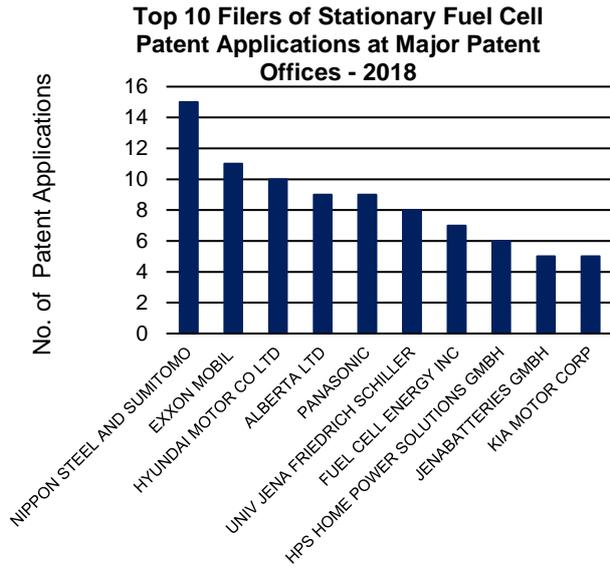


Figure A1.3.14. Top ten filers of stationary fuel cell patent applications at the Top 5 Patent Offices for 2018.

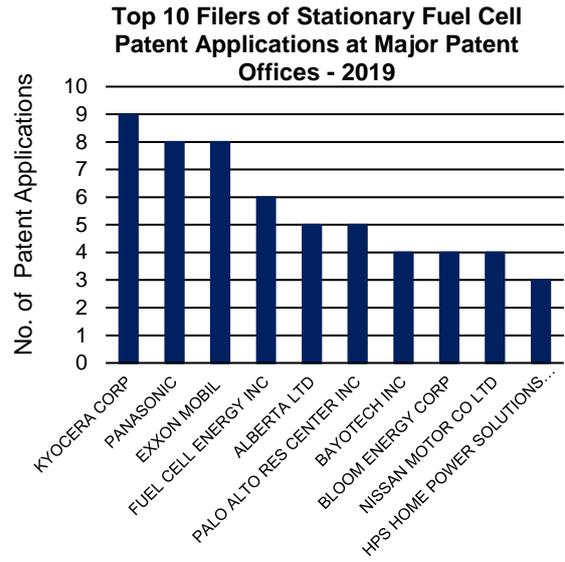


Figure A1.3.15. Top 10 filers of stationary fuel cell patent applications at the Top 5 Offices for 2019.

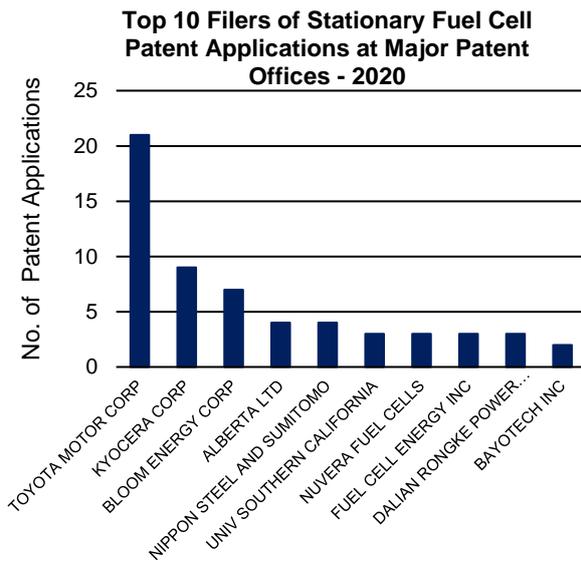


Figure A1.3.16. Top ten filers of stationary fuel cell patent applications at the Top 5 Patent Offices for 2020

Figure A1.3.17 provides a technical comparison between patents filed for Stationary FCs for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.3.17 shows that chemical technologies are becoming increasingly important.

In contrast to mobile FC position, the increase in purple bars shows that chemical technologies (purple bars) are becoming increasingly important, especially “Metallurgy” (major purple bar).

It should be noted that the size of the dataset for each respective period are not the same (2014/19> 2005/09) and so this graph provides information about relative changes between the periods.

Technological Breakdown for Stationary FC Patent Applications 2005 – 2009



Technological Breakdown for Stationary FC Patent Applications 2014 – 2019

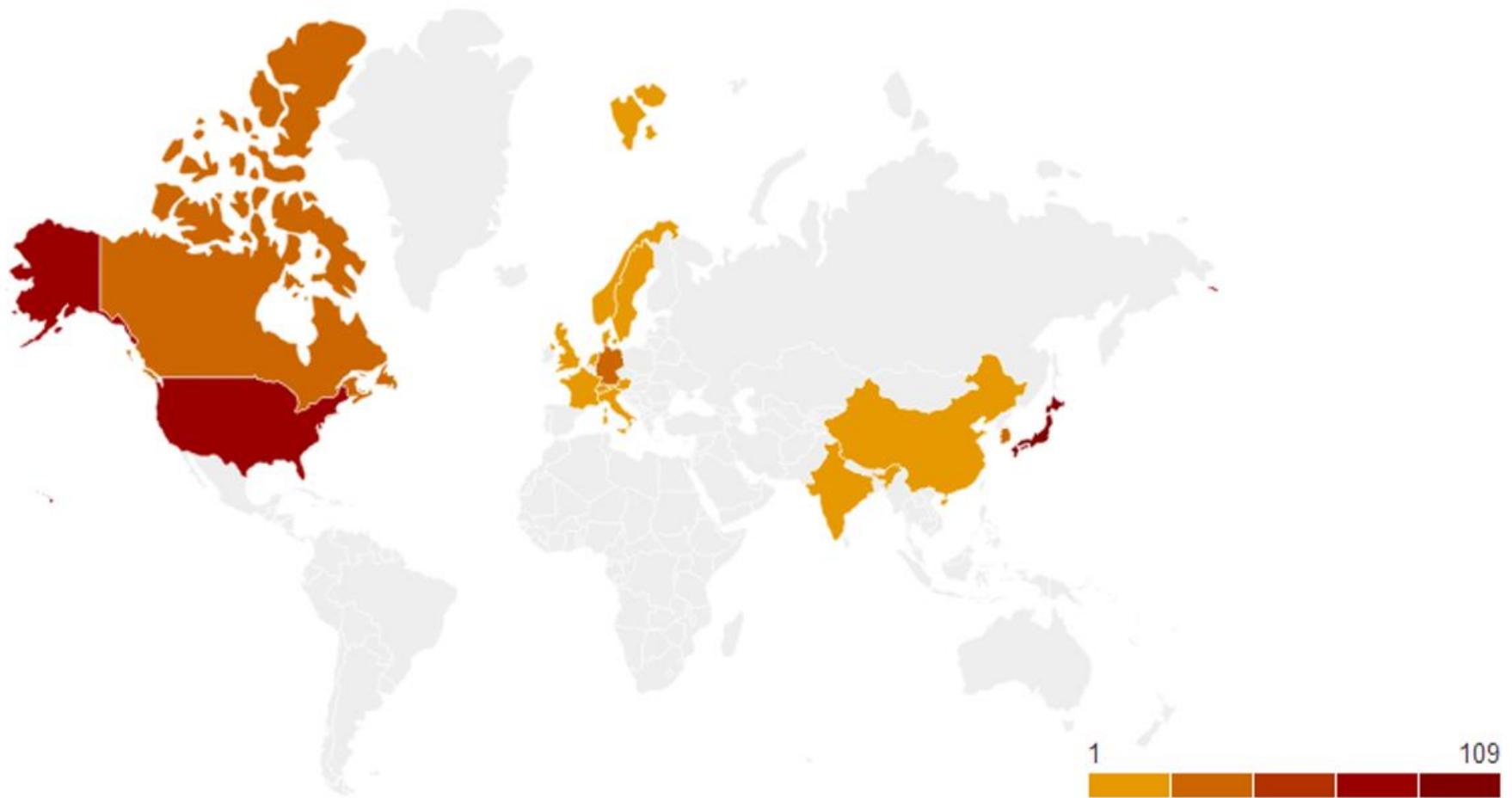


A1.3.17. Technological breakdown for Stationary FC patent applications in comparison with 2005-2009 (PI).

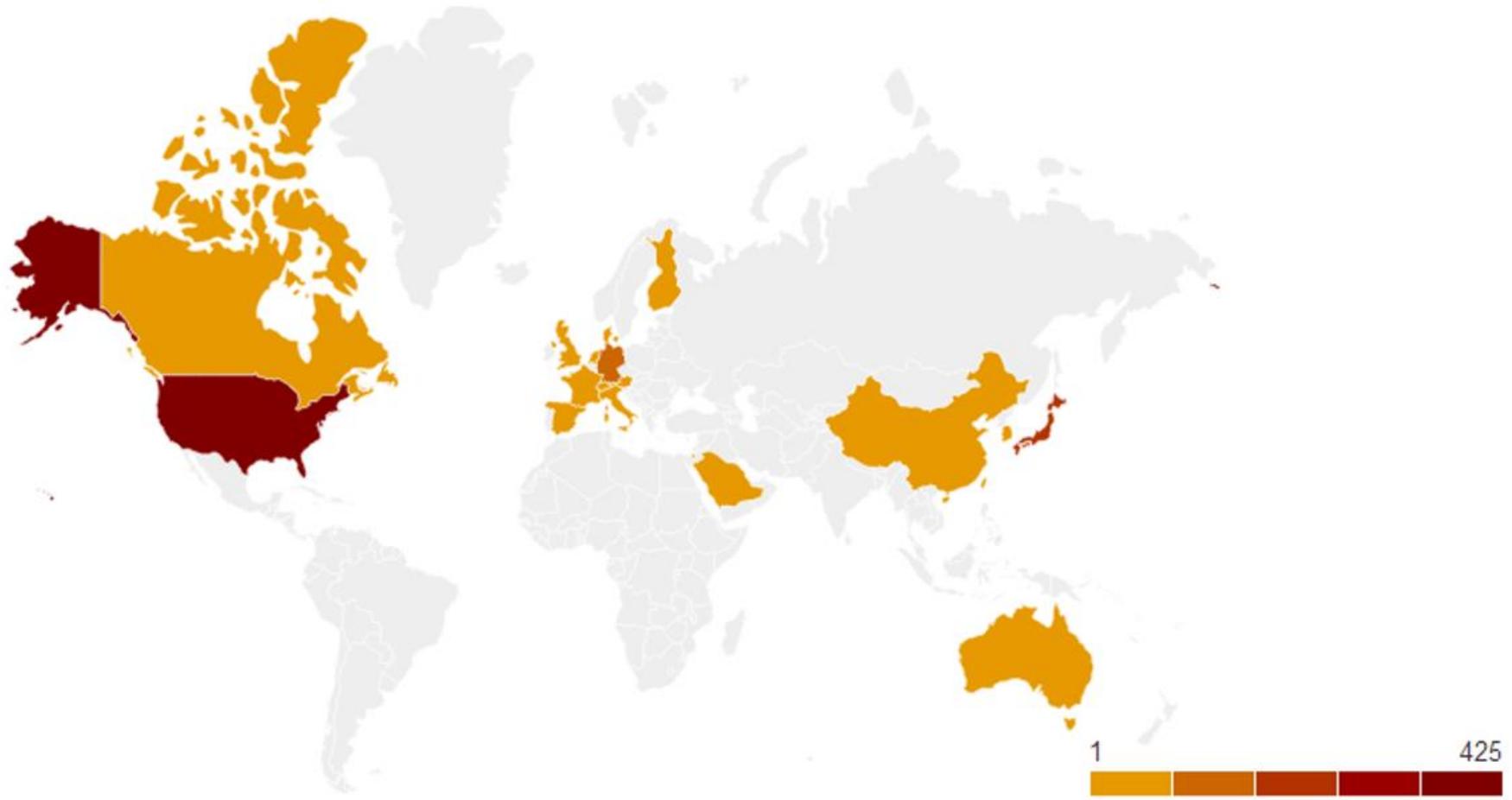
Figure A1.3.18 provides data to show how applicant location has varied over a ten-year window.

