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H₂

A large, clear water bubble is the central focus, containing the chemical formula H₂ in a white, outlined font. The bubble is surrounded by a dynamic splash of water with many smaller bubbles, set against a teal background.

The Power of Hydrogen

Patent analytics on hydrogen technologies
March 2023

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SUMMARY

This report analyses patent filing trends in hydrogen technologies, an expanding market as alternate energy sources become more important to global energy security. The findings from this investigation of patent families filed since 2010 show trends, markets, and commercial players in hydrogen technologies.

Recent patent data shows hydrogen technology is an area of growth and investment across the world. Between 2010 and 2014 patent filings in hydrogen technologies remained at constant levels, followed by steady growth from 2015. Large petroleum and motor corporations are strongly represented among the top patent applicants.

China dominates this sector as both the largest source of innovation and the largest patent filing destination in hydrogen technologies. China is responsible for much of the recent growth in patent filings, with China Petroleum Corporation filing the largest number of patents in hydrogen technologies in the world. However, China files less than 5% of its patents outside of China, showing a high preference for domestic patent protection.

The United States of America, Japan, Europe, and the Republic of Korea are the other major players in this sector. Australia ranks 16th globally as a source of innovation as shown by patent filings originating from Australian applicants, with specialisation in hydrogen production by electrolysis, fossil fuel conversion, and biomass and waste conversion. Leading Australian patent applicants include the Commonwealth Scientific and Industrial Research Organisation (CSIRO), AquaHydrex, Monash University and Hydrexia. Australian applicants have a focus on hydrogen production through electrolysis, accounting for 31% of the patents originating from Australian applicants.

Australia is the world's 13th largest economy¹ but ranks 8th in the world as a patent filing destination, demonstrating that our world-leading IP system encourages investment in Australia, and representing a strong opportunity for engagement of the domestic market. Fossil fuel conversion accounts for 32% of patent families filed into Australia making this Australia's most protected hydrogen technology area.

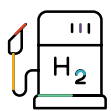
HYDROGEN TECHNOLOGIES



32,885 patent families have been filed globally in **hydrogen technologies since 2010**. **77%** are in an **active** state (in force or seeking patent protection).



Patent family filings in hydrogen technologies have **increased steadily from 2014** onwards.



China Petroleum Corporation is the top global filer in **hydrogen technology**, with 1,313 patent families.



Electrolysis is the **major focus of patents filed by Australian applicants**, with 60 patent families filed since 2010.



Applicants from the **United States of America, Germany and Japan** are the major players **filing patents in Australia relating to** hydrogen technologies.



Australian patent applicants are primarily targeting the **United States and China** for patent protection in hydrogen technologies.



193 patent families originating from Australia have been filed in hydrogen technologies.



INTRODUCTION

Energy production, storage and utilisation are critical to the Australian and global economies. With growing concerns about climate change, hydrogen energy represents a viable alternative to the conventional use of fossil fuels due to its abundance, energy density, and potential for clean and renewable production. The development of hydrogen technologies is essential to future energy infrastructure and resilience in Australia, with government incentives² and venture capital³ to fund innovation underpinned by the *National Hydrogen Roadmap*⁴ and *Australia's National Hydrogen Strategy*⁵. The Australian Government has a strong commitment to developing hydrogen technologies, workforce and manufacturing capability across the country^{6,7,8} and to expanding hydrogen refuelling stations on Australia's major freight routes⁹.

Analysing global patent filings in hydrogen technologies provides information for decision-makers as we strengthen and consolidate our national capability. This patent analytics report and its accompanying interactive visualisations¹⁰ identify innovative capability in hydrogen technologies and provide information on technological developments that can be leveraged to build our national capability. The report also identifies patent applicants who are actively working in the different fields of hydrogen production, storage and distribution, and utilisation. Patent filings between 2010 and 2020 have been analysed to investigate trends, innovators, filing destinations and commercial players.

Why patent data?

Patents can be used as indicators of innovative activity. By extracting and analysing data associated with patent documents, we can measure aspects of inventive activity such as scope, intensity, co-filing, and impact. These metrics can be developed across technology sectors and by measures including individuals (inventors), institutions (applicants), countries and regions. Patents are granted for devices, substances, methods, or processes that are new, inventive, and useful, giving exclusive commercial rights in exchange for full public disclosure of the invention. This means patents are a source of data on innovation trends in science and technology as shown in *Hydrogen patents for a clean energy future*¹¹ that demonstrates patents are a strong indicator into the state and direction of the science. More information about the patent system is given in [Appendix A: Definitions](#).

Global technology trends for hydrogen power were analysed using patent data from 2001 to 2018 by the United Kingdom Intellectual Property Office (UKIPO)¹². The UKIPO patent analysis showed growing innovation and investment in hydrogen power technologies, with the United States of America, China and Japan being the countries with the highest levels of patent protection. Relative specialisation analysis showed Australia ranking third in the world, with a particular focus on hydrogen power, and first globally in low-carbon hydrogen despite its relatively small share of patents applications. The relative specialisation analysis compared the fraction of a country's technology-specific patents, out of all its patents across all fields of technology, with the corresponding fraction of technology-specific patents worldwide, demonstrating that Australia has a strong base of capability in hydrogen innovation.

The authors and purpose of this report

This report provides an analysis of global innovation in hydrogen technologies with a focus on Australian capability. IP Australia is dedicated to building prosperity for Australia and ensuring that Australians benefit from great ideas. Using patent data analytics to provide evidence of innovation trends, we leverage our unique access to IP data, knowledge, and expertise to deliver value to the broader community.

