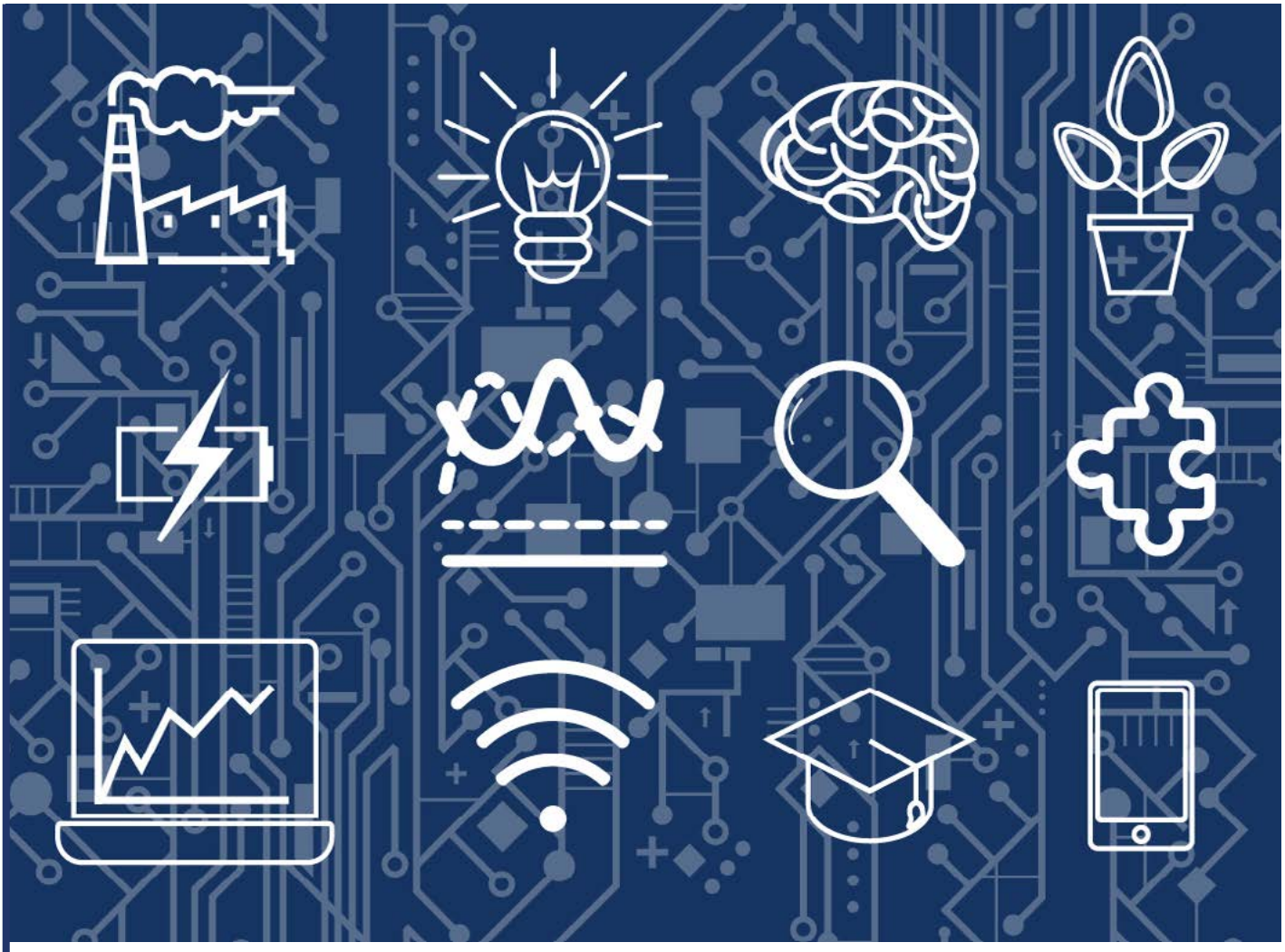
Intellectual Property Office

Low-carbon hydrogen

A worldwide overview of patenting related to the UK's ten point plan for a Green Industrial Revolution



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Low-carbon hydrogen
A worldwide overview of patenting related to the UK's ten point plan for a Green Industrial Revolution

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1. Introduction

1.1 Background

In June 2019, the UK became the first major economy to set a legally binding target to reach net zero greenhouse gas emissions by 2050, in recognition of the transformative change needed to tackle global climate change.[1]

The Energy White Paper (EWP)[2], published in December 2020, and the Industrial Decarbonisation Strategy[3], published in March 2021, set out complementary plans for the transformation of our energy system and industries, including actions to fully decarbonise electricity generation by 2050.

On the international stage, the UK has co-assumed[4] the presidency of COP26 (26th UN Climate Change Conference of the Parties) and is hosting the COP26 UN Climate Change Conference in Glasgow in November 2021.[5,6]

In November 2020 the UK government released a ten point plan for a green industrial revolution,[7] comprising:

- **Offshore wind:** produce enough offshore wind energy to power every home in the UK, producing up to 40 gigawatts by 2030.
- **Hydrogen:** reach a five gigawatt production capacity of 'low carbon' hydrogen by 2030 – for industry, transport, power and homes – and develop the first town heated by hydrogen by the end of this decade.
- **Nuclear:** provision for a large nuclear plant, as well as for advanced small nuclear reactors.
- **Electric vehicles:** phasing out sales of new petrol and diesel-powered vehicles by 2030, so as to accelerate the transition to electric vehicles and investing in grants to help buy cars and charge point infrastructure.
- **Public transport, cycling and walking:** making cycling and walking more attractive ways to travel and investing in zero-emission public transport for the future.
- **Zero-emission air and greener maritime travel:** supporting research projects for zero-emission planes and ships.
- **Homes and public buildings:** making homes, schools and hospitals greener, warmer and more energy efficient, including a target to install 600,000 heat pumps every year by 2028.
- **Carbon capture:** developing world-leading technology to capture and store harmful emissions away from the atmosphere, with a target to remove 10 million tonnes of carbon dioxide by 2030.

[1] https://www.gov.uk/government/publications/department-for-business-energy-and-industrial-strategy-outcome-delivery-plan/beis-outcome-delivery-plan-2021-to-2022 - b-introduction
[2] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[3] https://www.gov.uk/government/publications/industrial-decarbonisation-strategy
[4] Together with Italy: https://www.ukcop26.org/pre-cop/
[5] The conference was originally scheduled to take place in 2020, but has been postponed to 2021 in view of the COVID-19 pandemic
[6] https://www.ukcop26.org/the-conference
[7] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

- **Nature:** Protecting and restoring the natural environment, with plans to include planting 30,000 hectares of trees a year.
- **Innovation and finance:** Developing cutting-edge technologies and making the City of London the global centre of green finance.

Innovation may play a role in helping to achieve carbon net zero[8] and innovation may be reflected in patenting trends. Hence, this report is part of a series of studies relating to the technologies covered within the UK government's ten point plan for a green industrial revolution. This report analyses the worldwide patent landscape related to low-carbon hydrogen technologies.

This report is based on the analysis of published patent application data rather than granted patent data. Published patent application data gives more information about technological activity than granted patent data because a number of factors determine whether an application ever proceeds to grant; these include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

Throughout this report, patents are counted either as single published patent applications or as patent families depending on the context. A 'patent application' refers to a single patent application made in one jurisdiction and published in that jurisdiction. Patent applications are counted once regardless of the number of subsequent publications. A 'patent family' refers to a group of patent applications made and published in different jurisdictions. Each member of a patent family is considered to relate to the same invention. A patent family is counted once regardless of the number of members or publications it contains.

For this study, the LexisNexis worldwide patent database was interrogated using PatentSight[9]. The data coverage of this database is that of DOCDB, the European Patent Office's (EPO) database.[10]

Throughout this report, reference is made to 'active' patent families. A patent family in PatentSight is defined as active when at least one patent family member is either in the pending stage or 'in force' state. PatentSight updates the legal status of documents held within its database weekly.

[8] https://www.gov.uk/government/publications/promoting-innovation-and-growth-the-ipo-at-work-2020-21/innovation-and-growth-report-2020-21
[9] https://go.patentsight.com/BI2.0/bi/secure/src/resources/documentation/syntax-cheat-sheet/SyntaxCheatSheet.pdf?45be120476a49463f31ebcd79b10b19e
[10] https://www.epo.org/searching-for-patents/data/coverage/weekly.html

1.2 Low-carbon hydrogen

Hydrogen's use within fuel cells has been known since the 19th century.[11] Later, in the first half of the 20th century, hydrogen was utilised for transport with its use within airships. Liquid hydrogen was also explored as a potential fuel within rockets during the space race. In 1966, General Motors developed the Electrovan, a hydrogen fuel cell automobile.[12] Hydrogen technology has continued to evolve over this time. Hydrogen needs to be manufactured synthetically in order to be used. The most common method of this is through steam-methane reformation, where natural gas is reacted with steam to form hydrogen.[13]

Recently, the focus has been on developing low-carbon hydrogen production. As mentioned above, as part of the government's ten point plan for a green industrial revolution, the UK is aiming for 5GW of low-carbon hydrogen production capacity by 2030 for use across the economy.[14] Low-carbon hydrogen could link to carbon capture, utilisation and storage (CCUS) since the captured carbon from this process could be used in electrolysis during hydrogen production.[15]

[11] "Mr. W. R. Grove on a new Voltaic Combination". The London and Edinburgh Philosophical Magazine and Journal of Science. 1838
[12] https://www.researchgate.net/publication/233987484_Fuel_cell_electric_vehicles_and_hydrogen_infrastructure_Status_2012
[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf
[14] https://www.gov.uk/government/publications/uk-hydrogen-strategy
[15] https://www.toshiba-energy.com/en/hydrogen/rd/

2. Hydrogen power

This section provides an overview of the patent landscape surrounding hydrogen power before moving on to consider patenting activity in low-carbon hydrogen technologies.