Figure A1.3.18 shows that Canada has become a less important jurisdiction as a location for patent filers and that there has been some consolidation.

Applicant location for worldwide Stationary FC patent applications 2005 – 2009



Applicant location for worldwide Stationary FC patent applications 2014 – 2019



A1.3.18. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.3.3. Portable Fuel Cells

Figures A1.3.19 to A1.3.25 show the top 10 assignees of portable fuel cell patent applications for each of the top 5 offices.

Intelligent Energy are the top filer of portable fuel cell patent applications featuring in the top two annually between 2014 and 2019.

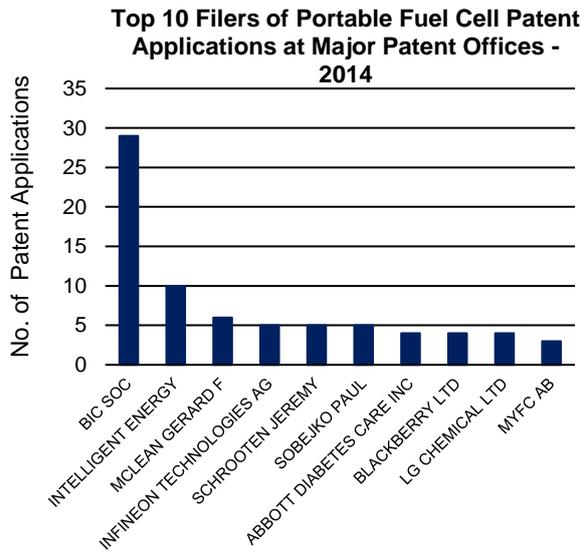


Figure A1.3.19. Top ten filers of portable fuel cell patent applications at the Top 5 Patent Offices for 2014.

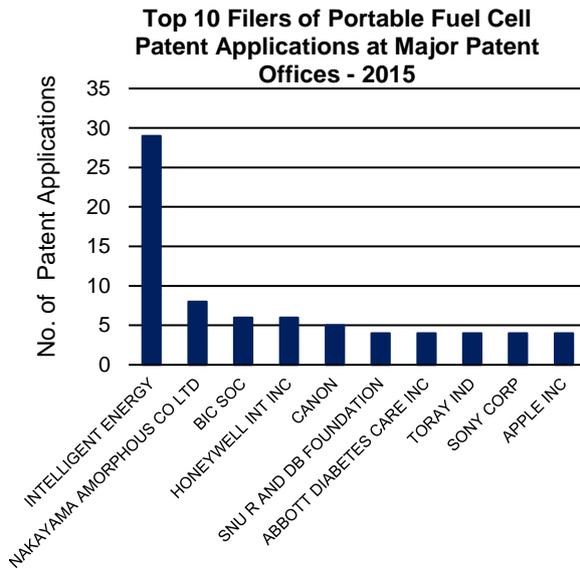


Figure A1.3.20. Top 10 filers of portable fuel cell patent applications at the Top 5 Offices for 2015.

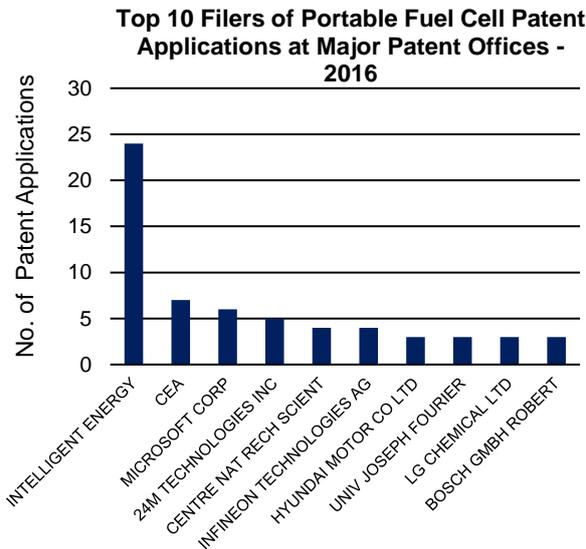


Figure A1.3.21. Top ten filers of portable fuel cell patent applications at the Top 5 Patent Offices for 2016.

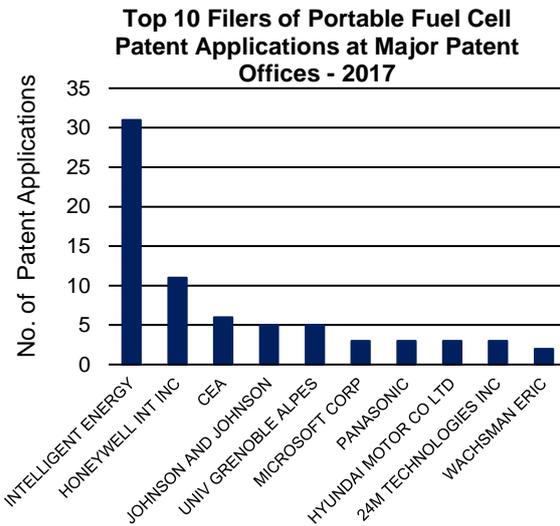


Figure A1.3.22. Top 10 filers of portable fuel cell patent applications at the Top 5 Offices for 2017.

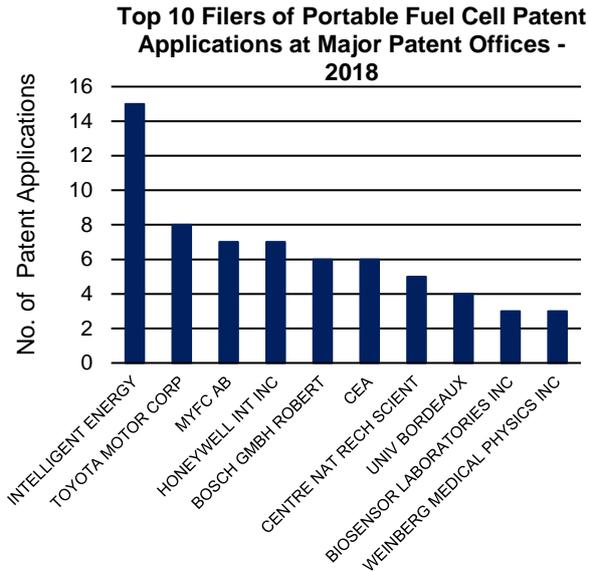


Figure A1.3.123. Top ten filers of portable fuel cell patent applications at the Top 5 Patent Offices for 2018.

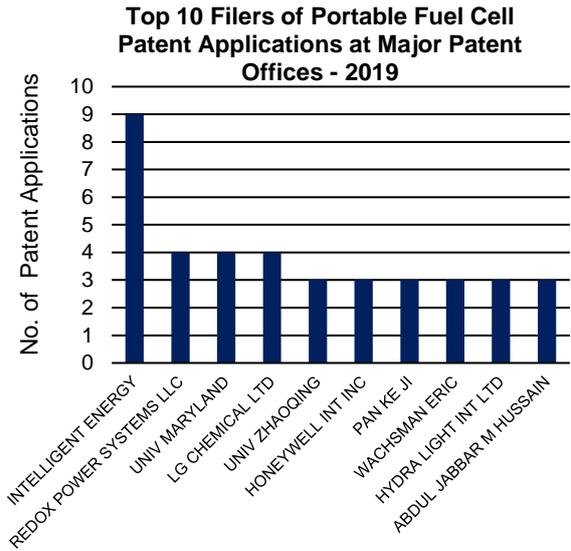


Figure A1.3.24. Top 10 filers of portable fuel cell patent applications at the Top 5 Offices for 2019.

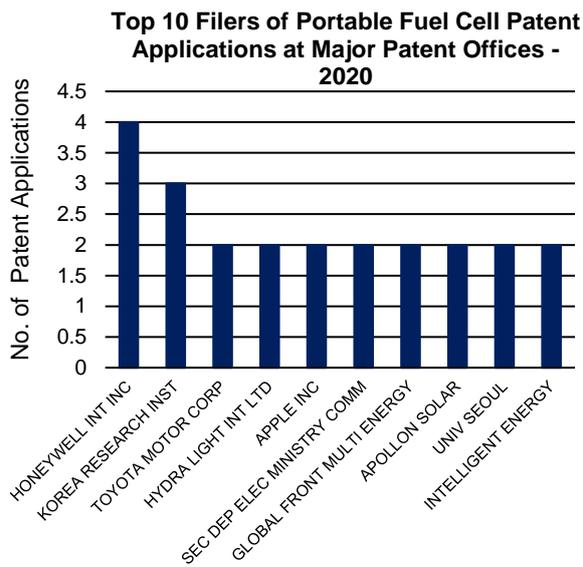


Figure A1.3.25. Top ten filers of portable fuel cell patent applications at the Top 5 Patent Offices for 2020

Figure A1.3.26 provides a technical comparison between patents filed for portable fuel cells for 2014 to 2019 as compared to a period ten years earlier.

Figure A1.3.26 shows that chemical technologies have become increasingly important with a relative decrease in handling technologies.

Again, the increase in purple bars shows that chemical technologies (purple bars) are becoming increasingly important, especially “Metallurgy” (major purple bar), with mechanical engineering technologies (green bars) (also slightly increasing relatively).

It should be noted that the size of the dataset for each respective period are not the same (2014/19< 2005/09) and so this graph provides information about relative changes between the periods.