The interactive visualisations

The interactive visualisations accompanying this report provide a rich source of information on hydrogen patenting activity and are publicly available on our website¹⁴. As well as providing direct links to full details and content of each patent, the interactive visualisations allow users to quickly identify applicants in different technologies, and to review co-applicants who are filing patents or where

This report was prepared to support Australian research and investment in developing national hydrogen capability and uses technology categorisation developed by CSIRO¹³.

In this patent analytics report we have analysed the development and uses of technology relating to hydrogen to provide insight into Australian and global innovators — based on patents filed — with potential connections for investment, research, development, and commercialisation.

entities have acquired patent rights ownership, in specific technologies of choice. The interactive visualisations enable users to select information on different types of hydrogen technologies in any combination to identify the relevant patents and patent applicants. Users can also investigate selections of different applicants, countries of patent filing destinations and the year of filing.

¹ The World Bank GDP data https://data.worldbank.org/indicator/Ny.Gdp.Mktp.Cd?most_recent_value_desc=true

² Fuel Cell & Hydrogen Energy Association (FCHEA) (2020) International Government Hydrogen Developments <https://www.fchea.org/transitions/2020/7/27/international-government-hydrogen-developments>

³ Critical Technologies Policy Coordination Office (CTPCO) (2021) Hydrogen and ammonia for power <https://www.industry.gov.au/sites/default/files/2022-08/ctpc-co-tech-cards-hydrogen-ammonia-power-aust.pdf>

⁴ CSIRO (2018) National Hydrogen Roadmap <https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Energy-and-Resources/National-Hydrogen-Roadmap>

⁵ COAG Energy Council Hydrogen Working Group (2019) Australia's National Hydrogen Strategy <https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf>

⁶ Fortescue (2022) Construction commences on world-leading electrolyser facility in Gladstone, Queensland <https://www.fmg.com.au/in-the-news/media-releases/2022/02/28/construction-commences-on-world-leading-electrolyser-facility-in-gladstone-queensland>

⁷ LINE Hydrogen (2022) Secure, well-paid jobs will be a key part of Labor's Better Future for Tasmania <https://www.linehydrogen.com.au/news/laborannouncement>

⁸ Sharon Claydon MP (2022) Training the new energy workforce of the future https://www.sharonclaydon.com/media_release_training_the_new_energy_workforce_of_the_future

⁹ Labor (2022) Driving the Nation <https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=ld%3A%22media%2Fpressrel%2F8552373%22;src=sm1>

¹⁰ IP Australia (2021) Patent analytics on hydrogen technologies <https://www.ipaustralia.gov.au/tools-and-research/professional-resources/data-research-and-reports/publications-and-reports/2022/09/30/hydrogen-technology-patent-analytics>

¹¹ EPO and IEA (2023) Hydrogen patents for a clean energy future <https://www.iea.org/reports/hydrogen-patents-for-a-clean-energy-future>

¹² Intellectual Property Office (UK) (2021) A worldwide overview of low-carbon hydrogen patents <https://www.gov.uk/government/publications/a-worldwide-overview-of-low-carbon-hydrogen-patents>

¹³ CSIRO (2019) Hydrogen Research, Development and Demonstration (RD&D): Priorities and Opportunities for Australia

<https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/hydrogen-research-and-development>

¹⁴ IP Australia (2021) Patent analytics on hydrogen technologies

<https://www.ipaustralia.gov.au/tools-and-research/professional-resources/data-research-and-reports/publications-and-reports/2022/09/30/hydrogen-technology-patent-analytics>



GLOBAL PATENTING TREND OVERVIEW

As a basis for this analysis, we searched the PATSTAT database (2021 Spring edition) for inventions relating to hydrogen technologies filed by global applicants and/or inventors (See [Appendix A: Definitions](#)). The search identified 32,885 unique International Patent Documentation (INPADOC) patent families (see [Appendix B: Search Strategy](#)) relating to hydrogen technologies filed worldwide since 2010.

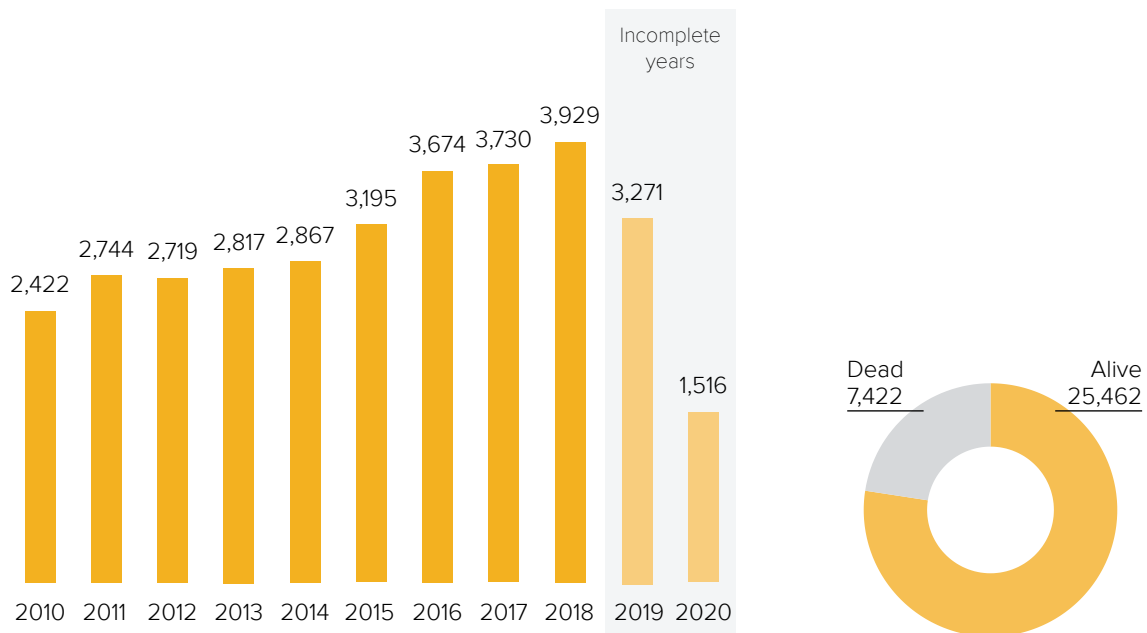
Patent filings

Analysing patent family filings across time indicates growth or decline in innovation. Additional in-depth analysis can help understand underlying factors and their correlation to these trends.