2.1 Worldwide patent landscape

Figure 1: Number of active hydrogen power patent families worldwide per priority (first filing) year, 2001-2018

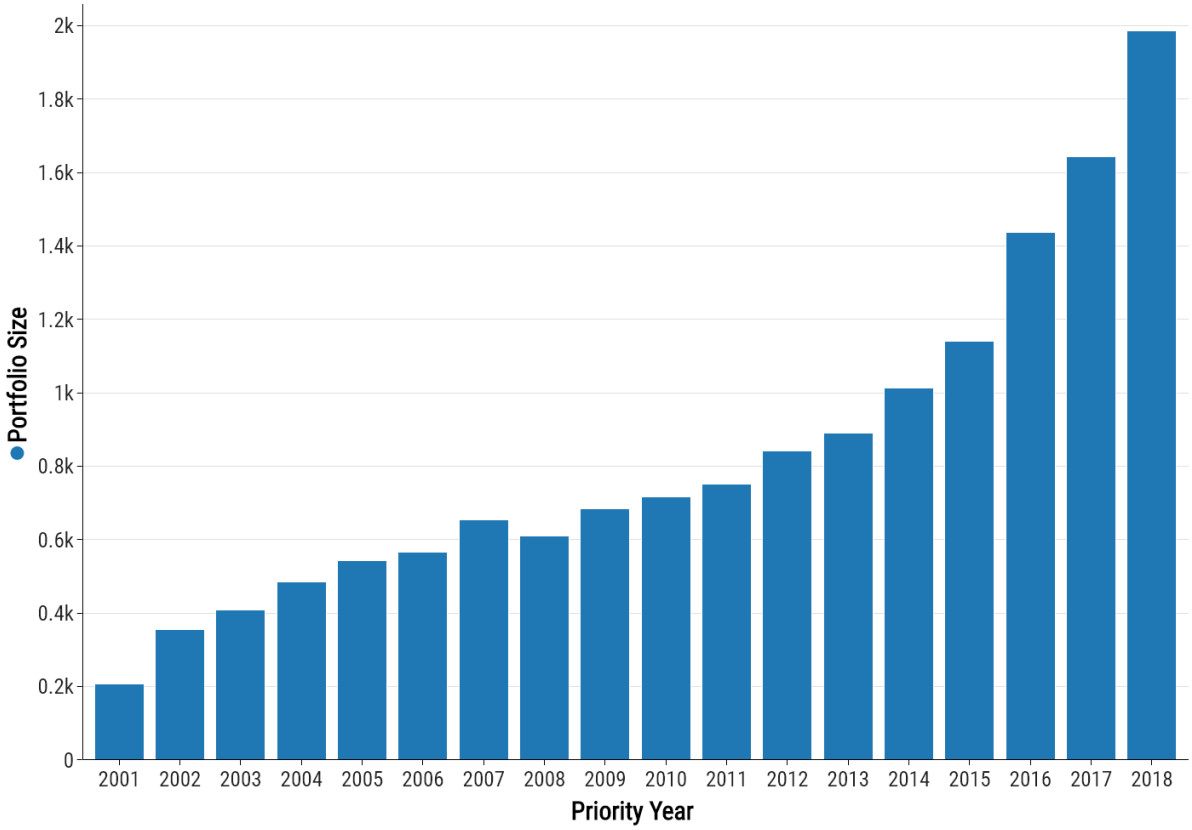


Figure 1 shows the number of active patent families worldwide which relate to hydrogen power (15,594 patent families). Data have been grouped by priority year (earliest filing) which helps provide the best representation of when the inventive activity took place. There is a clearly increasing trend over this time period, accelerating since 2014 and the number of active hydrogen power patents being filed each year has almost tripled in the past decade.

Figure 2: World map showing the patent coverage of hydrogen power patents, 2001-2018

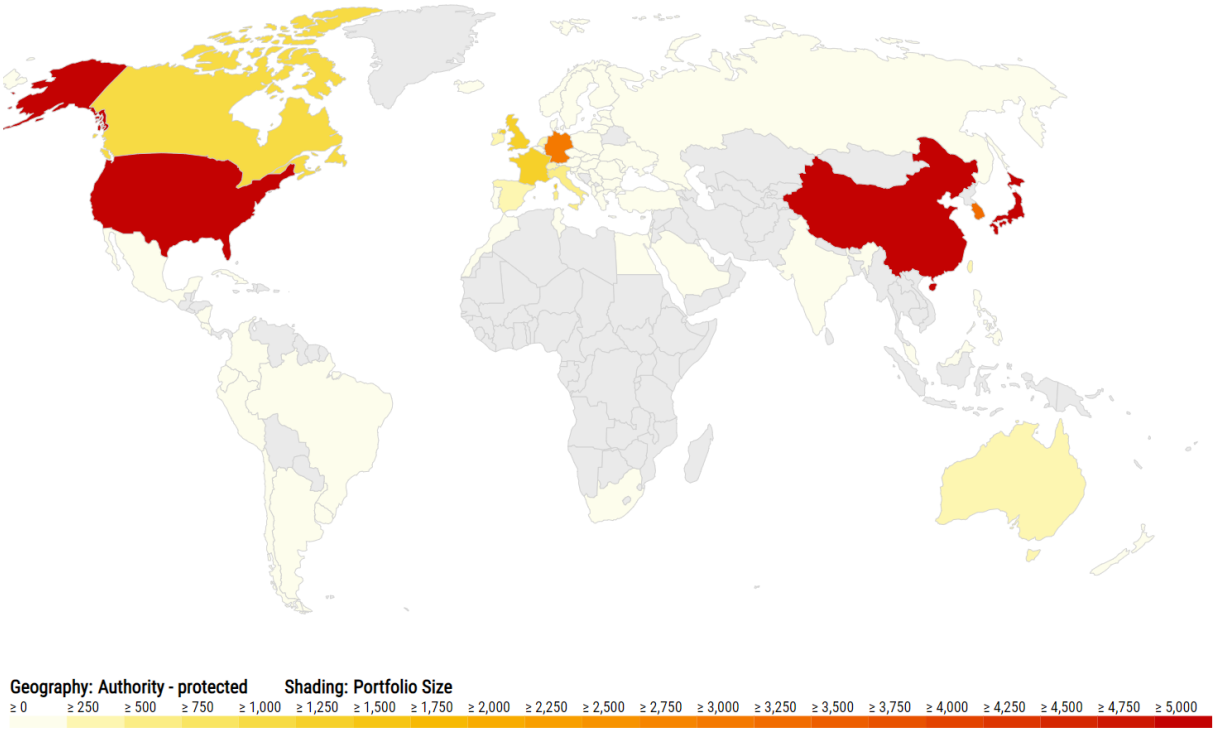
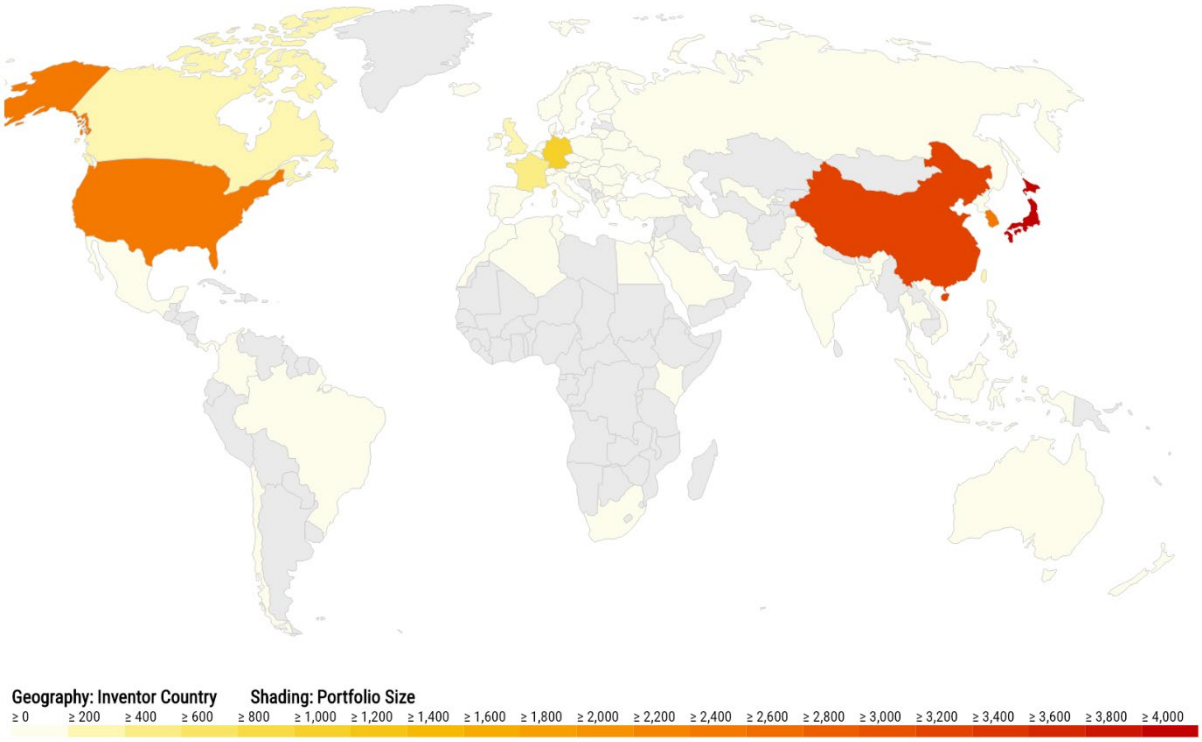


Figure 2 shows the worldwide patent coverage for hydrogen power technologies. The USA, China and Japan are the countries with the highest levels of patent protection. Looking specifically at Europe, Germany has slightly higher absolute levels of patent protection than other European nations.

Figure 3: World map showing where hydrogen power patents are being invented, 2001-2018



A heat map of hydrogen power patenting by inventor country is shown in Figure 3, which highlights that Japan has the highest levels of activity. This may be indicative of the Japanese government's commitment to developing hydrogen power.[16,17]

Using the Relative Specialisation Index (RSI) can help to account for the fact that some countries file more patent applications than others in all fields of technology. The RSI compares the fraction of a country's technology-specific patents, out of all of its patents across all fields of technology, with the corresponding fraction of technology-specific patents worldwide.

Table 1: Relative Specialisation Index (RSI) of selected nations for hydrogen power patents, 2001-2018

Country	Relative Specialisation Index
Germany	0.388
Canada	0.215
Australia	0.174
South Korea	0.146
Japan	0.106
USA	0.029
France	0.026
United Kingdom	**-0.052**
India	-0.076
China	-0.212

Table 1 shows the Relative Specialisation Index (RSI)[18] of the top 10 patenting countries for hydrogen power technologies. It shows that Germany is the most specialised country for hydrogen power. A value of approximately zero for the UK indicates that the UK is not a specialist in this field, but it is producing roughly as many hydrogen power related patents as you would expect given the absolute levels of patenting within the UK.