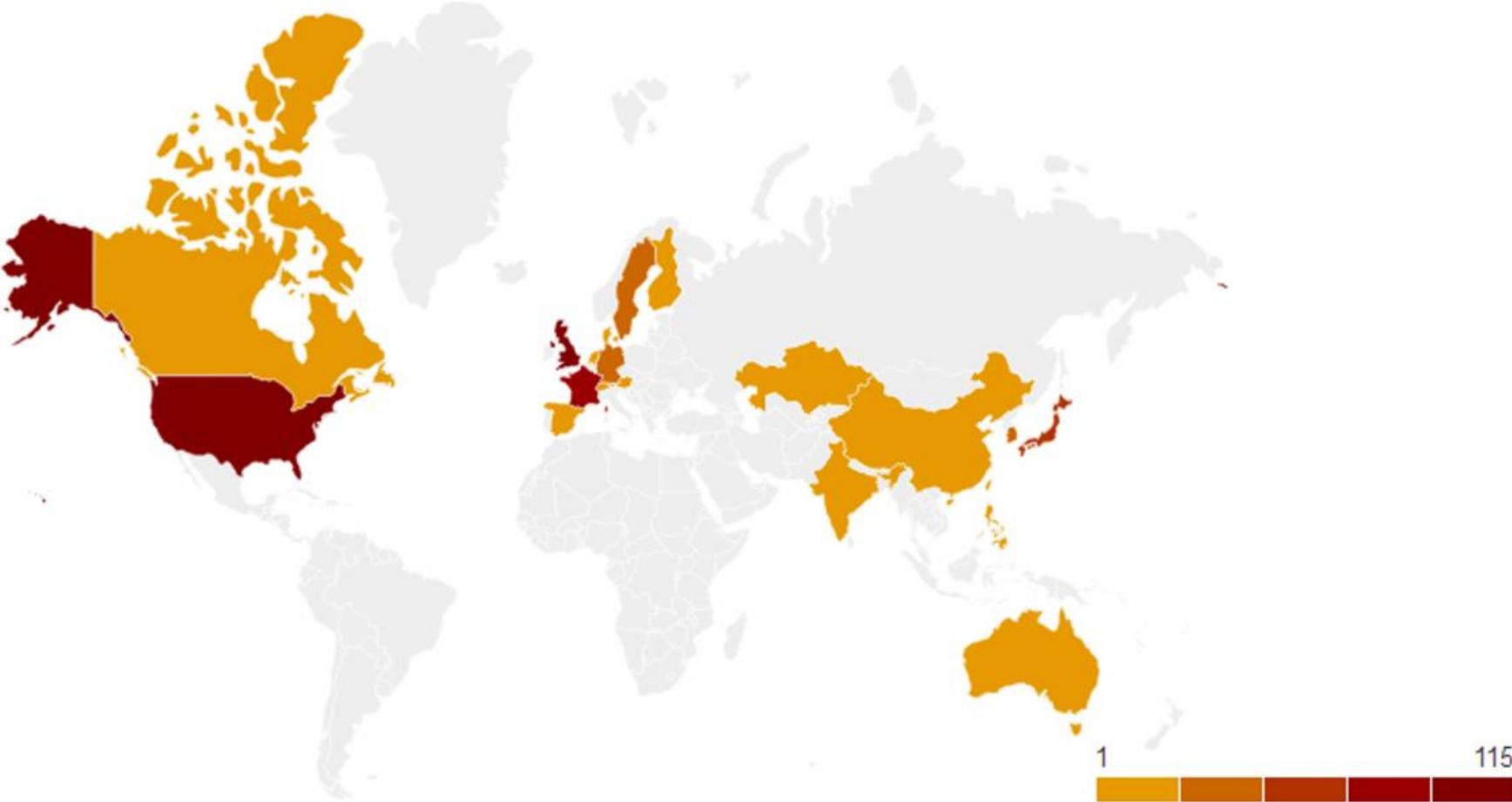
Technological Breakdown for Portable FC Patent Applications 2005 – 2009



Applicant location for worldwide Portable FC patent applications 2005 – 2009



Applicant location for worldwide Portable FC patent applications 2014 – 2019



A1.3.27. Geographical breakdown of application location in comparison with 2005-2009 (PI).

1.4. Hydrogen Transportation

The data presented below shows the top 10 filers of patent applications for hydrogen storage, distribution and production, for the years 2014 to 2019, for each of the top 5 offices. In each case the bars show the absolute number of patent applications associated with a particular entity.

1.4.1. Hydrogen Storage

The data presented below in Figures A1.4.1 to A1.4.7 shows the top 10 filers of hydrogen storage patent applications, for the years 2014 to 2019, for each of the top 5 offices.

The data shows that the number of patents filed by the top 10 assignees has increased significantly in 2019 and 2020 (compared to the period 2014 to 2018), with Toyota a prominent entity.

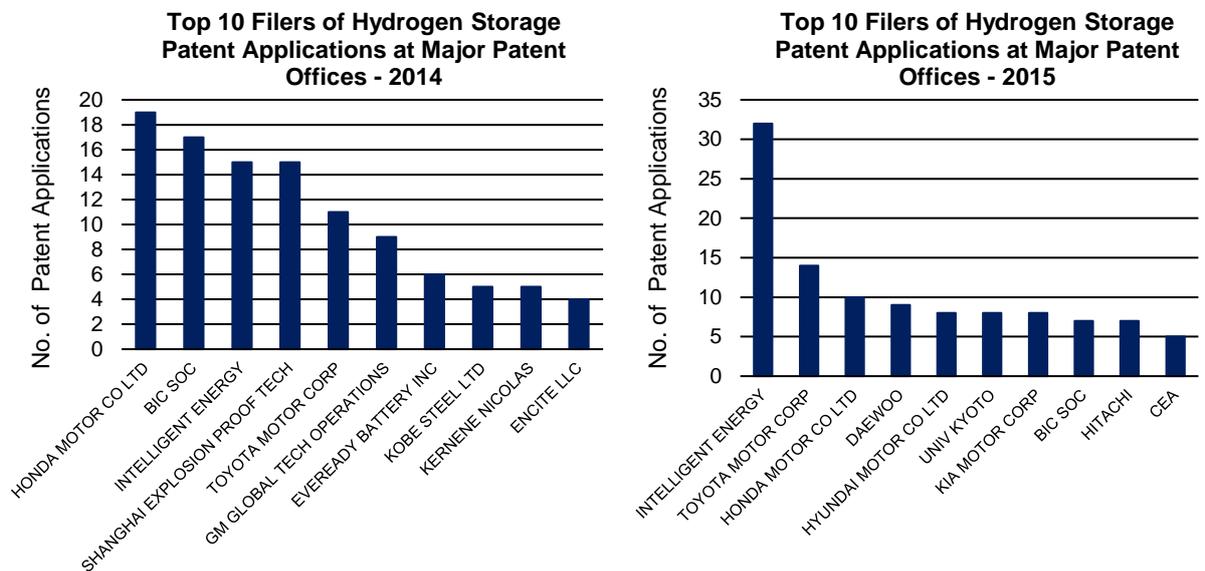


Figure A1.4.1. Top ten filers of hydrogen storage patent applications at the Top 5 Patent Offices for 2014.

Figure A1.4.2. Top 10 filers of hydrogen storage patent applications at the Top 5 Offices for 2015.

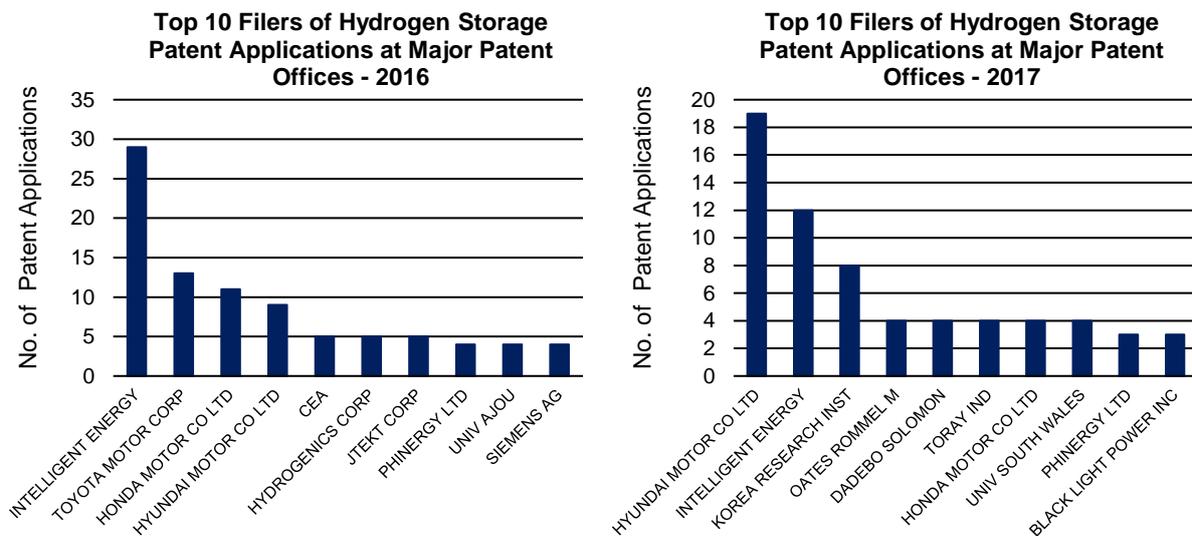


Figure A1.4.3. Top ten filers of hydrogen storage patent

Figure A1.4.4. Top 10 filers of hydrogen storage patent

applications at the Top 5 Patent Offices for 2016.

applications at the Top 5 Offices for 2017.

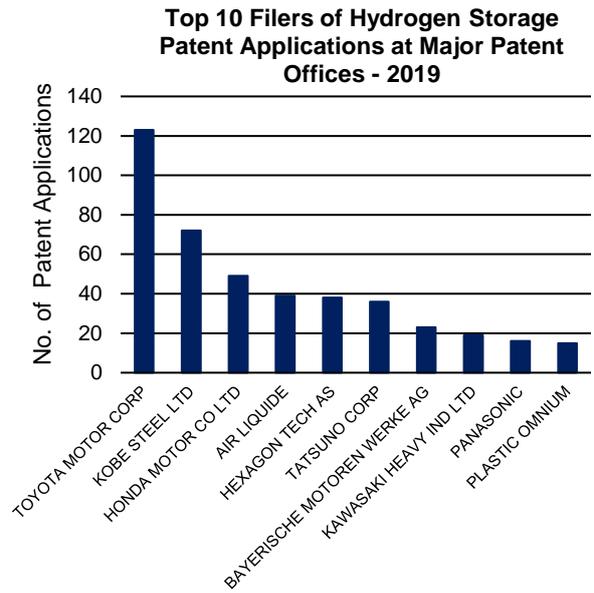
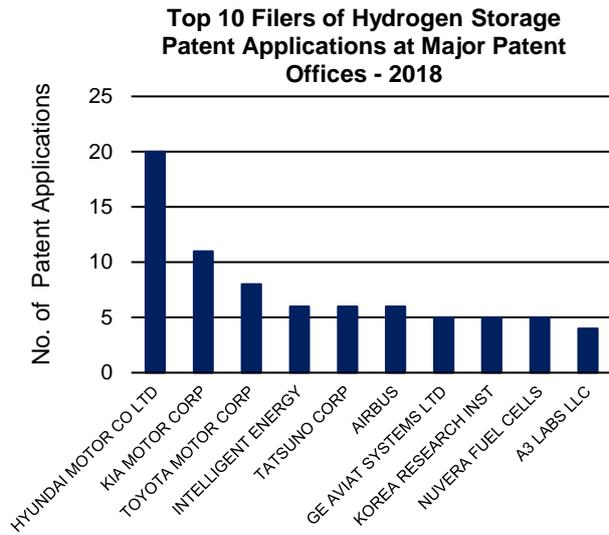


Figure A1.4.5. Top ten filers of hydrogen storage patent applications at the Top 5 Patent Offices for 2018.