Figure 1 indicates the number of patent families by their earliest priority year and overall patent family status. The dip in patent filings in 2019-2020 reflects incomplete data due to a lag in the publication of patents. More details on patent status are given in [Appendix A: Definitions](#).

Of the 32,885 patent families filed since 2010, 25,462 (77%) are in an active state with patent protection being sought or in force, and 25,092 patent families have a patent application granted in at least one jurisdiction. The low levels of patent families that have lapsed, expired, or been withdrawn may be reflective of both recent patenting activity in this technology area and high commercial interest in hydrogen technologies.

Figure 1: Hydrogen technology global patent family filings, by earliest priority year and patent status, 2010-20
Source: PATSTAT 2021 Spring Edition



Notes:

- 'Alive' patents are in an active state with patent protection being sought or in force for at least one family member; 'Dead' patent families have lapsed, expired or been withdrawn.
- The dip in patent filings in 2019-20 reflects incomplete data due to a lag in the publication of patents.

Patent origin

Analysis of patent family applicant or inventor address indicates origins of investment or interest in a specific area of innovation. Figure 2 shows the top 16 countries where patent families relating to hydrogen technologies originate. The top (yellow) bar for each country represents the total number of patent families from a given country of applicant origin. The lower (grey) bar represents the number of families from that location that have at least one member filed with a jurisdiction other than the home application jurisdiction (for example, a Chinese applicant filing in the United States of America or filing a Patent Cooperation Treaty (PCT) application with the World Intellectual Property Organization (WIPO)). Such international patent filings demonstrate investment in the global marketplace and can therefore indicate innovation with strong commercial potential.

Chinese applicants have filed the most patents globally (17,264 patent families), but only 809 (<5%) of these were filed in jurisdictions outside of China. The United States of America, which has the highest global amount of venture capital investment in hydrogen technologies¹⁵, and Japan, which rank 2nd and 3rd globally in terms of patent filings, respectively, have a far higher proportion of patents filed outside of their home jurisdiction. Australian applicants rank 16th globally, with 193 patent families filed from 2010-20, of which 155 (80%) were filed in jurisdictions outside of Australia, indicating that Australian innovation in hydrogen technologies is strongly globally competitive.

¹⁵CTPCO (Australian Government Critical Technologies Policy Coordination Office) (2021) Hydrogen and ammonia for power <https://www.industry.gov.au/sites/default/files/2022-08/ctpc-co-tech-cards-hydrogen-ammonia-power-aust.pdf>