[16] https://www.japan.go.jp/tomodachi/2020/earlysummer2020/hydrogen.html
[17] https://www.thechemicalengineer.com/features/japan-taking-a-lead-in-hydrogen/
[18] See Appendix C for details of how the Relative Specialisation Index (RSI) is calculated

Figure 4: Top 20 owners of active hydrogen power patent families, 2001-2018

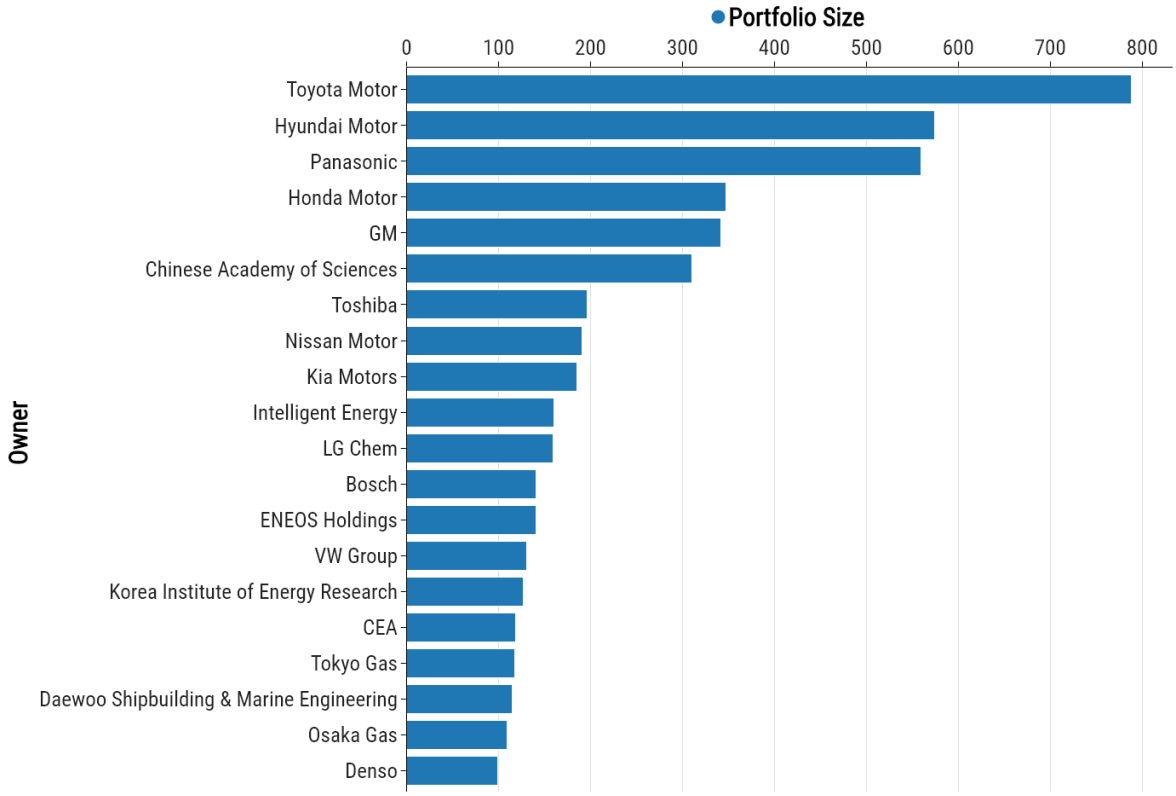
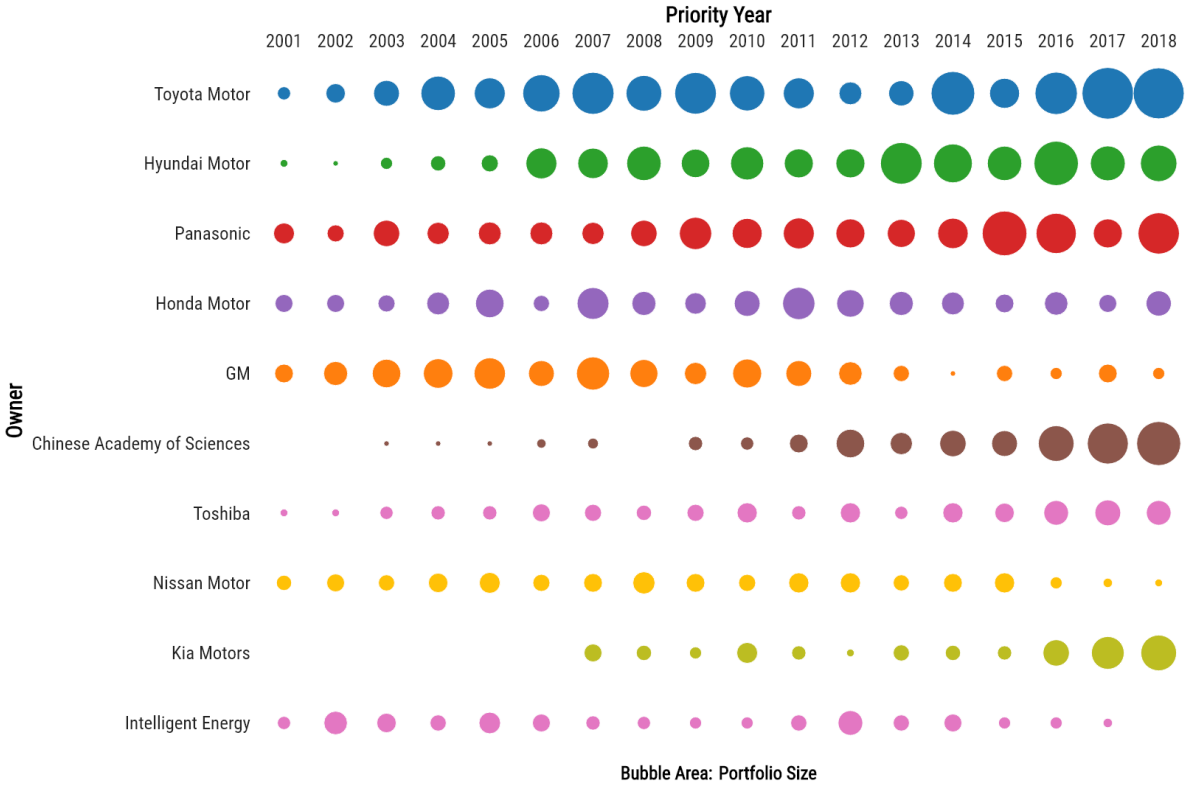


Figure 4 shows that there are a significant number of companies from the automotive industry in the field of hydrogen power, and these own a substantial number of the active patent families in this field. A UK company, Intelligent Energy, do appear in the top 10 patent owners for hydrogen power technologies.[19] Toyota Motor is the dominant player with nearly 800 active patent families in this field, which is more than double that owned by Honda Motor (around 350 patent families), a competing Japanese automotive company. These top 20 owners own around 32% of active patent families relating to hydrogen power.

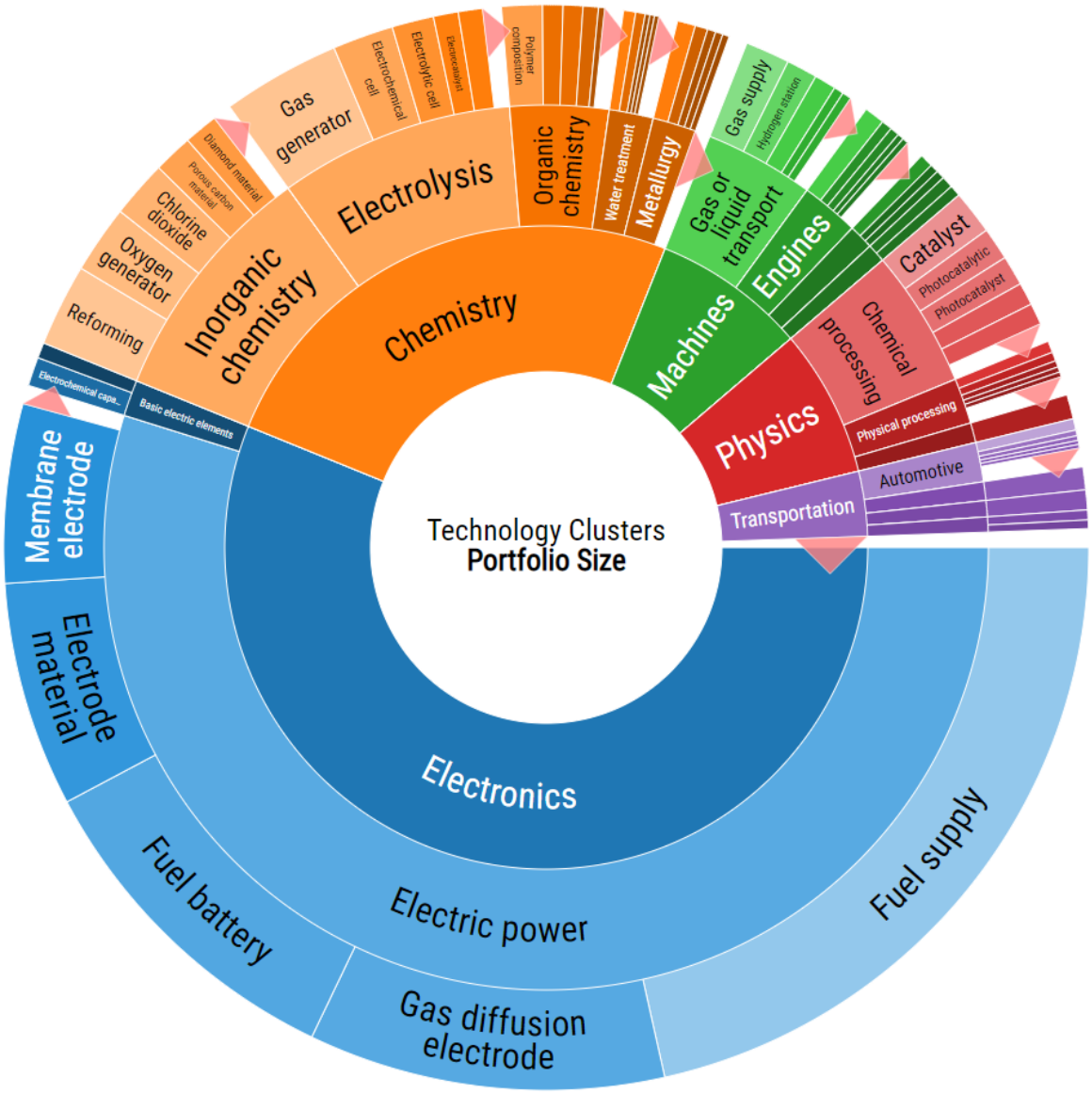
[19] https://www.intelligent-energy.com/about-ie/company-overview/

Figure 5: Bubble chart matrix showing patent portfolio size per year, grouped by the top 10 owners, 2001-2018



The bubble matrix in Figure 5 highlights the different activity levels of different patent owners in this field. Kia only became active in this area in 2007 whilst Nissan have maintained a relatively consistent portfolio size over this time period. The Chinese Academy of Sciences have significantly increased their portfolio size in recent years, whilst Toyota Hyundai and Panasonic have steadily increased their portfolio sizes over time.