Figure A1.4.6. Top 10 filers of hydrogen storage patent applications at the Top 5 Offices for 2019.

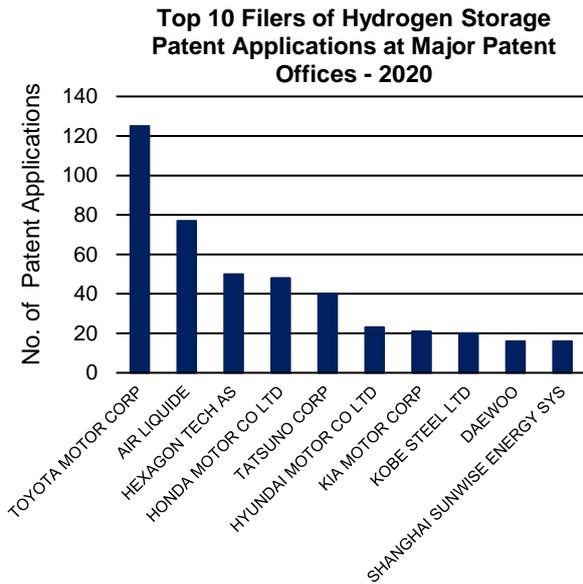


Figure A1.4.7. Top ten filers of hydrogen storage patent applications at the Top 5 Patent Offices for 2020.

1.4.2. Hydrogen Distribution

The data presented below in Figures A1.4.8 to A1.4.14 shows the top 10 filers of hydrogen distribution patent applications, for the years 2014 to 2019, for each of the top 5 offices.

Whilst the top filers appear to vary over the period, the number of patent applications filed within this sector remain relatively low.

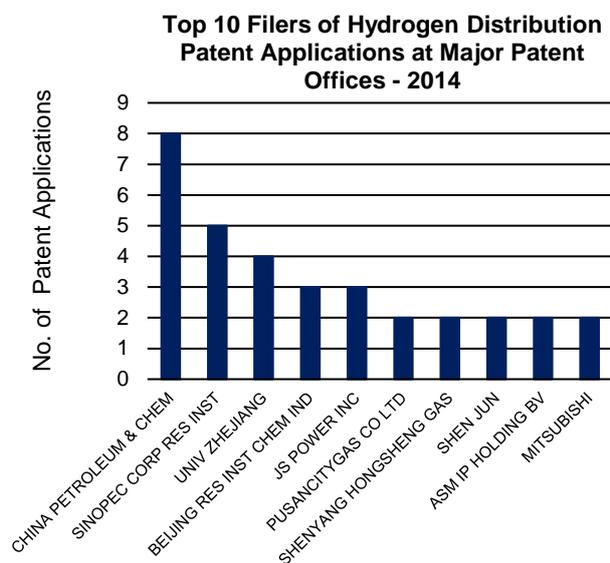


Figure A1.4.8. Top ten filers of hydrogen distribution patent applications at the Top 5 Patent Offices for 2014.

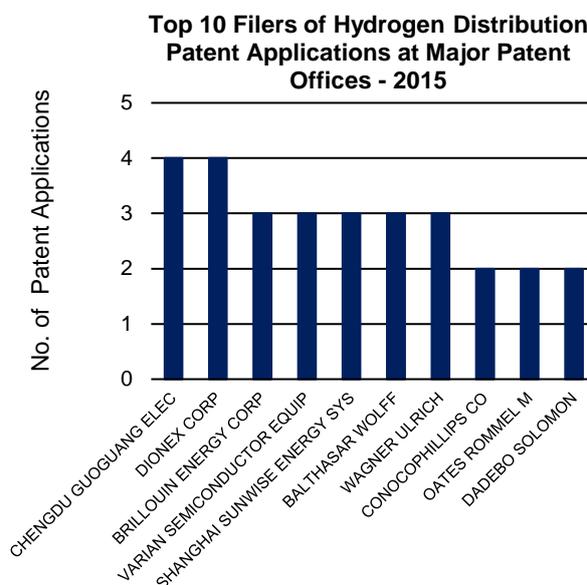


Figure A1.4.9. Top 10 filers of hydrogen distribution patent applications at the Top 5 Offices for 2015.

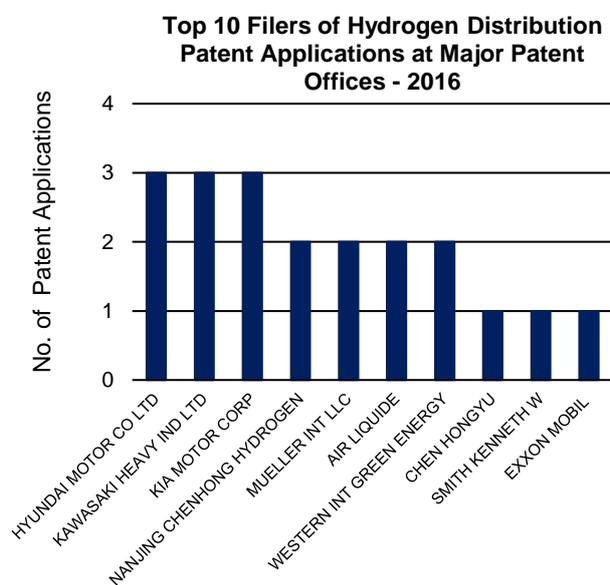


Figure A1.4.10. Top ten filers of hydrogen distribution patent applications at the Top 5 Patent Offices for 2016.

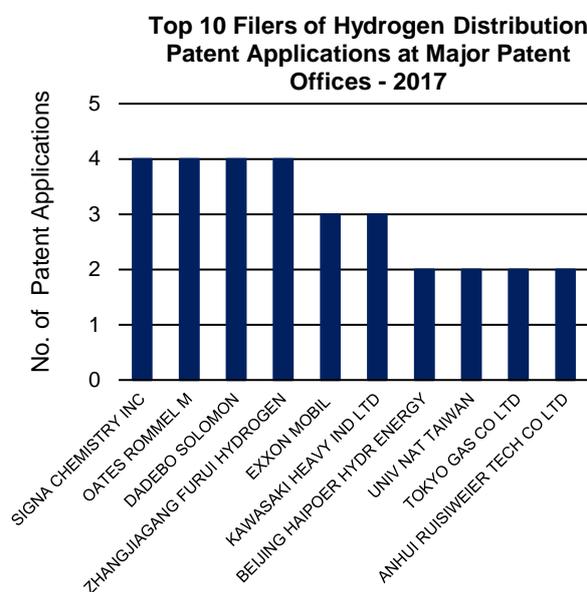


Figure A1.4.11. Top 10 filers of hydrogen distribution patent applications at the Top 5 Offices for 2017.

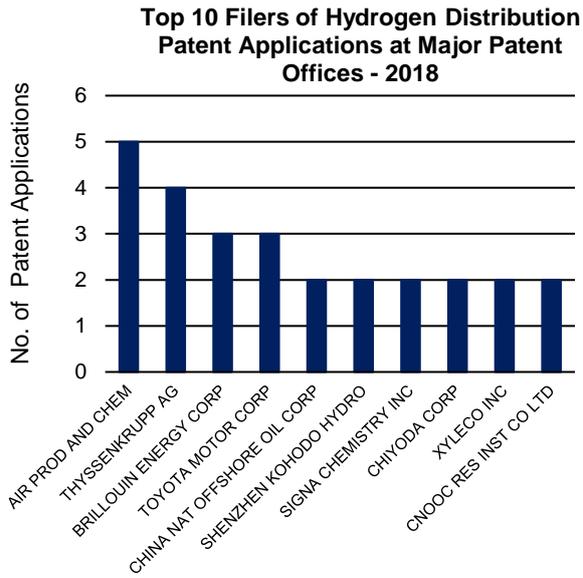


Figure A1.4.12. Top ten filers of hydrogen distribution patent applications at the Top 5 Patent Offices for 2018.

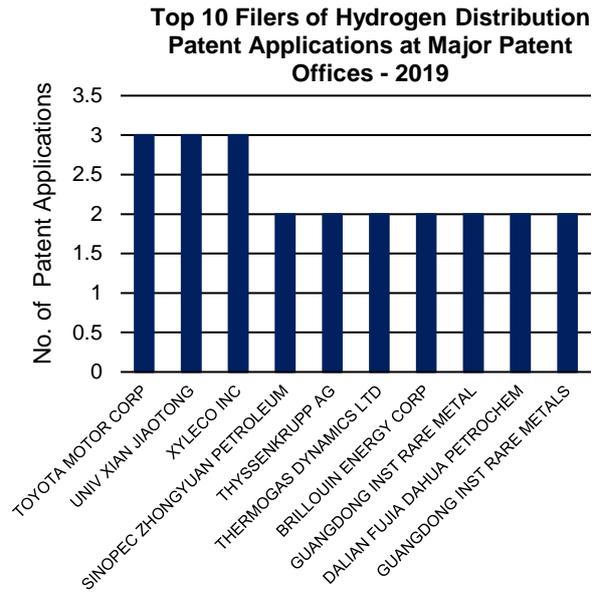


Figure A1.4.13. Top 10 filers of hydrogen distribution patent applications at the Top 5 Offices for 2019.

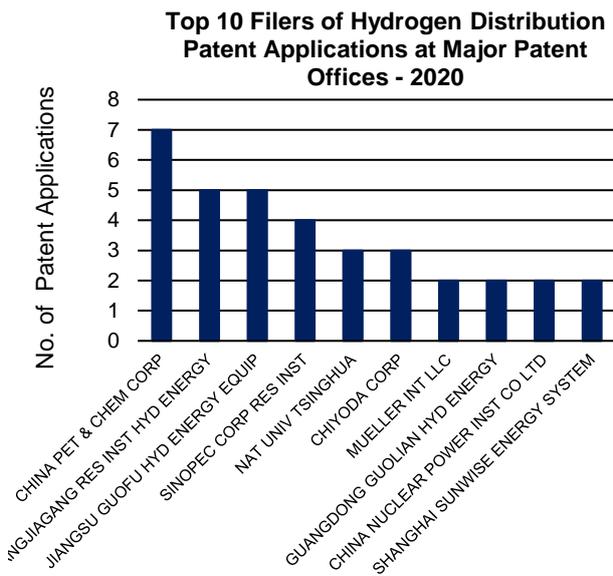


Figure A1.4.14. Top ten filers of hydrogen distribution patent applications at the Top 5 Patent Offices for 2020.

1.4.3. Hydrogen Production from Electrolysis

The data presented below in Figures A1.4.15 to A1.4.21 shows the top 10 filers of hydrogen production from electrolysis across the top 5 patent offices.

The top filers appear to vary over the period.

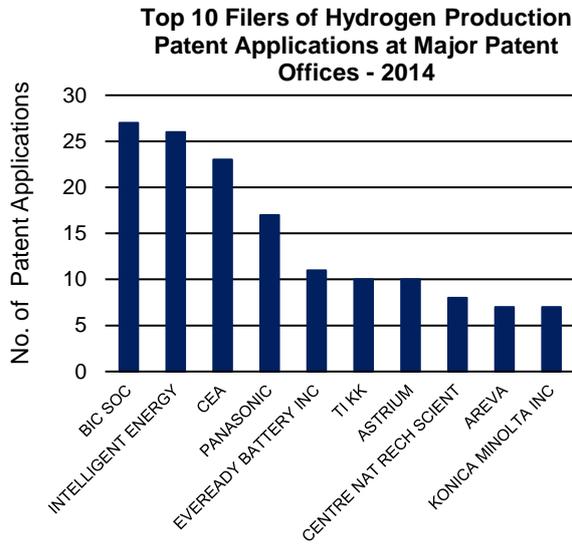


Figure A1.4.15. Top ten filers of hydrogen production patent applications at the Top 5 Patent Offices for 2014.