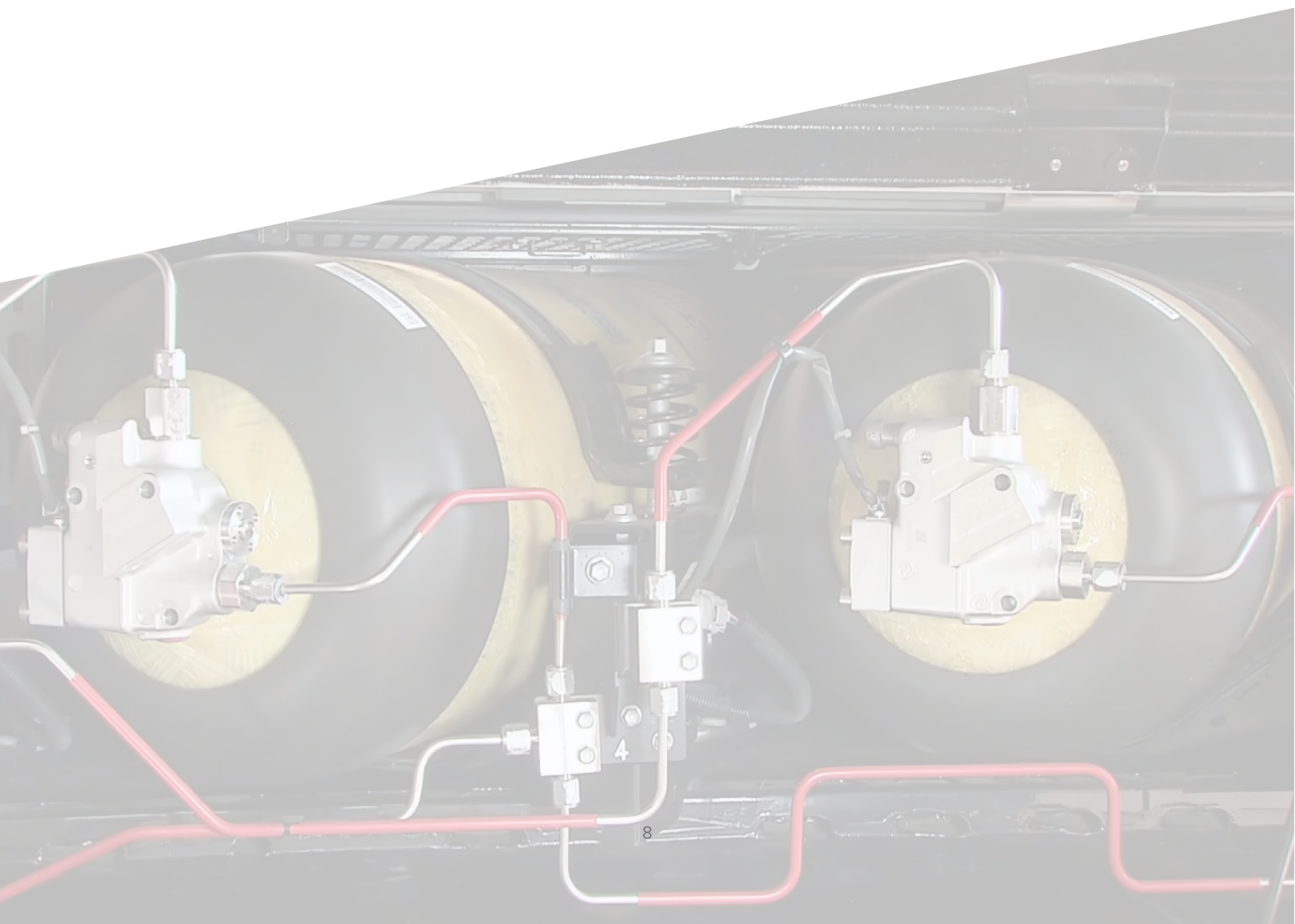
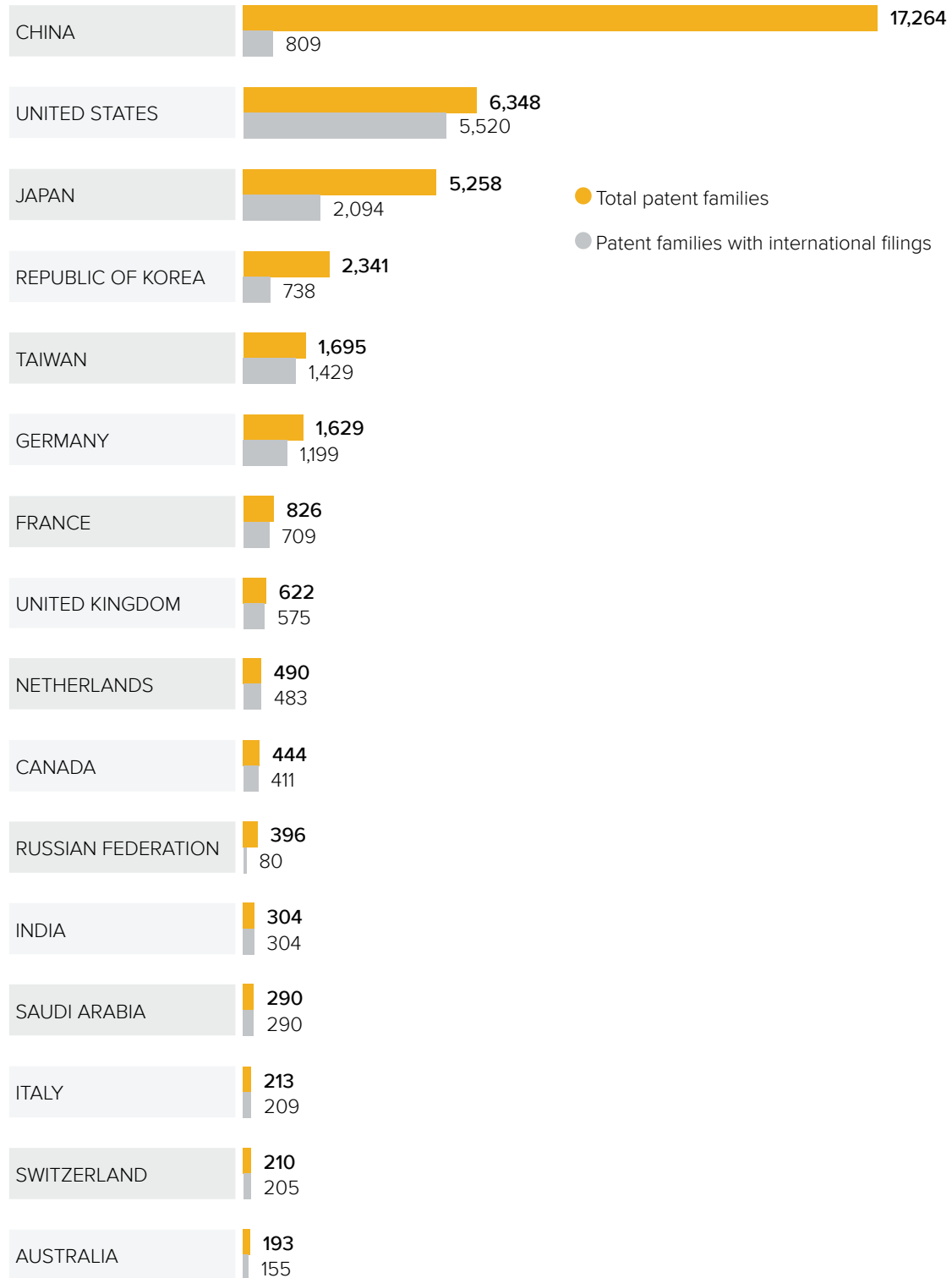


Figure 2: Hydrogen technology patent family filings, by patent origin, 2010-20
 Source: PATSTAT 2021 Spring Edition