Figure 6: Sunburst chart of the technology clusters covered by hydrogen power patent families, 2001-2018



Sunburst charts provide a quick and intuitive understanding of a technology area, including the categories of inventions that are protected and in what proportions. Figure 6 shows that over half of hydrogen power patent families relate to electric power, and 16% of all hydrogen power patents relate to fuel supply.

The large proportion of patents relating to the underlying technology itself (e.g. the production, storage and use of hydrogen) suggests that hydrogen power is still in the relatively early stages of development, and this is also reflected in the relatively small proportion of end-user applications (e.g. patents for transportation technologies using hydrogen power).

2.2 UK patent landscape

It is useful to consider how the hydrogen power patent landscape looks in the UK.

Figure 7: Number of hydrogen power patent families active in the UK, grouped by priority (first filing) year, 2001-2018

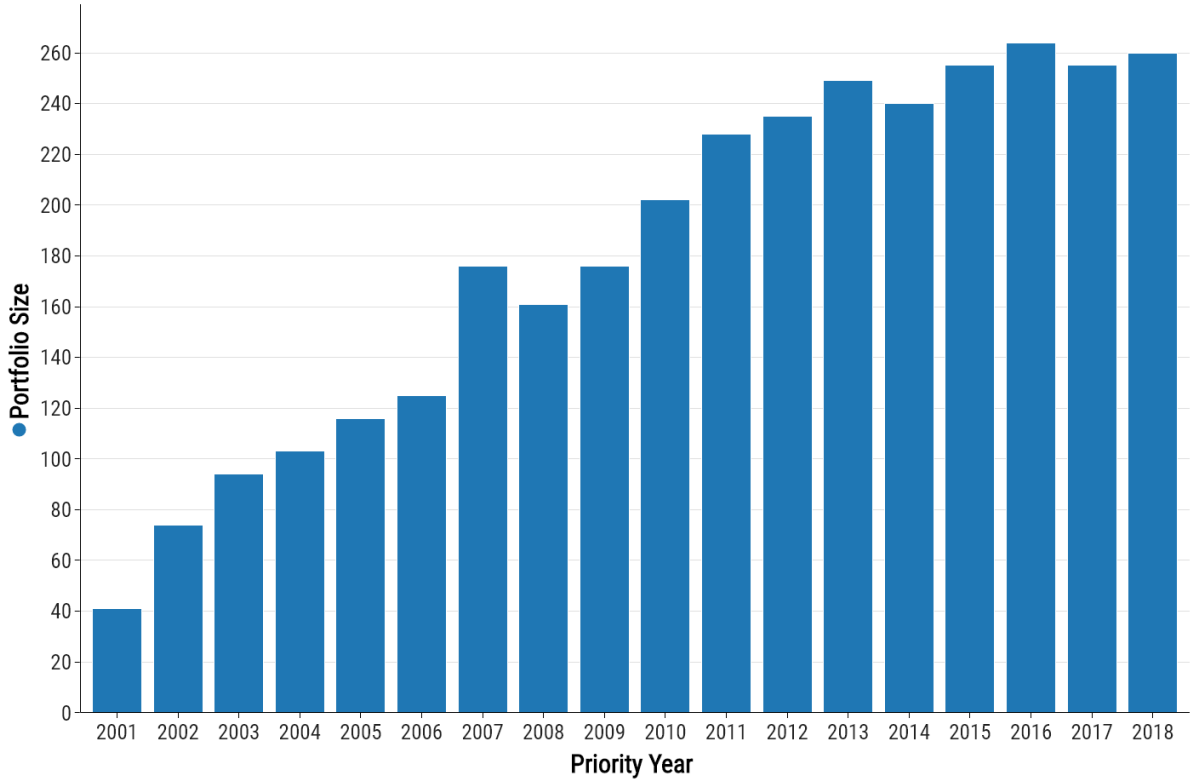
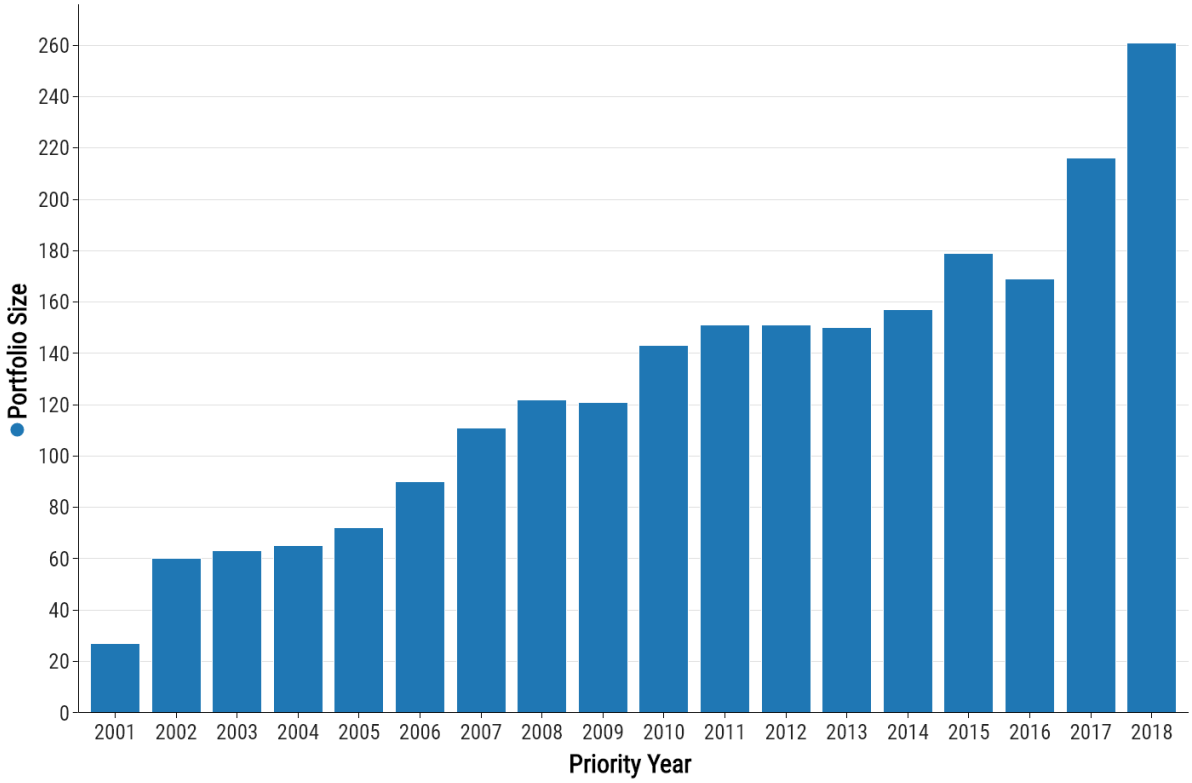


Figure 7 shows an increase in active patent families between 2001 and 2018, where the number of active patent families filed each year increased five-fold over the first decade. However, this trend appears to have been levelling off in more recent years. This suggests that the growth rate of patent families in this area has become steadier in the past five years.

Figure 8: Number of active hydrogen power patent families invented in the UK, 2001-2018



When looking at the trend of active patent families invented in the UK in Figure 8, there appears to be a significant increase in growth rate over time and the increase seems to have accelerated in the most recent years in particular.

Figure 9: World map showing where hydrogen power patents invented in the UK are being protected, 2001-2018

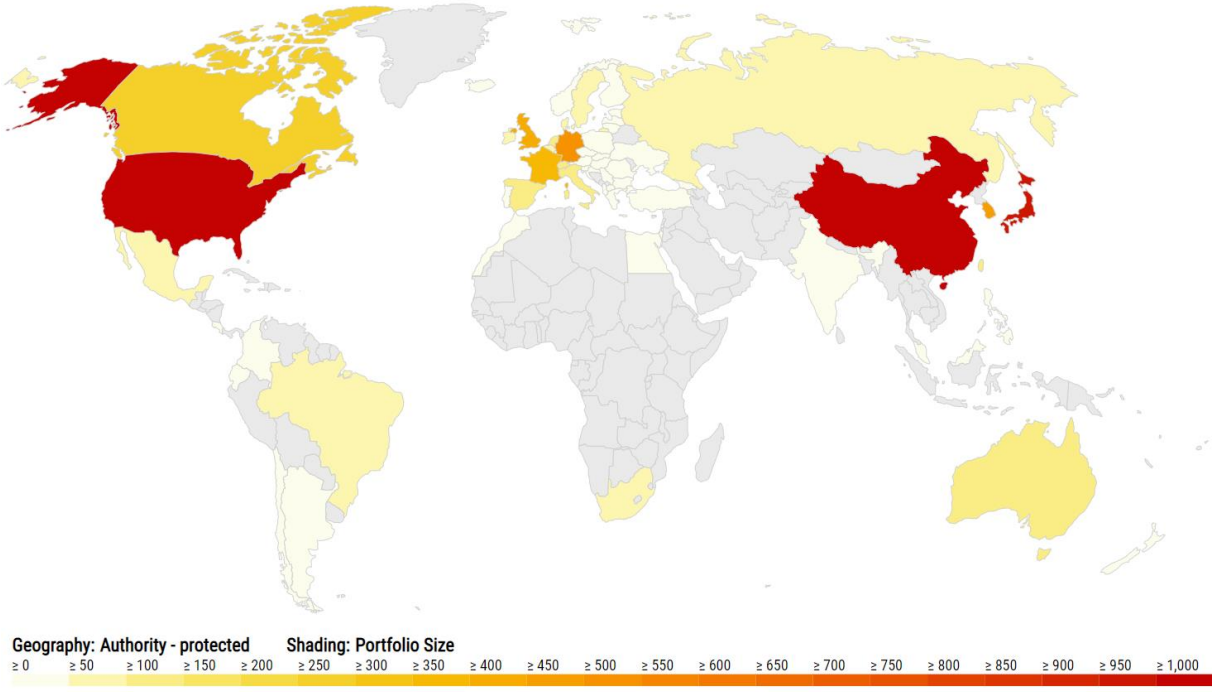
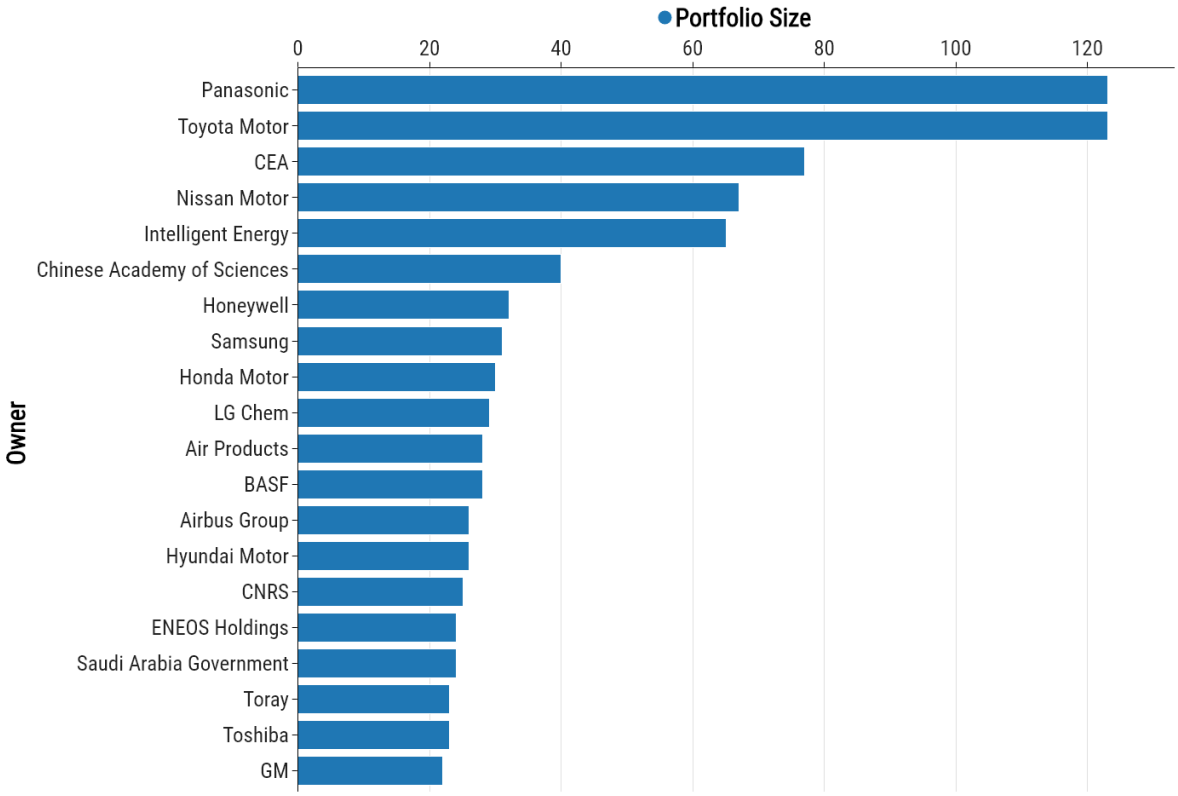