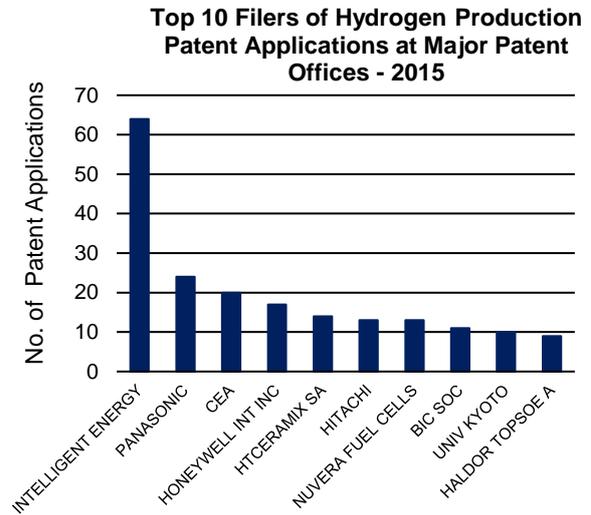


Figure A1.4.16. Top 10 filers of hydrogen production patent applications at the Top 5 Offices for 2015.

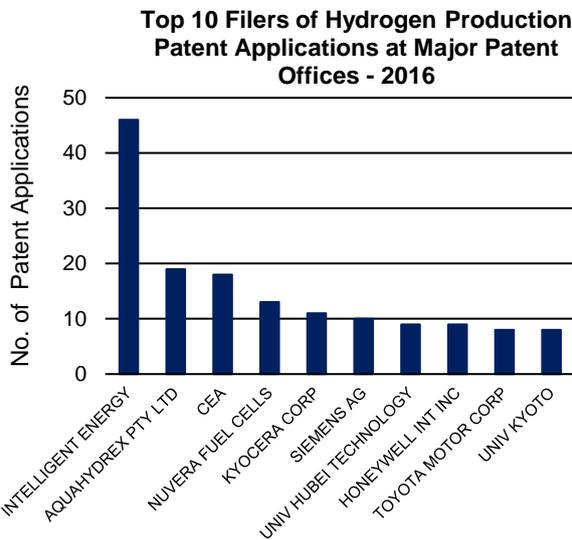


Figure A1.4.17. Top ten filers of hydrogen production patent applications at the Top 5 Patent Offices for 2016.

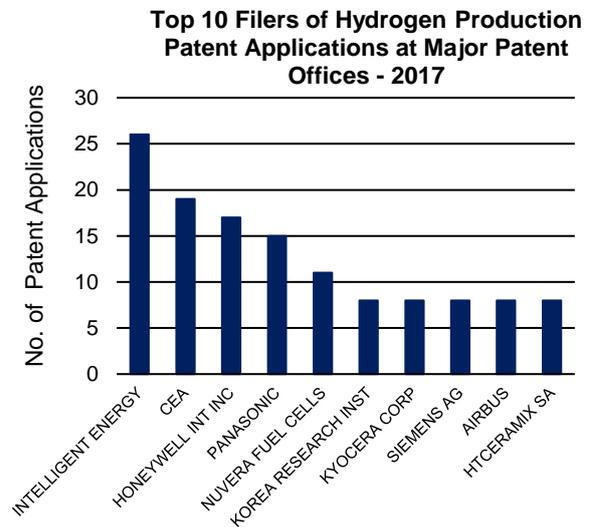


Figure A1.4.18. Top 10 filers of hydrogen production patent applications at the Top 5 Offices for 2017.

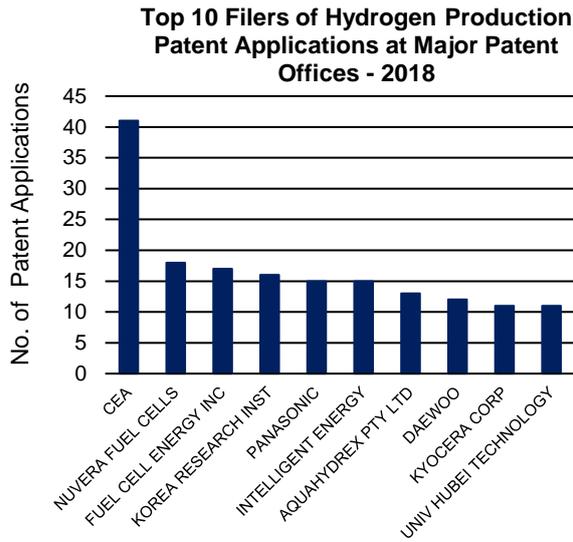


Figure A1.4.19. Top ten filers of hydrogen production patent applications at the Top 5 Patent Offices for 2018.

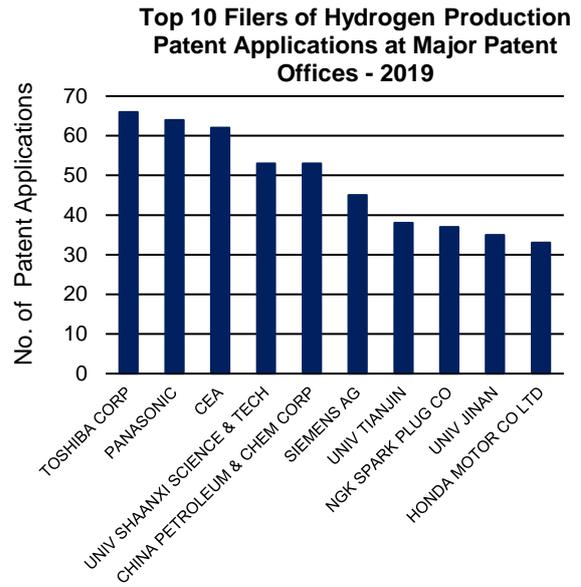


Figure A1.4.20. Top 10 filers of hydrogen production patent applications at the Top 5 Offices for 2019.

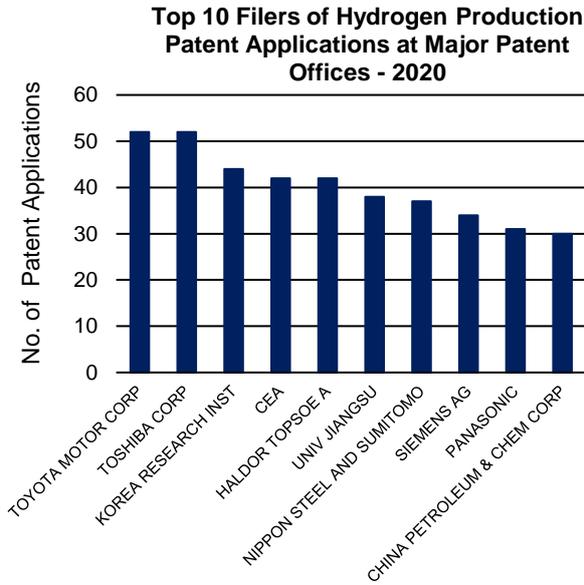


Figure A1.4.21. Top ten filers of hydrogen production patent applications at the Top 5 Patent Offices for 2020.

Chapter 6

2021 Education & Training Report

July 2021



Disclaimer

This report is based on data gathered as part of the Fuel Cells and Hydrogen Observatory as at 31st May 2021. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case by case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the FCH 2 JU. Neither the FCH 2 JU, other European Union institutions and bodies, nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein.

This report was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from <https://www.fchobservatory.eu/>

The Fuel Cells and Hydrogen Observatory has been prepared for the FCH 2 JU under a public procurement contract.

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Executive Summary

The Fuel Cells and Hydrogen Observatory (FCHO) is an ambitious project to collect available valuable sector information in a single go-to source and make it available to all interested stakeholders. The Education and Training module within the FCHO offers a single repository of training and materials in the field of hydrogen and fuel cells available across Europe.

The development and deployment of fuel cells and hydrogen (FCH) in the European market has highlighted the need for a trained and skilled workforce able to conceive, design, repair, maintain and operate the technologies of the sector. As the FCH market moves to commercialization and widescale sector adoption, the requirement for suitable training to provide the necessary skills to meet this market needs is becoming increasingly apparent.

With this idea in mind, the objective of the Education and Training chapter of the Observatory is two-fold. Firstly, it aims to list training offers providing a range of qualifications to assist in working in the FCH ecosystem. This first report evaluates the data collected between March and April 2021 through a survey sent to stakeholders active in the sector. To this date, 177 different training courses are mapped on the FCHO and whilst this mapping is not exhaustive, the ambition over time is to encompass all relevant training within the database.

Training courses included in the mapping refer to the different levels of education: Vocational training, Bachelor, Master, Doctorate and Post-Doctorate programmes. Off-curricula training is also listed, such as summer schools, workshops, or internships, as well as lifelong education opportunities with the professional training category.

Secondly the Education and Training chapter of the Observatory encompasses Education materials publicly accessible for learners and students interested in the field of FCH. The goal is to provide an online library relevant for different level of education, as described by the the International Standard Classification of Education (ISCED), different interests and in different languages.

Purpose:	<p>The Training section of the Education and Training module of the FCHO offers a repository of training available in Europe. In addition to the training programmes, Educational materials which are publicly accessible online, are also available to access on the FCHO.</p> <p>https://www.fchobservatory.eu/observatory/education-and-training</p>
Scope:	<p>The training courses are displayed by location within a map and users can explore the data by selecting the type of training of interest. Two additional filters on the language and the focus of the training are available to refine the search according to user needs. Users of the online tool can be students, professionals and individuals wishing to learn and be trained on FCH. To complement this mapping, a repository of online resources is accessible on the FCHO. Users may retrieve reliable materials available for self-learning.</p>
Key Findings:	<p>Master programmes and professional training courses were the most mapped categories.</p> <p>There is a prevalence of training courses offered by Western European countries in the mapping.</p> <p>The majority of the training courses mapped are targeted at technicians, engineers and doctorate.</p> <p>For Bachelor and Master programmes, FCH is more often an element integrated in a programme than its main focus.</p> <p>“Hydrogen Production” and “Hydrogen end-uses: transports” were the most selected focus of courses among the 11 categories proposed.</p> <p>“Regulations, Codes and Standards” was the least selected focus with only one training out of five tackling these aspects.</p> <p>Professional training is more often focusing on end-uses and safety than Master programmes.</p> <p>Master programmes put a strong emphasis on “Basic electrochemistry”, “Hydrogen production”.</p> <p>European projects are the main source for publicly accessible materials to learn on FCH.</p> <p>Most of the materials listed are available in English.</p> <p>“Hydrogen End-Uses” is the focus category the most common in the materials listed.</p>

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1. Introduction

Despite the global pandemic of 2020, the FCH sector has not experienced a crisis questioning its existence and hindering its development, in fact quite the opposite. On the political stage, several milestones set the European ambitions for the sector: the European Commission¹, the Council of the EU², and the European Parliament³ all adopted their institutional strategy in view of the largescale deployment of hydrogen in the economy.