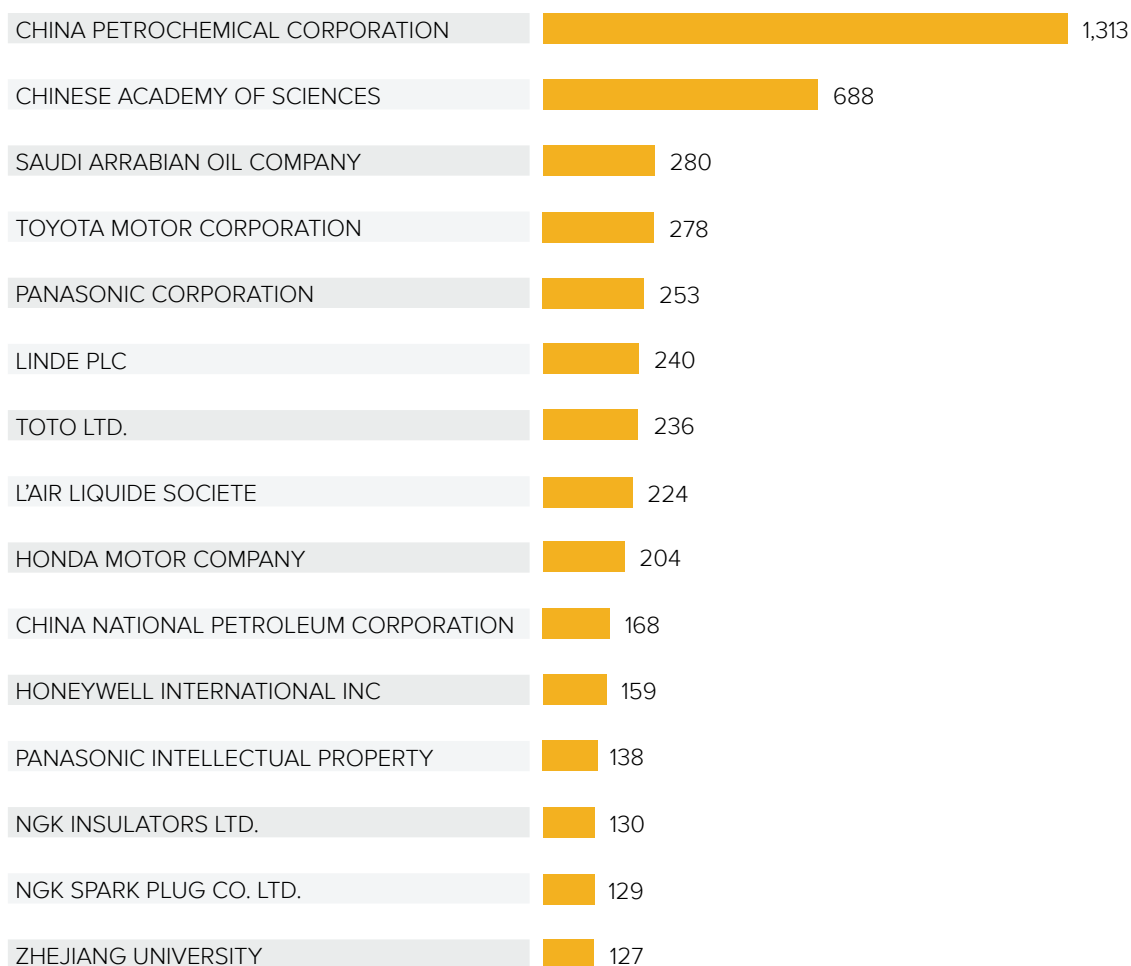


Top applicants

A patent provides an exclusive right to the patent owner for up to 20 years to protect their ideas and products. The number of patent families filed by an applicant in a particular technology can be indicative of their interests and market presence, or desire to build and maintain a market share.

Figure 3 shows the top 15 global applicants filing patents across all hydrogen technologies identified in this report. The top 2 applicants - China Petrochemical Corporation and the Chinese Academy of Sciences - together have filed 2,001 patent families, accounting for 6% of all patent families filed globally in all hydrogen technologies. Petroleum companies show up in the top applicants list and work on technologies such as fossil fuel conversion and electrolysis; for example see patent application [CN111689469](#).

Figure 3: Hydrogen technology patent family filings by applicants, 2010-20
 Source: PATSTAT 2021 Spring Edition



Patent destination

Applicants must file patent applications in each country or patent jurisdiction where they wish to have enforceable patent protection. Reasons for seeking patent protection include the country being a target for commercialisation, further research and development, or manufacturing.