Figure 9 shows where hydrogen power patents invented in the UK are being protected. As previously, China, the USA and Japan clearly stand out here in comparison to other nations as being the key markets in which to protect hydrogen power patents.

Figure 10: Top 20 owners of hydrogen power patent families active in the UK, 2001-2018



Many of the owners of hydrogen power patents active in the UK shown in Figure 10 are the same as those seen in Figure 4. Of particular note is the presence of CEA, the French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives).[20] About 23% of patents active in the UK are owned by these top 20 owners.

[20] https://www.cea.fr/english

3. Low-carbon hydrogen

This section investigates the patent landscape of patents relating specifically to low-carbon hydrogen, rather than hydrogen power in general.

3.1 Worldwide patent landscape

Figure 11: Number of active patent families relating to low-carbon hydrogen, grouped by priority (first filing) year, 2001-2018

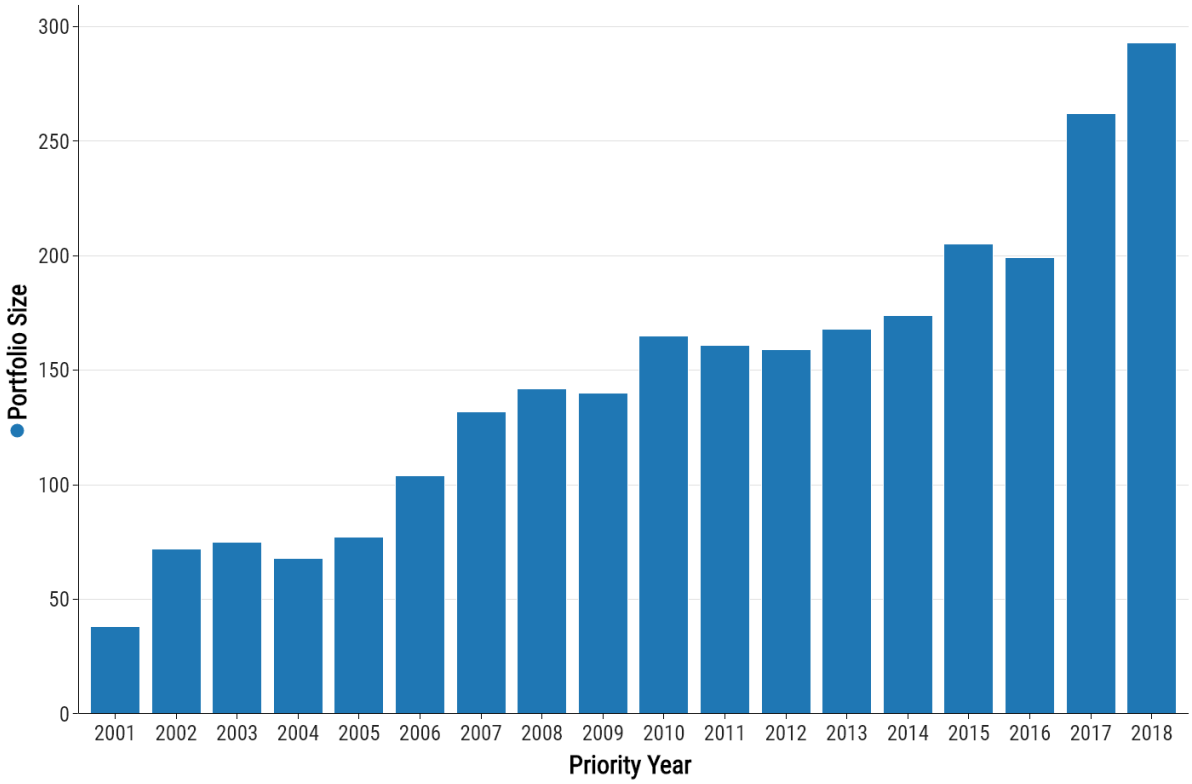
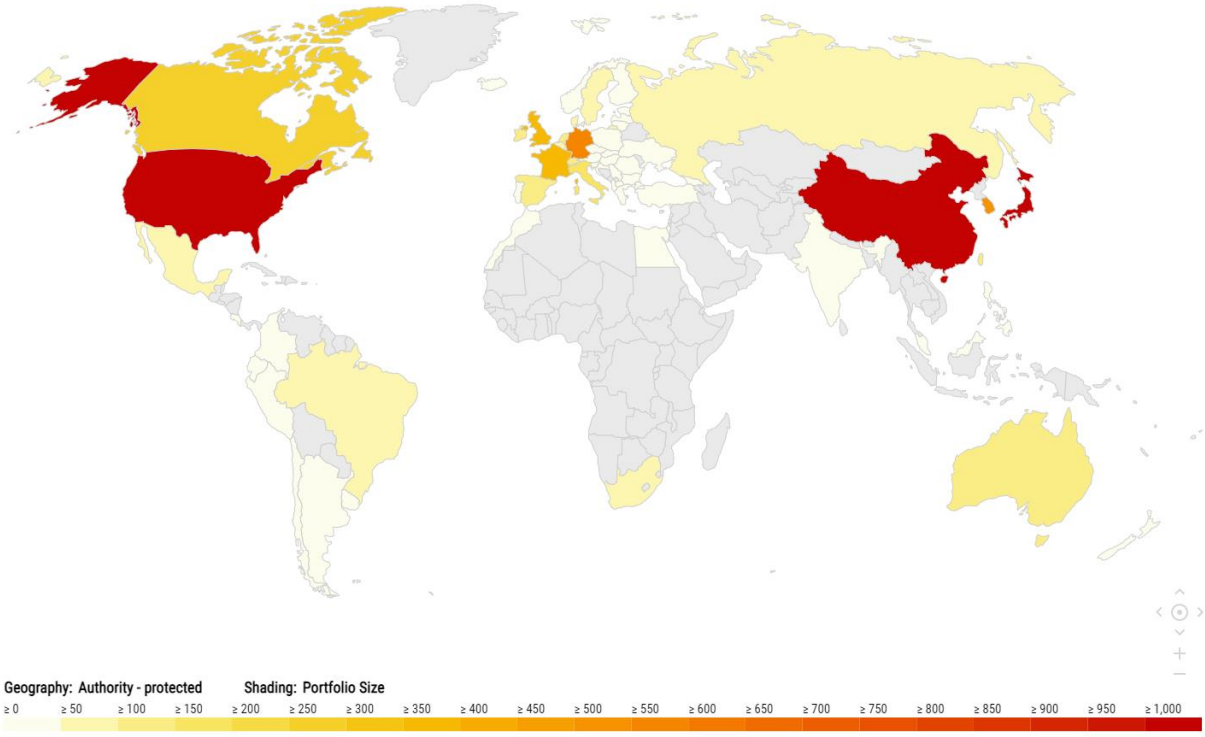


Figure 11 shows how the number of active patent families filed each year (3189 patent families in total) relating to low-carbon hydrogen have increased over time. There is a notable increase since 2017, suggesting that development in this area may be ramping up.

Figure 12: World map showing jurisdictions protected by patents relating to low-carbon hydrogen, 2001-2018



As shown in Figure 2 in relation to general hydrogen power technologies, Figure 12 shows how patent protection in China, Japan and the USA stands out and these are the three main jurisdictions to seek protection in low-carbon hydrogen.

Table 2: Relative Specialisation Index (RSI) of selected nations for low-carbon hydrogen patents, 2001-2018

Country	Relative Specialisation Index (RSI)
Australia	0.426
Canada	0.249
USA	0.136
France	0.135
Germany	0.126
Japan	0.079
United Kingdom	**0.032**
South Korea	-0.084
India	-0.175
China	-0.270

Table 2 shows that a number of countries, notably Australia, are more specialised in low-carbon hydrogen power, then they are in general hydrogen power technologies, as shown previously in Table 1.