Furthermore, the launch of the Clean Hydrogen Alliance in July 2020 mobilised stakeholders from all over Europe to coordinate efforts at EU level to create a clear view on investment needs. One of the alliance goals is to “*support the related skills and labour market adjustments where needed*”. The question of the need for skills and training courses has also been stressed by the European Parliament’s initiative report.

MEPs called on the Commission “to adopt an action plan aimed at guiding Member States to develop and maintain dedicated training programmes for workers, engineers, technicians, and the general public and to create multi-disciplinary teaching programmes for economists, scientists and students”⁴

Considering the challenges to train, reskill and upskill workers for jobs in the hydrogen sector, the training section of the FCHO aims to provide a first tool to assess the supply of training courses available and to list reliable learning materials available online. This database created will be useful for students interested in starting a career in the field of hydrogen, companies wishing to upskill and reskill their workforce to adapt to technological changes, but also to education providers and policy makers, to identify gaps and create new training courses to meet those needs.

Whilst the FCHO does not have the pretention to map all relevant training opportunities in Europe, it does provide a first basis to capture the current landscape for further analysis. With time and growing visibility, the ambition of the FCHO is to encourage training providers to contribute to this mapping and to be a part of this growing community of Education & Training providers.

The initial data collection for training took place in May/June 2020, which provided useful feedback to feed into the latest data collection cycle and refine the objectives and methodology of the activity. The questionnaire which collected the course data, was reviewed to include more categories of training (professional and vocational training courses) and to present additional information on each training which had been identified as important to users. Lastly, further categorization of the training courses (‘focus’) was included to enable useful filtering, which will be particularly important as the database grows.

This report aims to provide an overview of the data collected between March and April 2021 and an analysis of the main trends.

The second section of this report focuses on the learning materials publicly accessible online. The report provides a general overview on the ones identified and focuses on the breakdowns for each of the filters displayed on the website.

¹ Communication from the Commission on “A hydrogen strategy for a climate-neutral Europe”, 8 July 2020

² Council conclusions “Towards a hydrogen market for Europe”, 11 December 2020

³ Initiative report of the European Parliament “A European Strategy for Hydrogen”, adopted in plenary on 25 May 2020

⁴ Ibid., point 30.

2. Training programmes

2.1. Data collection methodology

The data presented on the Observatory was predominantly collected through an online questionnaire sent to stakeholders. The responder could participate via a survey set up on Google Form for each of the training categories identified.

The 2021 data collection took place over March and April. Over 200 organisations were contacted to reply to the questionnaire, amongst those contacted were universities, research centres, companies, and public authorities. Different networks were employed to maximise the number of respondents: Hydrogen Europe Research, the Hydrogen Valleys S3 partnership and Hydrogen Europe’s skills working group. Additional organisations were identified through online research. The call to participate was broadly shared in France through a regional network (Régions de France) and the French Research network on Hydrogen energy of the CNRS.

The data collection and update of the existing training courses will be completed annually and will enable an understanding of how the roll-out of fuel cells and hydrogen is supported by the development of appropriate training courses.

Respondents

More than 2/3 of the training courses were provided by universities. Other training providers include RTOs, companies, professional training organisations, training courses from European projects, other higher education organisations, public entities, clusters, etc. This can be seen in the Figure 1 below. The data is shown for all the trainings listed however one contributor may have listed several trainings.

Figure 1 – Training providers for the identified training

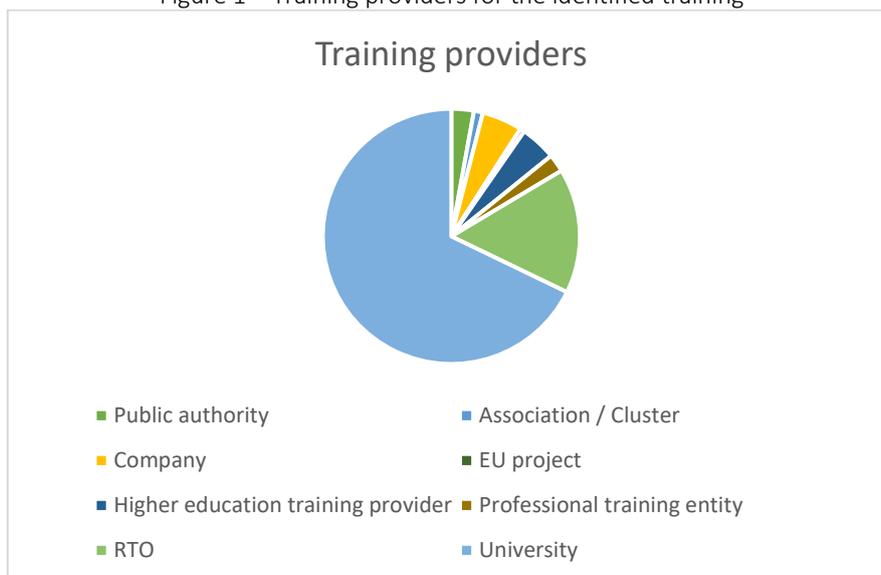


Figure 4 provides an overview of the country participation.

Entries from the French Parcours Sup

Thanks to an exchange with a French expert missioned by the ministry of Higher Education, Research and Innovation to evaluate the supply of training courses in the field of fuel cell and hydrogen in France, several training programmes for students were identified.

Some of them – specifically focusing on hydrogen – were already included in the mapping. Others were added after this discussion using the Parcours Sup database⁵. Two programmes were added with 195 entries corresponding to the different locations where the programmes are taught. These entries matched the vocational training category as they refer to the level 5 of the ISCED classification. Not all the training courses identified by the French expert were included as an educational reform is ongoing on some of the courses identified, and due to time constraints to complement the mapping for this year's annual review.

A number of actions have been identified as potential ways to increase the stakeholder participation in the annual survey:

- The use of Parcours Sup will be further explored for the next update. Identifying similar databases in use in other countries will be of added value to grasp a comprehensive view of the educational system across Europe.
- Get in touch with human resources and training organisations working in the field of hydrogen and fuel cells.
- Identify on a national basis the actors implementing continuous professional development and vocational training courses.
- Find online databases publicly accessible at national or regional level and identify there relevant training courses.
- Use social media outreach from the FCHO / FCHJU communications activities as a 'call to participate'

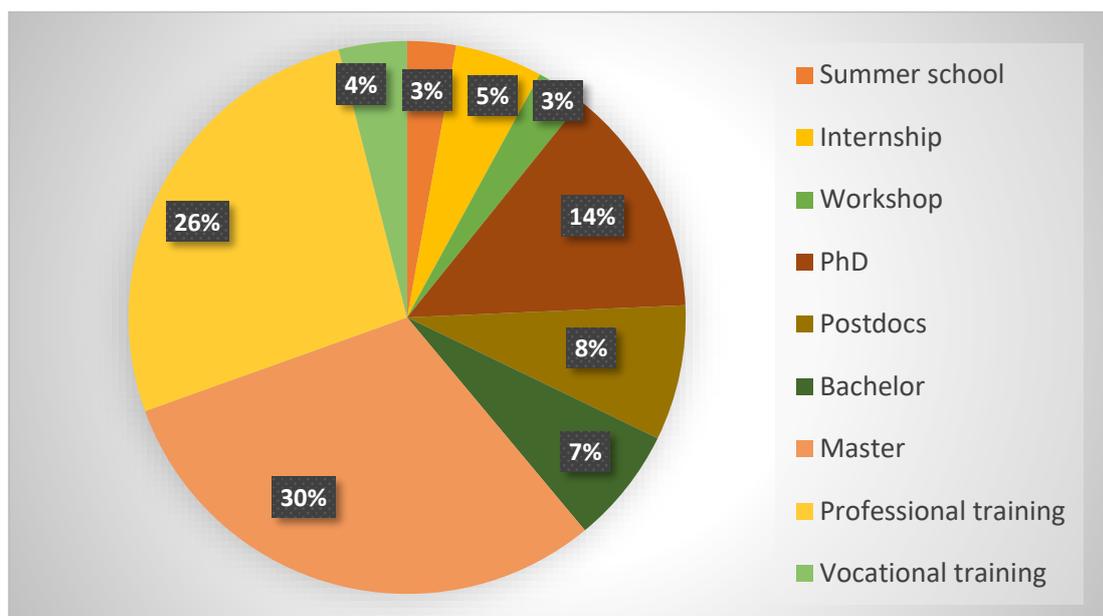
2.2. Analysis of responses received

2.2.1. Focus on the training categories

177 training courses are currently listed on the FCHO (two of which are French programmes with a further 195 discrete training courses in different locations). In the following analysis, only the 177 training courses will be considered.

⁵ The Parcours Sup database is a web platform designed to collect and manage the assignment wishes of future students in French higher education.

Figure 2 - Share of training courses by category⁶



Bachelors and Masters

- Bachelor and Master programmes account for over 1/3 of the training courses mapped. As these programmes are harmonised across Europe thanks to the Bologna system, it makes them more easily comparable from one country to another.
- All but one of the Bachelor and Master programmes listed aim at training engineers.
- Only a few Masters provide training courses specifically on FCH; more often FCH is part of a broader curricula such as Chemical engineering, Mechanical engineering, or Materials Sciences.
- The Bachelors programmes listed remain general and do not focus on FCH.

Professional Training courses

- The scope of professional training courses range from general to specific. For example, training courses on a specific electrolysis process can be found.
- The professional training courses captured mainly target engineers and technicians. However, some of them reach out to a non-expert audience (e.g. decision makers).
- Most training courses can be taken online or organised in different locations.
- About 4/5 of the training courses listed are available in English.

Vocational Training courses

- Only 7 different training courses⁷ were listed in this category. Three of them provided by the same entity put an emphasis on maritime and shipping.
- The diversity of vocational training system across Europe makes it difficult to capture the different nuances existing at national level in a one-size-fit all questionnaire. The functioning may greatly differ when it comes to the length of the training, the target audience, the level of qualification required and the likely jobs functions, from one region to another.
- Having a closer look into the national systems of vocational training courses and assess if subcategories are necessary might be beneficial to give a more accurate picture of European training courses in this category.

⁶ 195 vocational training courses are counted as 2 in this analysis

⁷ This accounting the 195 French vocational training courses as two entries.

- Furthermore, these training courses are sometimes defined by national or regional authorities in charge of education and in collaboration with stakeholders from the sector. A top-down approach might be preferable to a bottom-up approach in this case. Identifying the relevant curricula rather than sending a questionnaire to entities that might be providing vocational training courses in the field of FCH could help to create a more comprehensive mapping.

PhDs, Postdocs and Internships

- A few of the PhD schools listed specifically address FCH, whilst the majority of them have a broader focus, for example on energy or mechanical engineering.
- The approach chosen to identify postdoctoral positions and internships was to list organisations providing such opportunities on a regular basis without describing in detail the offer. The relevance of these categories for users should be confirmed and a more systematic approach could be taken by asking members of different associations whether they provide such opportunities and wish to participate on the FCHO. Only a limited number of details could be shown there, including the focus of the training proposed.