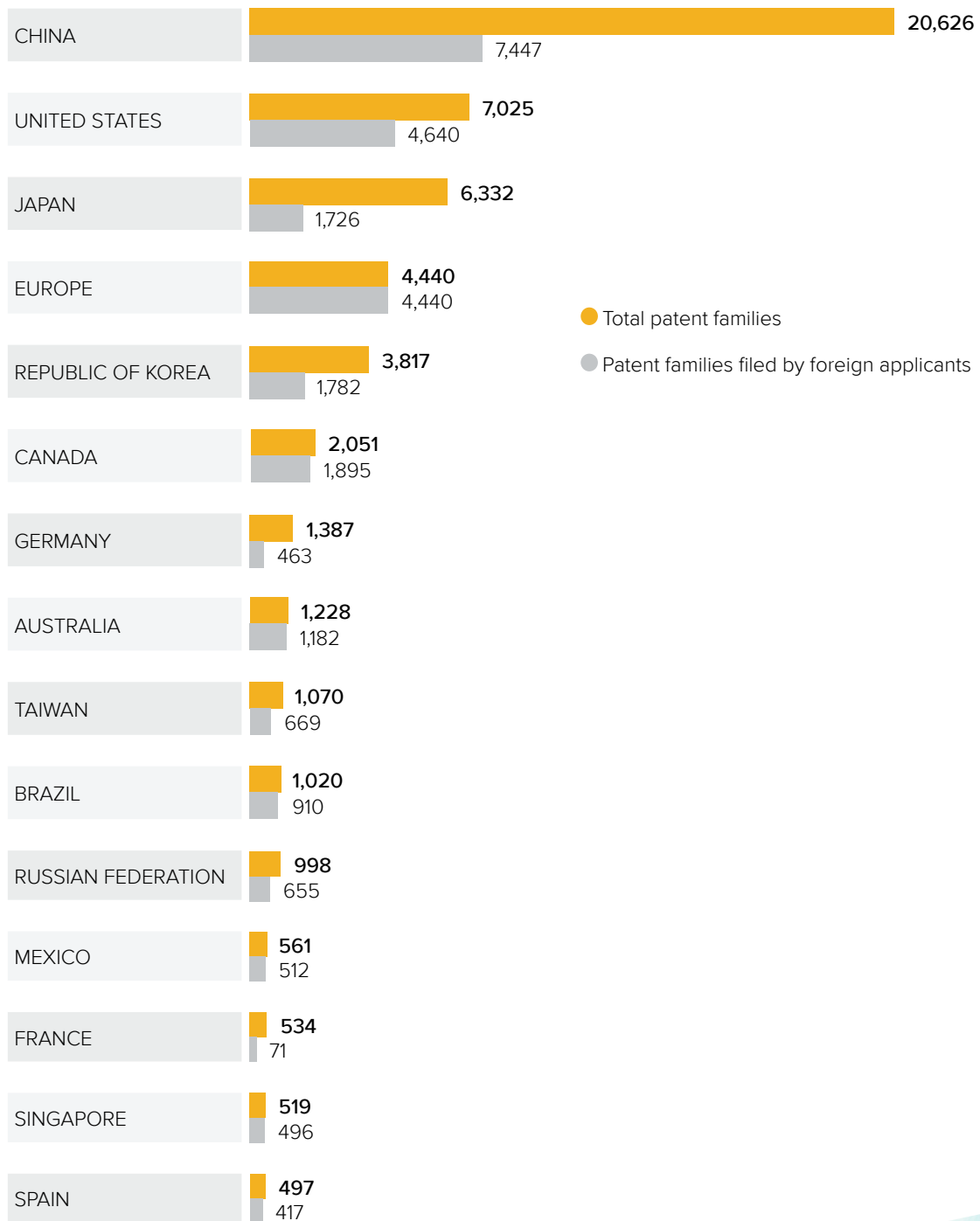
Figure 4 shows the number of patent families filed in different jurisdictions. The top (yellow) bar represents the total number of patent families filed in each jurisdiction. The second (grey) bar indicates the number of patent families filed into that jurisdiction by an applicant from another jurisdiction (for example, an applicant from the United States of America filing a patent in China). This demonstration of investment in patent protection indicates the relative perceived value of each market to global innovators from outside the jurisdiction. PCT applications have been excluded from this figure because PCT applications do not represent an enforceable right in any jurisdiction.

European patents are enforceable in designated contracting states to the European Patent Convention at the date of filing of the application and are included in this analysis. Patent protection may also be sought in European countries directly, e.g., in Germany. In Figure 4, 'Europe' identifies patent families filed with the European Patent Office and does not include filings with European countries' individual patent offices, which are reported separately by country. Additionally, since 'Europe' is not an originating jurisdiction for patent applicants, all applications filed in 'Europe' are designated international.

Global commercial interest in hydrogen technologies is obvious from Figure 4. The top destination for filing patents is China with 20,626 families (of which 36% are filed by global applicants), followed by the United States of America with 7,025 patent families (66% filed by global applicants).



Figure 4: Hydrogen technology patent family filings, by patent filing destination, 2010-20
 Source: PATSTAT 2021 Spring Edition



AUSTRALIAN PATENTING TREND OVERVIEW

Analysis of patent data provides information both on Australians who are innovating in a technology area, as well as on the market and potential for investment and commercialisation in Australia.

Patent filings originating from Australia

Figure 5 indicates the number of patent families filed in any jurisdiction by Australian applicants or inventors by year, with 2012 having the highest number of filings since 2010 in the figures to date. While Australians¹⁶ have consistently filed patents in hydrogen

technologies since 2010, patent filing by Australians accounts for less than 1% of global patent filings.

Of the 193 patent families filed by Australians since 2010, 142 (74%) are in an active state, with patent protection being sought or in force, and 131 patent families have a patent application granted in at least one jurisdiction. The dip in patent filings in 2019-2020 reflects incomplete data due to a lag in the publication of patents.

Figure 5: Hydrogen technology patent family filings by Australians, by earliest priority year and patent status, 2010-20. Source: PATSTAT 2021 Spring Edition



Notes:

1. 'Alive' patents are in an active state with patent protection being sought or in force for at least one family member; 'Dead' patent families have lapsed, expired, or been withdrawn.
2. The dip in patent filings in 2019-20 reflects incomplete data due to a lag in the publication of patents.

¹⁶ Who are Australians? In this analysis, a patent family is considered to have been filed by an Australian if any one of the patent applicants (generally companies, universities, or research institutes) or inventors has listed an Australian address. More details are given at [Appendix A: Definitions](#).