Figure 13: Top 10 owners of active low-carbon hydrogen patent families, 2001-2018

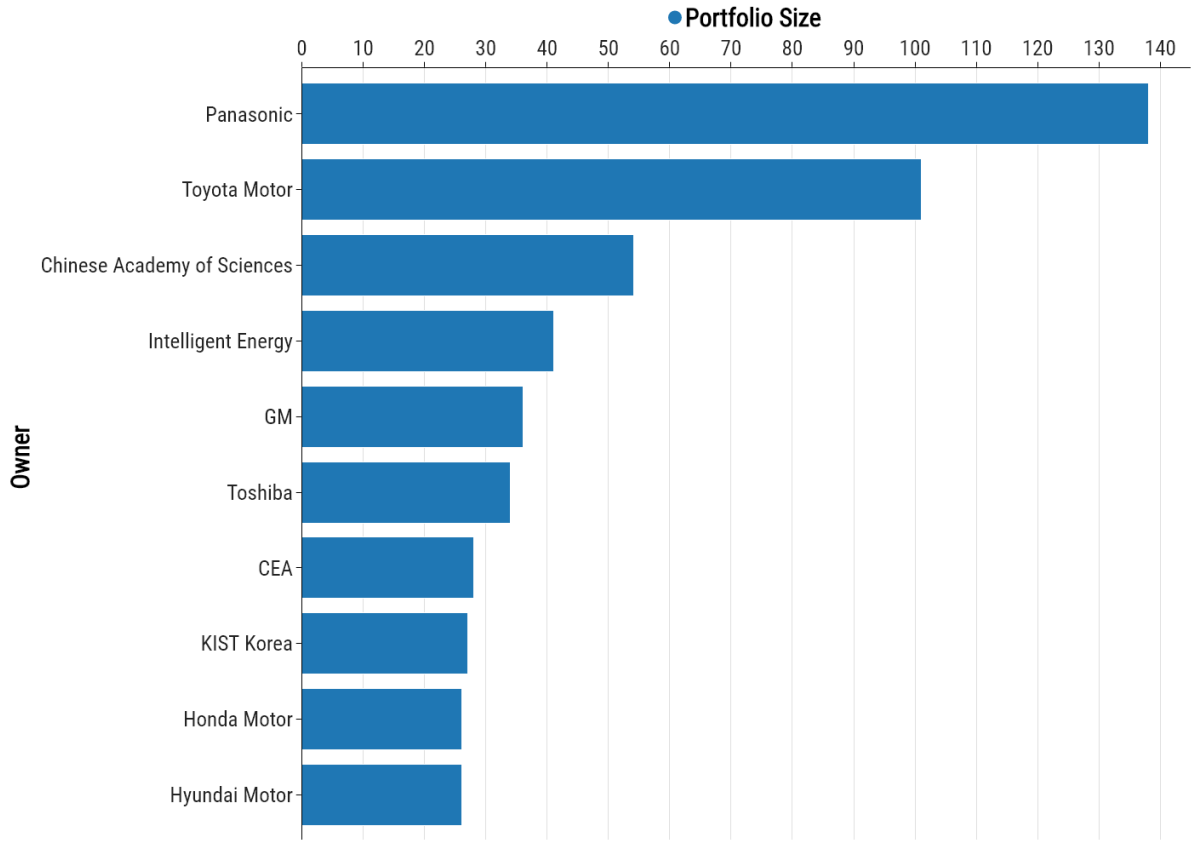


Figure 13 shows that a substantial number of patent families are owned by companies in the automotive industry, reflecting what was seen with general hydrogen power technologies. Panasonic appear to be especially active in the field of low-carbon hydrogen, with over 25% of their total hydrogen power patents being focused in the area of low-carbon hydrogen. 16% of patents relating to low-carbon hydrogen are owned by these top 10 owners.

3.2 UK patent landscape

Figure 14: Number of low-carbon hydrogen patent families active in the UK, grouped by priority (first filing) year, 2001-2018

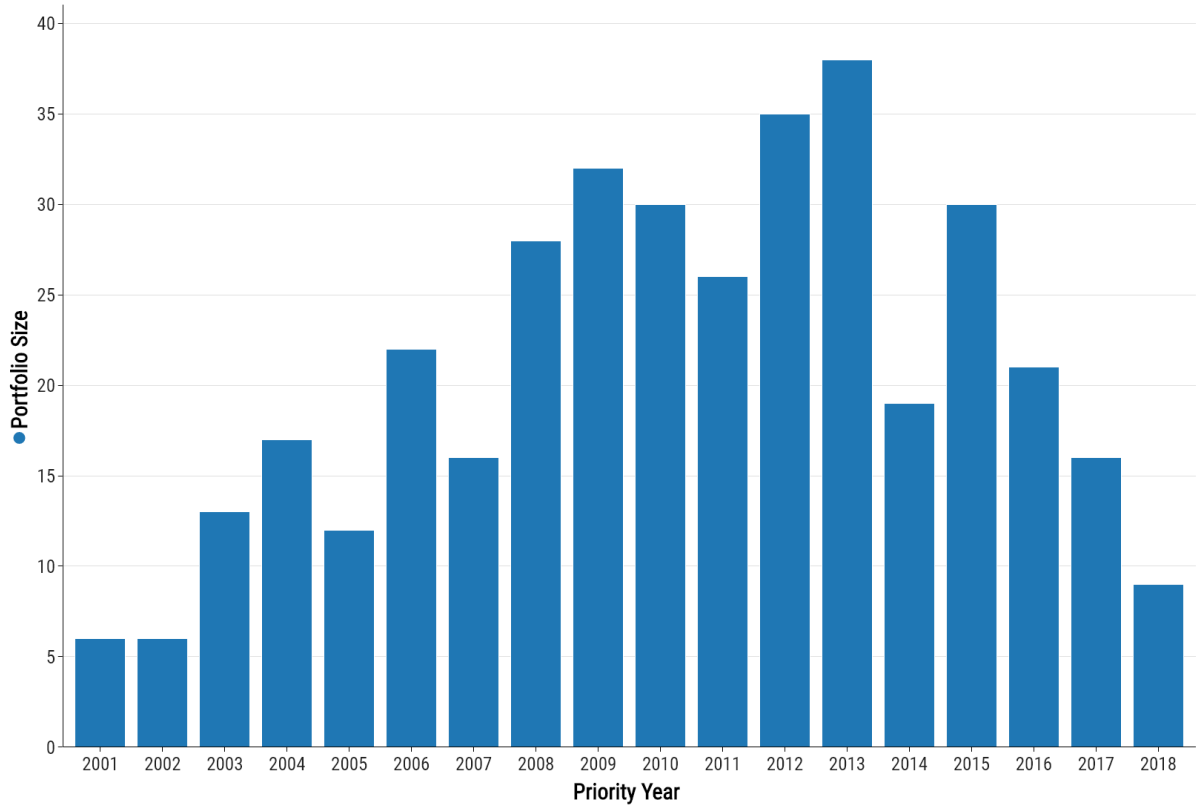
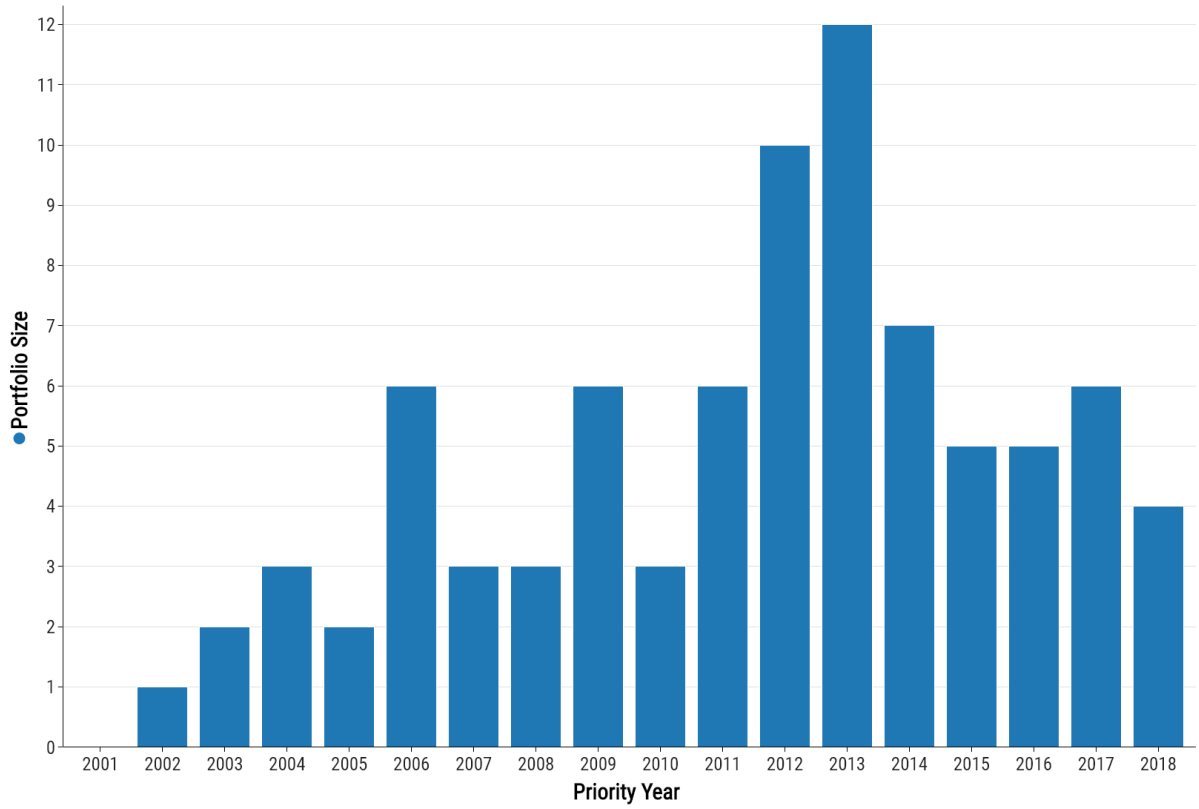


Figure 14 shows the number of low-carbon hydrogen related patents active in the UK (380), grouped by priority year. Absolute levels of UK patenting activity for low-carbon hydrogen is low and therefore subject to a degree of volatility, although there was an increase in the number of active patent families being filed between 2008-2013, but this rate has appeared to slow from 2015 onwards.

Figure 15: Number of active low-carbon hydrogen patents invented in the UK, grouped by priority (first filing) year, 2001-2018



The number of active low-carbon hydrogen patent families being filed each year which were invented in the UK, as shown in Figure 15, broadly follow a similar trend to the worldwide pattern, where here we see an increase in the number of active patent families being filed from 2011-2013, followed by a decrease in the growth rate of active patent families being filed in more recent years.