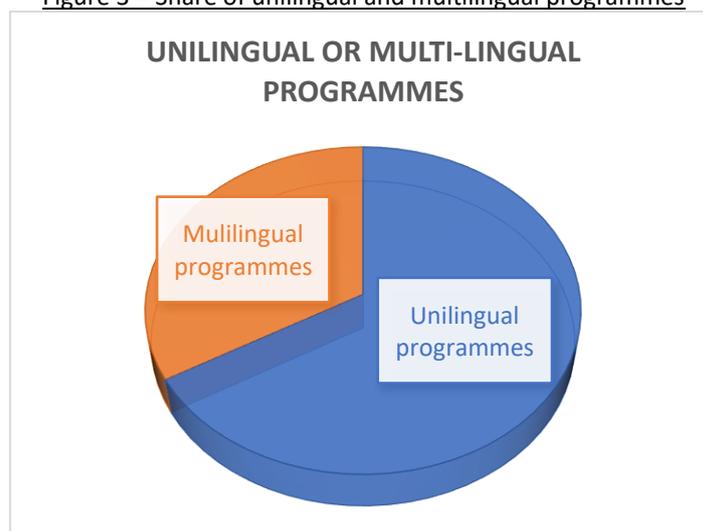
Summer Schools and Workshops

- By including Summer Schools and Workshops, the goal is to map regular learning opportunities for the FCH community.
- For the moment, 10 recurring events are listed. This information may be useful for students but also for professionals.

2.2.2. Focus on the languages of the programme

As shown in Figure 2, about two thirds of the programmes mapped are unilingual against one third being multilingual. This doesn't necessarily mean that both languages must be spoken but rather indicates the possibility to choose the language of teaching.

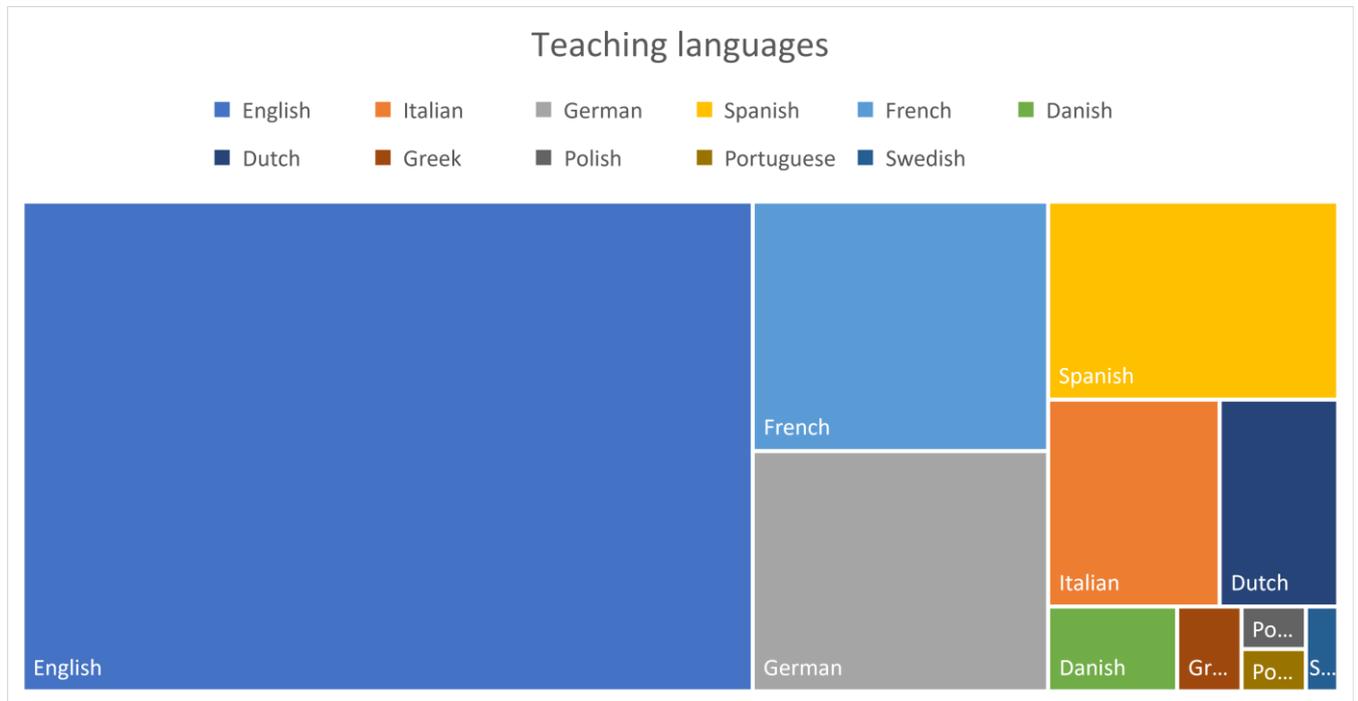
Figure 3 – Share of unilingual and multilingual programmes



Most of the programmes mapped are taught in English (55%). French and German are then the most common teaching languages (about 11% for each), followed by Spanish (9%), Italian (6%), Dutch (4%), Danish (2%). Other languages include Greek, Polish, Portuguese and Swedish (less than 1% of the trainings each).

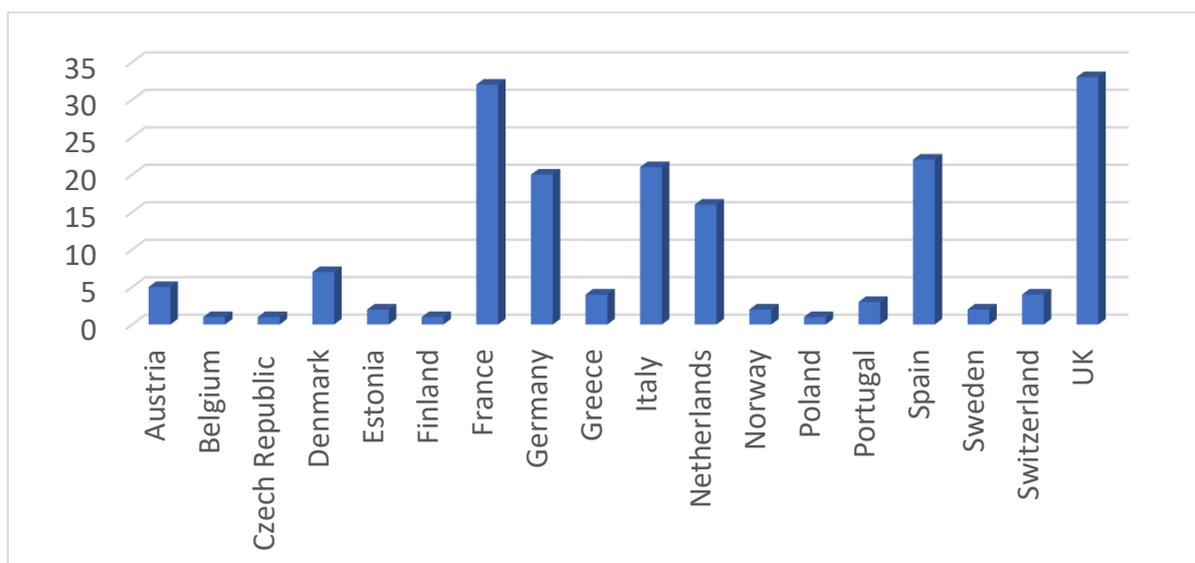
Having a majority of training programmes taught in English mapped on the Observatory makes sense, as the website itself is in English and the data collection was organised in English.

Figure 4 – Overview of the teaching languages



2.2.3. Focus on the geographic spread

Figure 5 - Training courses by country⁸



⁸ This accounting the 195 French vocational training courses as two entries.

18 countries are included in the mapping and offer training opportunities in the field of FCH. However, this does not mean that countries not mentioned here do not offer relevant opportunities.

One may note there is a prevalence of Western European countries, both in numbers and in share of training courses offered. However, Czechia, Poland and Estonia are also included in the mapping.

Together, 6 countries (FR, DE, IT, NL, ES, UK) account for more than 4/5 of the training courses entered. These countries either have a dedicated hydrogen strategy/roadmap and/or have publicly given their support to the development of a FCH market. Of course, these countries are also the most populated ones in Europe and as such a high number of training courses might be expected.

2.2.4. Focus on the subjects of the training

When describing a training offer, the responder was always asked to identify the relevant ‘focus’ for the relevant course. There were no limits in terms of number of focus categories that could be selected. You can find below the categories proposed and the explanations of the different items:

- a) **Basic Electrochemistry** *refers to chemistry on the interrelation of electrical and chemical changes caused by the passage of current.*
- b) **H2 Production** *refers to the different means to produce hydrogen (electrolysis, gasification, biomass, etc.)*
- c) **H2 Storage, Transport and Distribution** *refers to the methods used to store, transport and distribute hydrogen (e.g. storage in salt cavern, transport via pipelines, etc.)*
- d) **H2 End-uses: transports** *refers to vehicles using hydrogen or hydrogen derivative synthetic fuels in fuel cells or ICE. All transport sectors are included: road, maritime, aviation, rail and off-road.*
- e) **H2 End-uses: industry** *refers to hydrogen used in some industrial processes (e.g steel manufacturing, chemicals, etc.)*
- f) **H2 End-uses: buildings** *refers to electrical, heating and cooling applications including fuel cells, CHP, boilers, etc. using hydrogen, hydrogen derivative synthetic fuels, biomass or biogas, etc.*
- g) **H2 End-uses: energy, power generation** *refers to the production of electricity using hydrogen, hydrogen blends or ammonia in turbines and/or fuel cells.*
- h) **Regulations, Codes, Standards** *refers to the development and use of harmonized performance-based standards for FCH appliances and systems.*
- i) **Safety** *refers to the safe production, handling and use of hydrogen, particularly hydrogen gas fuel and liquid hydrogen.*
- j) **Life Cycle and Social Assessment, eco-design, recycling,** *refers to environmental and sustainability aspects of FCH.*
- k) **Technical-economic evaluation** *refers to training courses at the crossroad of business and engineering to evaluate the technical possibilities of the technology whilst considering its economic cost.*

As the ‘focus’ filter is common to all training categories, it provides a relevant tool of analysis to see the topics that are most widely taught within the training courses listed.

Table 1 below provides an indication of the most often encountered training focus categories, however, it does not indicate how central the focus category on a given topic is. For example “Safety” could be either one of the areas tackled in a programme or the main focus category of the training.

Table 1 – Breakdown by focus for all training courses

Coloured in grey you may see the focuses that are tackled in more than half of the training courses.

Training Focus	Percentage of training indicating the focus category
Basic Electrochemistry	51%
H2 Production	64%
H2 Storage, Transport and Distribution	57%
H2 End-uses: energy, power generation	56%
H2 End-uses: industry	38%
H2 End-uses: transports	62%
H2 End-uses: buildings	33%
Safety	45%
Regulations, Codes, Standards	19%
Life Cycle and Social Assessment, eco-design, recycling	29%
Technical-economic evaluation	32%

About two thirds of the training courses tackled the topic of “H2 production” (64%) and/or “H2 End-uses: transports” (62%). They were the most selected areas of focus across training courses. The least selected focus was “Regulations, Codes and Standards” (RCS), which was only tackled in about 1/5 of the training courses mapped.