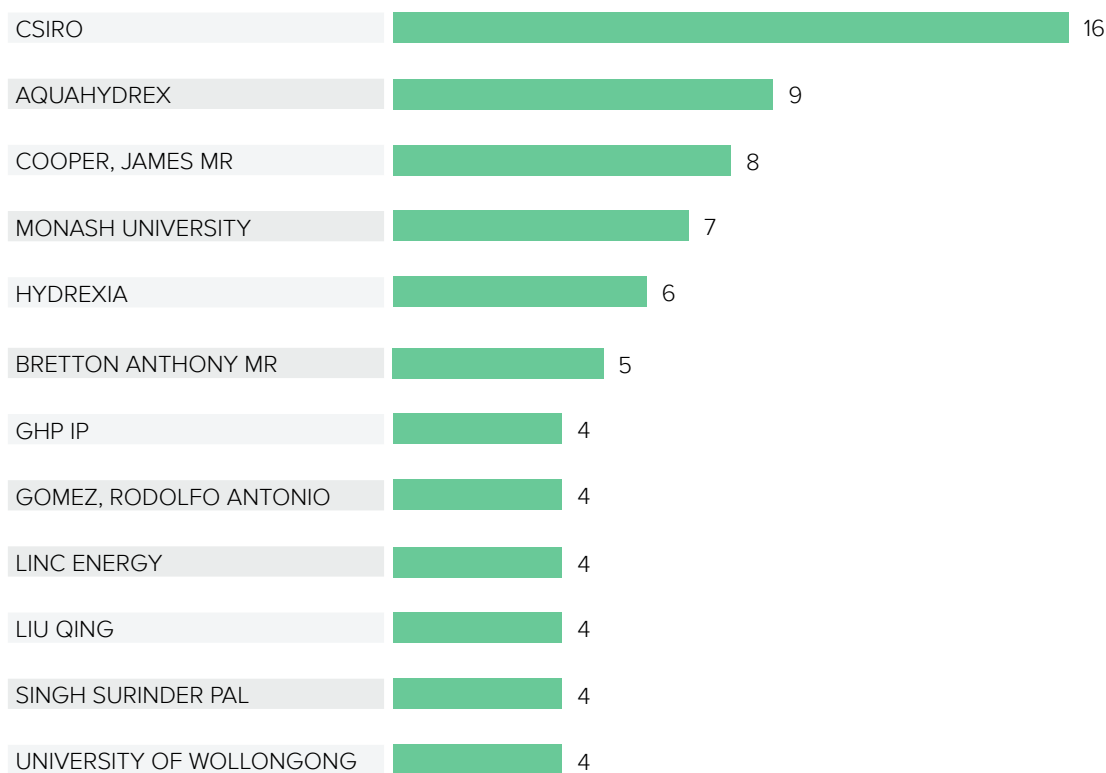
Top Australian applicants

Figure 6 shows the top Australian applicants who have at least four patent families filed, from a total of 96 Australian applicants who filed patents across all hydrogen technologies identified in this report. These are either Australian entities or are non-Australian entities that have filed patents listing an Australian applicant or inventor.

Information on the top four Australian applicants, who have each filed more than six patent families in hydrogen technologies and their co-applicants are

summarised in Table 1. Each of these applicants were also identified as highly ranked Australian research institutes or patent filers by the Critical Technologies Policy Coordination Office (CTPCO)¹⁷. The applicants Mr James Cooper and Mr Anthony Bretton are inventor-applicants affiliated with Renewable Hydrogen Pty Ltd. All but one of their patent applications are innovation patent filings. Innovation patents comprised Australia’s second tier patent system and are in the process of being phased out.

Figure 6: Hydrogen technology patent family filings by Australian applicants, 2010-20
 Source: PATSTAT 2021 Spring Edition



¹⁷ CTPCO (2021) Hydrogen and ammonia for power <https://www.industry.gov.au/sites/default/files/2022-08/ctpcotech-cards-hydrogen-ammonia-power-aust.pdf>

Table 1: Top four Australian applicants filing patents in hydrogen technologies, with co-applicants

Applicant	Applicant description	Co-applicants
CSIRO	CSIRO's Hydrogen Energy Systems Future Science Platform supports new Australian industries across the emerging hydrogen value chain to drive large-scale emissions reduction ¹⁸	Chevron Corporation Grains Research and Development Monash University Security International University of Melbourne
AquaHydrex Pty Ltd	AquaHydrex was formed in 2012 by True North Venture Partners, an investment firm set up to create disruptive innovations to achieve a clean and sustainable future ¹⁹	Monash University University of Wollongong
Monash University	The Monash Energy Institute's Low Emission Coal Technologies Laboratory improves energy production from brown coal through hydrogen ²⁰	CSIRO Deakin University Security International University of Melbourne AquaHydrex
University of Wollongong	The University of Wollongong has a strong focus on research and development in clean energy, including hydrogen ²¹	Australian National University AquaHydrex

Notes:

Co-applicants can be co-filing collaborators jointly listed on a patent application or can be entities who acquired patent rights ownership from the applicant prior to publication of one of the patent family members.

¹⁸CSIRO Hydrogen Energy Systems <https://research.csiro.au/hydrogenfsp/>

¹⁹AquaHydrex Overview <https://AquaHydrex.com/companu/>

²⁰Monash Energy Institute <https://www.monash.edu/energy-institute/research/facilities>

²¹University of Wollongong (2021) UOW Submission in response to the Inquiry into the development of a hydrogen industry in New South Wales <https://www.parliament.nsw.gov.au/lcdocs/submissions/70713/0012%20University%20of%20Wollongong.pdf>