Figure 16: World map showing where low-carbon hydrogen patents invented in the UK are being protected, 2001-2018

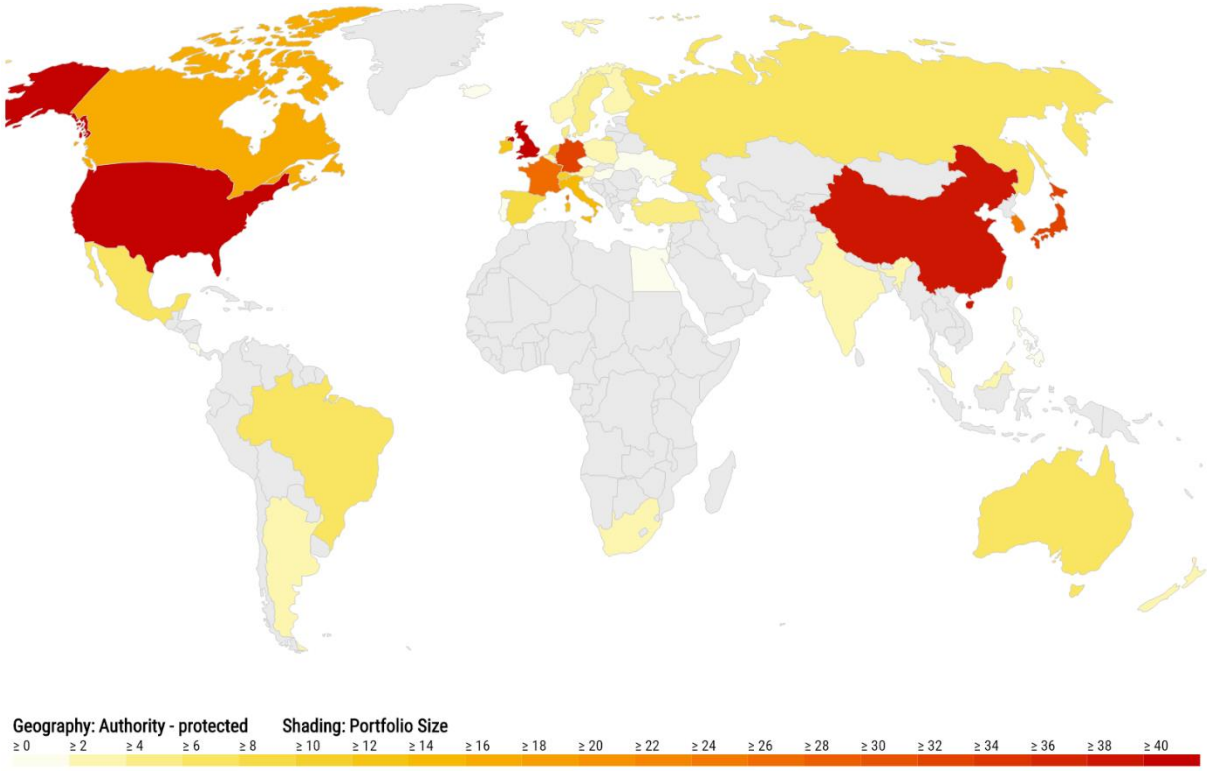


Figure 16 shows where low-carbon hydrogen patent families invented in the UK are being protected. The UK itself, as well as the US and China are most popular. These are then followed by Germany, France, Japan and South Korea.

Figure 17: Top 10 owners of low-carbon hydrogen patent families active in the UK, 2001-2018

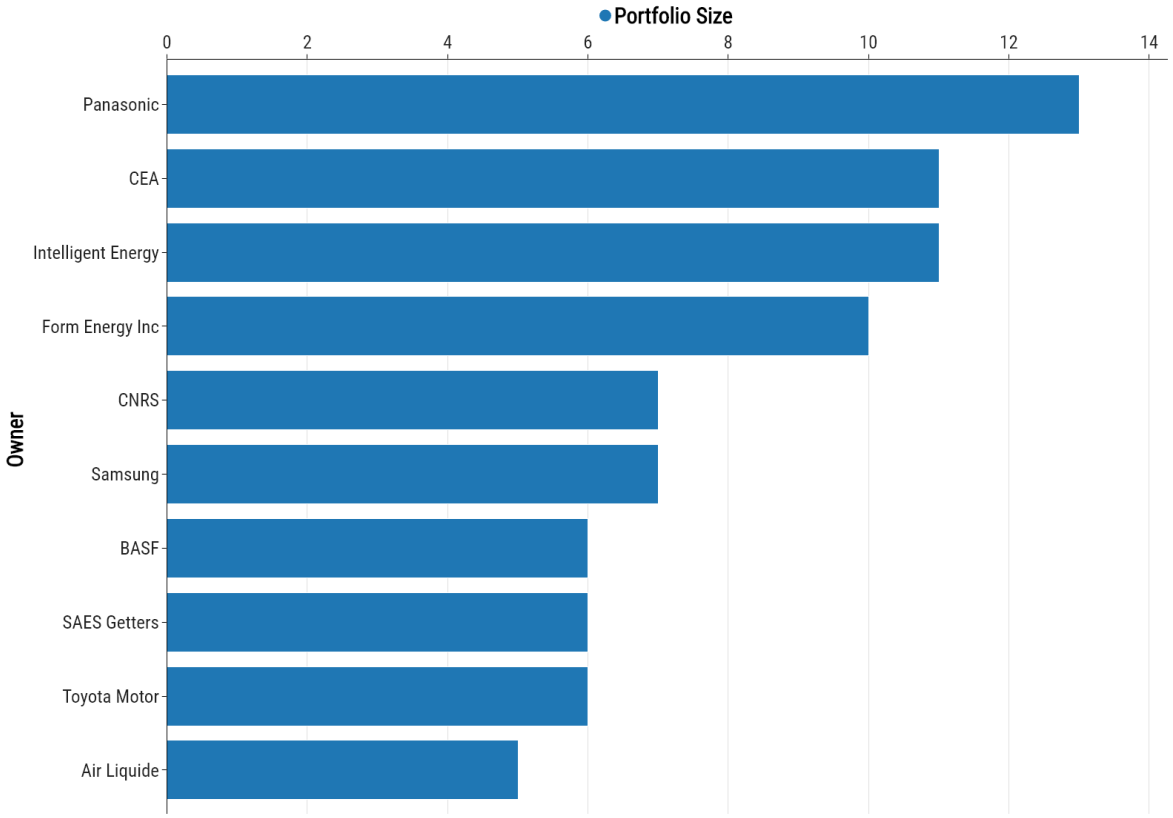


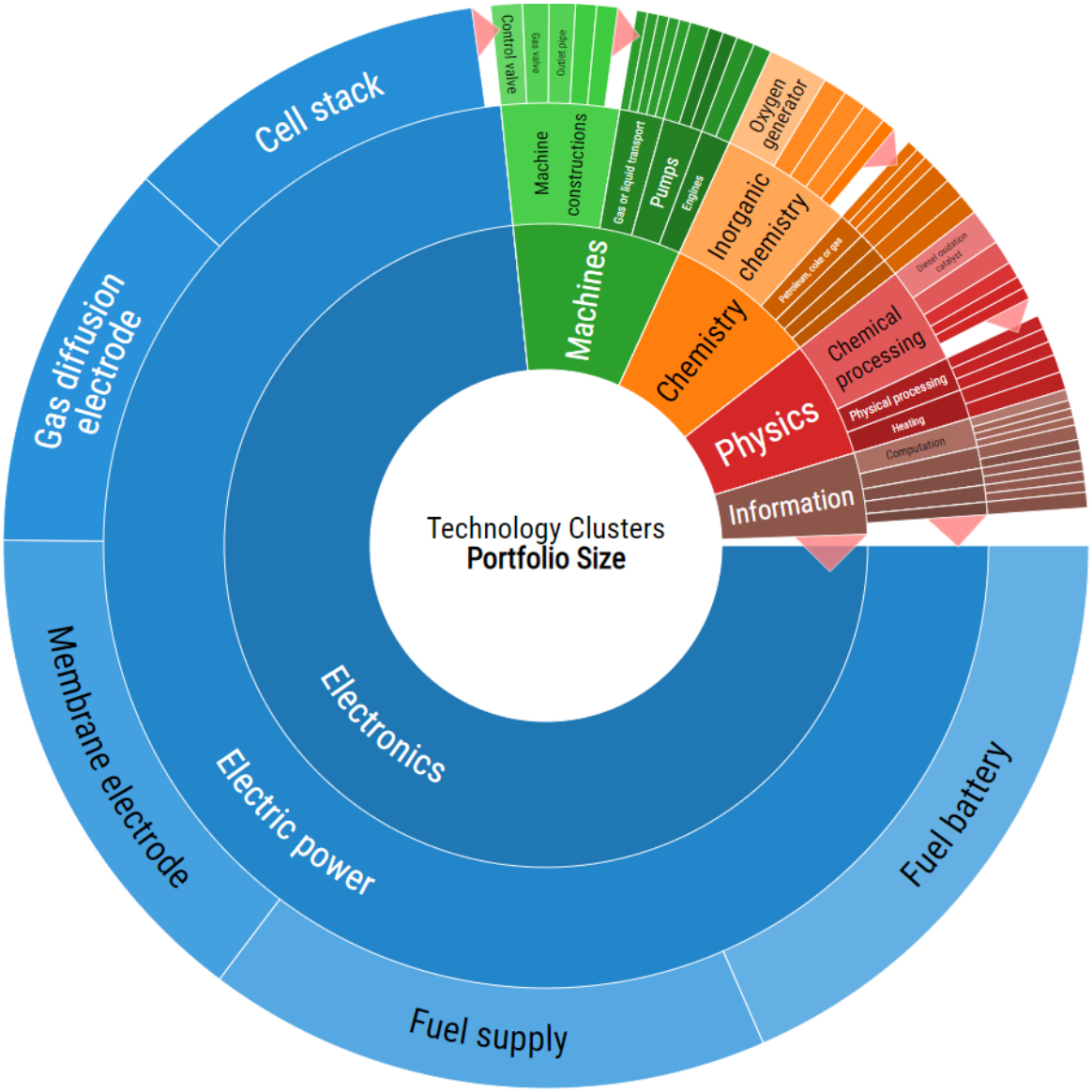
Figure 17 shows the top 10 owners of patents active in the UK, which relate to low-carbon hydrogen. The owners present here are generally similar to those who own active patent families which relate to hydrogen power in general. Around 22% of low-carbon hydrogen patents active in the UK are owned by these top 10 owners.