As professional training courses and Master programmes have had a significant number of entries, a comparison for these two training categories can be made. The results are presented in the Table 2.

Table 2 – Breakdown by focus for professional training courses and Master programmes
Coloured in grey you may see the focuses that were picked to describe more than half of the training courses in the corresponding category.

Training Focus	Percentage of professional training courses indicating the focus category	Percentage of Master programmes indicating the focus category
Basic Electrochemistry	51%	72%
H2 Production	49%	74%
H2 Storage, Transport and Distribution	47%	67%
H2 End-uses: energy, power generation	45%	37%
H2 End-uses: industry	34%	12%
H2 End-uses: transports	57%	33%
H2 End-uses: buildings	40%	22%
Safety	45%	22%
Regulations, Codes, Standards	32%	13%
Life Cycle and Social Assessment, eco-design, recycling	9%	20%
Technical-economic evaluation	26%	19%

The focus categories of the training courses tend to be more diverse for professional training courses than for Master programmes.

A shift in the focus from Master programmes to Professional training courses

Professional training courses more often tackle end-uses than Master programmes. The latter are more emphasising on basic electrochemistry, hydrogen production and hydrogen storage, transport and distribution focuses.

About 3/4th of the Master programmes mapped focus on basic electrochemistry (72%) and hydrogen production (74%) and this indicates that these are central elements of the programmes proposed. Comparatively, only half of the professional training courses listed focus on these same topics (49% for production and 51% for basic electrochemistry). These numbers remain high respectively to the percentage indicated for the professional training category.

Industry end-uses

Within the end-uses, the industry focus was the least selected for both Master programmes and professional training courses. Having a closer look at the university path to work, for example, in the steel or in the chemicals industries could provide some elements of answers this figure. Furthermore, investigating how hydrogen is taken into consideration in the training of workers in this area could be relevant to analyse this aspect from a qualitative perspective.

Safety, RCS, Technical-economic evaluation

The topics of Safety and of RCS were more often chosen as a focus for professional training courses than for Master programmes. One possible explanation could be that skills needed on these particular thematic are taking a new dimension in a given work context. Master programmes might choose to put less emphasis on these issues that may vary from one workplace to another.

Technical-economic evaluation is also a more chosen topic for professional training courses than Master programmes, but the difference is low. The topic was generally not broadly chosen compared to others. This may be explained by the fact that a majority of the training courses mapped were targeted at engineers and/or technicians, for whom the technical-economic evaluation might not be relevant. It could be interesting to reach out to more business centred training provider (e.g. business schools) to understand the offers they have in relation to hydrogen including techno-economic evaluation.

LCSA eco-design and recycling

Finally, LCSA eco-design and recycling is generally the least selected category. It was more often chosen for Master programmes than for professional training courses. This could indicate that these questions are at an earlier stage of development than the other that were included in the questionnaire and may be less interesting for professionals.

2.3. Areas for future consideration in the Training section

Areas for consideration in improving the data collection and analysis are mentioned throughout the report. On the data collection and how to reach out to more training providers, several ideas are discussed in the data collection methodology section.

After the publication of a White paper on skills and professions in the hydrogen sector⁹ and a repository of jobs and skills¹⁰ by [France Hydrogène](#), some new conceptualisation tools could be implemented to better analyse and map training courses.

A list of suggestions that could be considered are as follows:

1. Adding a colour code to describe how much the training focuses on hydrogen or on a given topic. This could translate into percentages for each training.

e.g. Safety could be the main focus of a training (100%) or be a smaller aspect tackled throughout other problematics (10%).

2. Providing an indicator to describe the activities to which the training is targeting.

e.g. conception, manufacturing, installation, operation, maintenance, etc.

3. Specifying the type of job function/role the training is addressing.

e.g. engineers, technicians, sales, etc.

⁹ Livre blanc des compétences et métiers de la filière hydrogène, France Hydrogène, avril 2021

¹⁰ Référentiel des métiers et compétences, France Hydrogène, avril 2021

3. Education materials

The Education materials module of the Observatory lists courses and education materials publicly accessible online. This section is meant to act as an online library on FCH learning materials. 241 reliable materials may be retrieved on the platform. It is conceived as a go-to-resource gathering materials developed in the framework of European projects and will be periodically updated.

Several filters are available in the library to refine the search of users according to their needs. It is possible to select the ISCED level (ranging from 2 to 8), the course focus, the language, or the source. The materials listed were created between 2006 and 2020. Most of them are slides or text documents. Some exercises, videos, games, or experiments are also available.

3.1. Focus on sources

The materials listed were collected through pre-identified European projects. 8 different sources are currently included. The 8 source projects are the following:

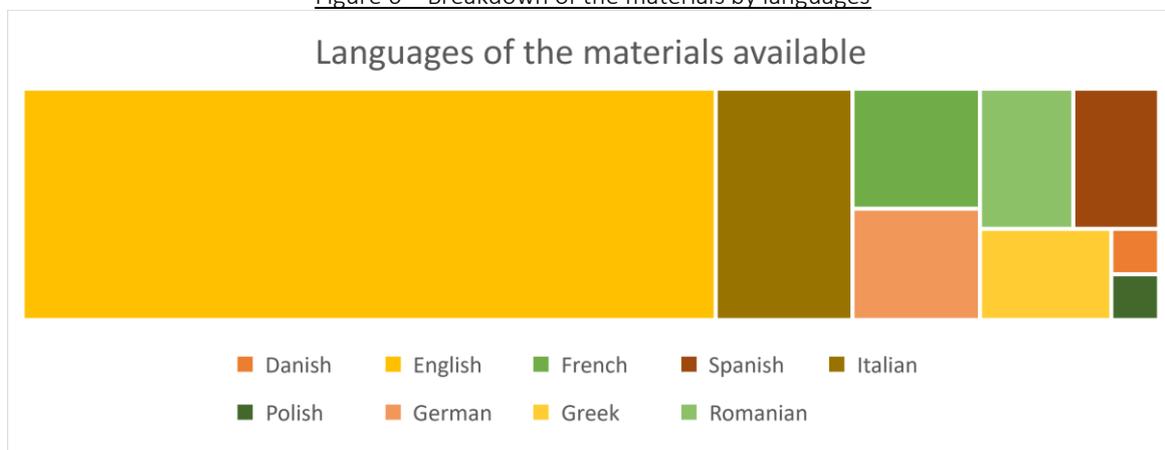
- TrainHy
- CertifHy
- FCHGO
- H2 Training
- HyFacts
- HyResponse
- NET-Tools
- PACE

The approach chosen was to list materials developed by European projects as their ownership is usually clear and the project results benefit from advertisement. Therefore, only materials created with the goal of being public were shared in the library.

3.2. Focus on languages

Materials in 9 different languages are currently listed in the library. Most of them are in English language (61%). Materials in Italian language are then the most common ones (12%), followed by French (6%), German (5%), Romanian (5%), Spanish (5%), Greek (5%), and then Polish (less than 1%) and Danish (less than 1%).

Figure 6 – Breakdown of the materials by languages



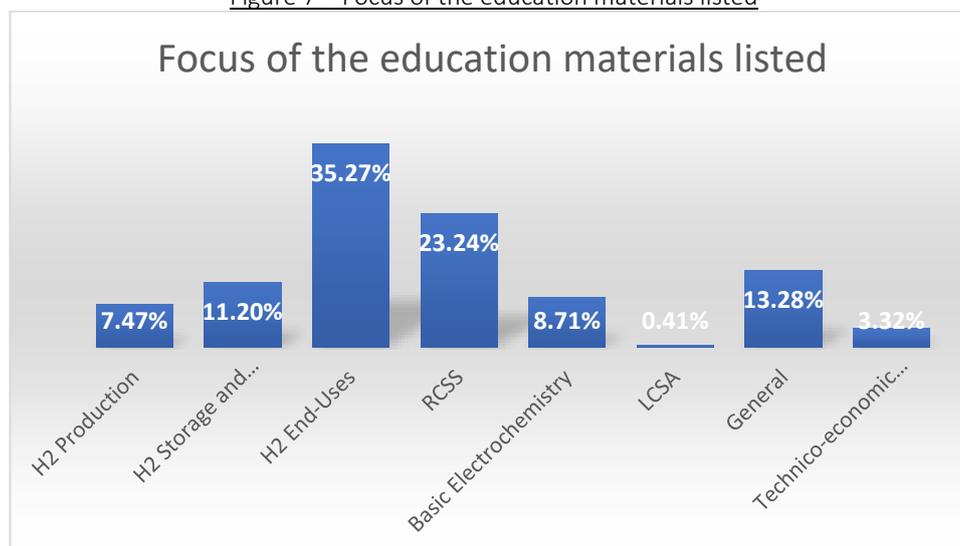
3.3. Focus on the course topic

Several categories have been defined to classify the materials on the website and allow users to retrieve courses on a given topics. The following categories were identified:

- **General** refers to information remaining at a broad level of understanding, not going into technical details
- **H2 Production** refers to the different means to produce hydrogen (electrolysis, gasification, biomass, etc.)
- **H2 Storage and Distribution** refers to the methods used to store, transport and distribute hydrogen (e.g. storage in salt cavern, transport via pipelines, etc.)
- **H2 End-Uses** refers to hydrogen usages in transport, industry, buildings or to generate power.
- **Regulations, codes, standards and safety** (referred to as RCSS in Figure 6) refers to the development and use of harmonized performance-based standards for FCH appliances and systems and to the safe production, handling and use of hydrogen, particularly hydrogen gas fuel and liquid hydrogen.
- **Basic Electrochemistry** refers to chemistry on the interrelation of electrical and chemical changes caused by the passage of current.
- **Life Cycle and Social Assessment, eco-design, recycling** (referred to as LCSA in the Figure 6) refers to environmental and sustainability aspects of FCH.
- **Technico-economic evaluation** refers to courses at the crossroad of business and engineering to evaluate the technical possibilities of the technology whilst considering its economic cost.

Over one third of the materials listed tackle H2 End-uses and about a quarter of them focus on RCSS. The European projects tackled greatly these two areas. LCSA is the least tackled focus category in comparison with only one material focusing on this specific issue.

Figure 7 – Focus of the education materials listed



3.4. Areas for future consideration in the Education materials module

1. Implementing an automatic reporting for materials developed in European projects

Implementing an automatic reporting between European projects on FCH developing materials and trainings on hydrogen and fuel cells and the FCH Observatory team would be of great added value to

develop the library. All materials developed as part of project could automatically be added to the website. The responsible project partners could be able to download from the website a template to list and classify their materials as required. This would help overcome the language barrier when listing learning materials in foreign languages and ensure that the different categories are filled in appropriately by the authors.

2. Expand the scope of listed materials

The scope of what is included in the library could be expanded to include more documents, such as studies and reports on FCH development or on a particular assessment of the FCH sector. A dedicated category outside the ISCED scope might need to be established if this change is pursued. Expansion of the materials section would need to be in line with appropriate copyright law.