3.3 Case study: Intelligent Energy

Intelligent Energy is a fuel cell engineering business, headquartered in the UK, with offices in the USA, Japan, Korea and China. It originated from Loughborough University, and has partnered with multiple companies to deliver fuel cells within vehicles. It is also a founding member of UKH$_2$ Mobility, a government/industry led group aiming to accelerate the commercial roll out of hydrogen vehicles.[21,22]

As of 12 August 2021, Intelligent Energy had 391 active patent families across all areas of technology.

Figure 18: Sunburst chart showing the technology cluster areas where Intelligent Energy has active patents, 2001-2018



[21] https://www.lboro.ac.uk/service/publicity/news-releases/2012/08_UKH2-Mobility.html -
[22] http://www.ukh2mobility.co.uk/

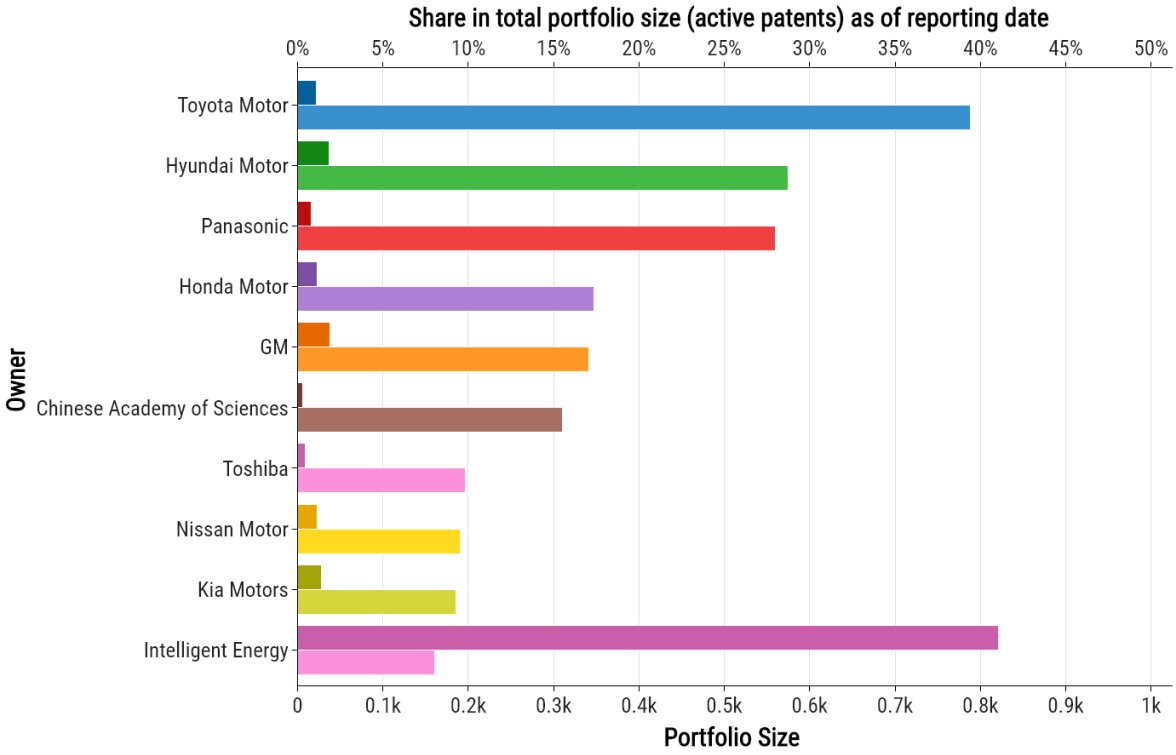
Figure 18 shows Intelligent Energy's patent portfolio across all areas of technology. It is clear that they have a clear focus on patents relating to electric power, with 73% of their portfolio relating to this technology area. Specifically, they appear to have a focus in technology areas which could relate to hydrogen power. Table 3 reinforces this and shows the prevalence of hydrogen technologies and fuel cell related patents within Intelligent Energy's patent portfolio.

Table 3: Top patents owned by Intelligent Energy, ranked using by Competitive Impact[23]

Patent family	Filing year	Title	Current owners	Active authorities (today)
US2019295193.A1	2015	Energy resource network	Intelligent Energy	CN, GB, JP, US
EP1649528.A1	2003	Fuel cartridge with flexible liner	Intelligent Energy	CA, DE, GB, JP, KR, MX, MY, US, ZA
US2008216906.A1	2005	Hydrogen Generating Fuel Cell Cartridges	Intelligent Energy	CN, JP, KR, MY, US, ZA
EP1690309.A2	2003	Fuel cell supply including information storage device and control system	Intelligent Energy	CA, CN, DE, JP, KR, MY, US
EP1711974.A2	2003	Fuel cell supply having fuel compatible materials	Intelligent Energy	CA, CN, DE, FR, JP, MY, US, ZA
EP2206185.A2	2007	Fuel cell system	Intelligent Energy	AR, CN, DE, FR, GB, JP, KR, MX, US, ZA
US2009205727.A1	2003	Fuel Cartridge with Connecting Valve	Intelligent Energy	AR, CA, JP, KR, MY, US, ZA
EP1915794.A2	2005	Fuel cell with fuel monitoring system and method of use	Intelligent Energy	CA, CN, DE, FR, GB, JP, MX, MY, US, ZA
EP1306918.A2	2001	Replaceable fuel cell apparatus having information storage device	Intelligent Energy	DE, FR, GB, JP, US
EP2795418.A1	2006	Hydrogen-generating fuel cell cartridges	Intelligent Energy	DE, JP, KR, MY, US, ZA

[23] The Patent Asset Index " A new approach to benchmark patent portfolios" (reedtech.com), https://go.reedtech.com/hubfs/Ernst%20and%20Omland%202011.pdf?__hstc=126863762.e481f5cbcf2fcec9d27e93b648c48bc4.1622723829624.1630933776639.1631885094004.38&__hssc=126863762.3.1631885094004&__hsfp=1064556855

Figure 19: Share of hydrogen patents within an owner's overall patent portfolio for the top 10 owners, 2001-2018



Using the top 10 hydrogen power patent owners from Figure 4, Figure 19 provides some deeper analysis and looks at what share of each company's total patent portfolio relates to hydrogen power. For most owners, hydrogen power patents make up only a small percentage of their total patent portfolios whereas, by comparison, it is a clear specialism of Intelligent Energy, with over 40% of their total patent portfolio relating to hydrogen power.

4. Conclusions

The UK is committed to delivering a low-carbon hydrogen standard, and is aiming for 5GW of low-carbon hydrogen production capacity by 2030. The UK government is currently holding a consultation on a UK low energy carbon hydrogen standard, which sets out options for an emissions standard that could underpin the deployment of low-carbon hydrogen for use across the economy.[24]

It is therefore interesting to note that the substantial increase in worldwide patenting activity of hydrogen power between 2001 and 2018. This trend is reflected both in patent families active in the UK, as well as patents invented in the UK. Toyota Motors are the most prolific filers worldwide, but worthy of note are Intelligent Energy, a UK-based company ranked amongst the top patent owners globally.

Trends seen by general hydrogen power technologies are mirrored in low-carbon hydrogen patenting activity, and this is seen both globally and in the UK.

The Relative Specialisation Index (RSI) shows that, from a patent perspective, the UK is slightly more specialised in low-carbon hydrogen compared to hydrogen power more generally. The patent data suggests that UK-based companies such as Intelligent Energy may play a key role in developing low-carbon hydrogen power technologies to help the government's meet its 5GW target for low-carbon energy production by 2030.

Companies in the automotive industry own a notable share of patents in this field, which suggests that hydrogen-powered vehicles may be an important end-user application of this technology.

[24] https://www.gov.uk/government/publications/options-for-a-uk-low-carbon-hydrogen-standard-report

Appendices

Appendix A: Search strategy

For this study, the LexisNexis worldwide patent database was interrogated using PatentSight[25].

A.1 Hydrogen power

IPC=(C01B 3/00, H01M 8/22) OR CPC=(C01B 3/00, H01M 8/22, Y02E 50/00, Y02E 60/30) AND PriorityDate=(2001-01-01 TO 2018-12-31) and tac=(hydrogen* and (power* or fuel* or energy*)).

A.2 Low-carbon hydrogen

IPC=(C01B 3/00, H01M 8/22) OR CPC=(C01B 3/00, H01M 8/22, Y02E 50/00, Y02E 60/30) AND PriorityDate=(2001-01-01 TO 2018-12-31) and tac=(hydrogen* and (power* or fuel* or energy*)AND ((low or reduc* or neutral* or recycl* or reuse*) near3 (carbon* or CO or CO2))).

Appendix B: Cooperative Patent Classification (CPC) definitions

C01B3/00	Hydrogen; Gaseous mixtures containing hydrogen; Separation of hydrogen from mixtures containing it (separation of gases by physical means B01D); Purification of hydrogen (production of water gas or synthesis gas from solid carbonaceous material C10J; purifying or modifying the chemical compositions of combustible technical gases containing carbon monoxide C10K)
H01M8/22	Fuel cells in which the fuel is based on materials comprising carbon or oxygen or hydrogen and other elements; Fuel cells in which the fuel is based on materials comprising only elements other than carbon, oxygen or hydrogen
Y02E50/00	Technologies for the production of fuel of non-fossil origin
Y02E60/30	Hydrogen technology

[25] https://go.patentsight.com/BI2.0/bi/secure/src/resources/documentation/syntax-cheat-sheet/SyntaxCheatSheet.pdf?45be120476a49463f31ebcd79b10b19e

Appendix C: Relative Specialisation Index (RSI)

Relative Specialisation Index (RSI) was calculated to account for the fact that some countries file more patent applications than others in all fields of technology. In particular US, Chinese and Japanese applicants and inventors are prolific patentees.

The RSI compares the fraction of a country's technology-specific patents, out of all of its patents across all fields of technology, with the corresponding fraction of technology-specific patents worldwide.

A logarithm is applied to scale the fractions more suitably; an RSI of zero then represents a country that is no more or less specialised than the worldwide average.

The Relative Specialisation Index (RSI) for country c in technology t is defined as:

$$RSI_{c,\,t} = \ln\left(\frac{n_{c,t}/n_t}{N_c/N}\right)$$

where:

$n_{c,t}$ = number of patents for country c in technology t
n_t = sum of patents in all countries in technology t
N_c = number of patents for country c
N = sum of patents for all countries.

A value above positive indicates that a country has a higher specialisation in this field than would be expected, whilst a negative value indicates a lower specialisation than expected for that country.

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