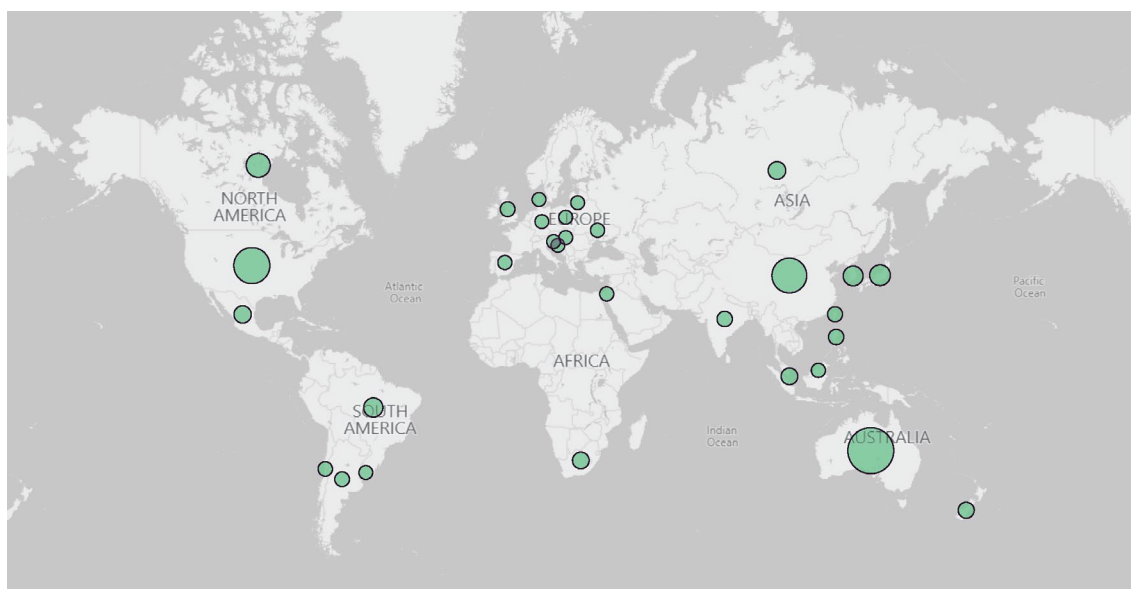
Where do Australian innovators seek patent protection?

Figure 7 indicates the number of patent families filed by Australians in different jurisdictions. PCT applications are excluded from this figure because these do not represent an enforceable right in any jurisdiction.

Australian applicants in hydrogen technologies are exporting their technical knowledge worldwide,

with a focus on the United States of America and China that is only slightly less than their filing in the Australian market. Australian applicants have filed 80% of their patent families in overseas jurisdictions, which indicates strong global competitiveness by Australian innovation in this sector.

Figure 7: Hydrogen technology patent family filings by Australian applicants, by patent destination, 2010-20
 Source: PATSTAT 2021 Spring Edition



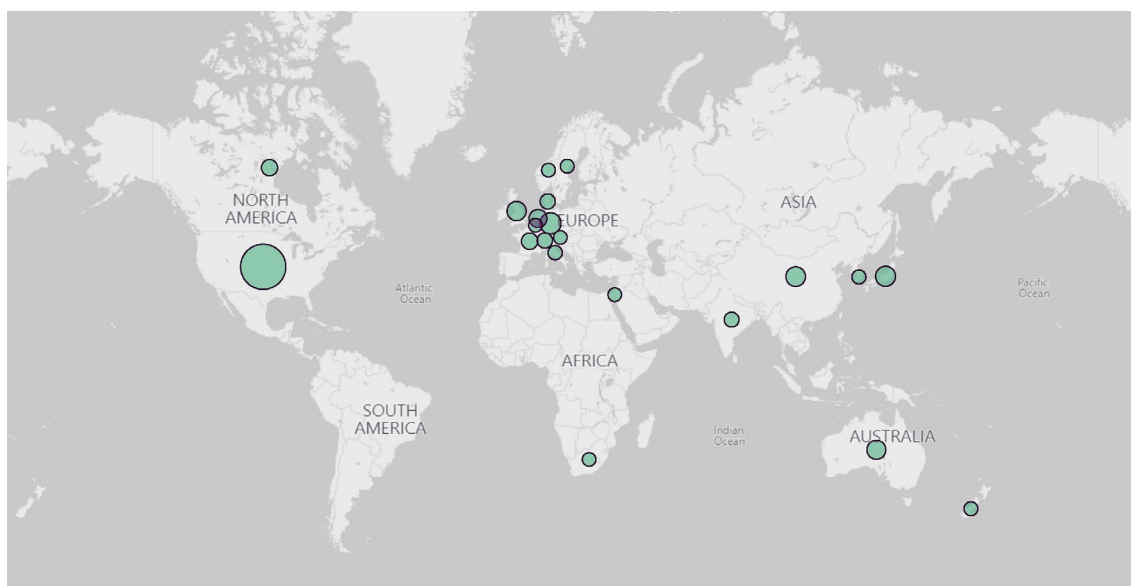
AUSTRALIA	102	RUSSIAN FEDERATION	13
UNITED STATES	71	MEXICO	12
CHINA	67	SINGAPORE	10
EUROPE	44	SOUTH AFRICA	10
CANADA	33	NEW ZEALAND	8
JAPAN	23	INDIA	6
REPUBLIC OF KOREA	20	PHILIPPINES	6
BRAZIL	18		

Where do patents filed in Australia come from?

Figure 8 indicates the number of patent families relating to hydrogen technologies filed in Australia by the top-ranked country of applicant or inventor origin. The map indicates the origin of applicants who have filed ten or more patent families that include patent family members filed in Australia.

Patent applicants from the United States of America are responsible for most patents filed in Australia, followed by Germany and Japan. Australia ranks as the 6th highest-filing country of origin, with 102 patent families including members filed in Australia. This indicates that Australia is a location of commercial interest and investment in the field for countries such as the United States of America, Germany, and Japan, aligning with Australian Government plans to foster international partnerships in this sector²².

Figure 8: Hydrogen technology patents filed in Australia, by applicant’s country of origin, 2010-20
Source: PATSTAT 2021 Spring Edition



UNITED STATES	551	CANADA	54
GERMANY	139	SWITZERLAND	41
JAPAN	119	DENMARK	38
CHINA	113	INDIA	32
UNITED KINGDOM	105	ITALY	23
AUSTRALIA	102	REPUBLIC OF KOREA	19
NETHERLANDS	84	NEW ZEALAND	16
FRANCE	60		

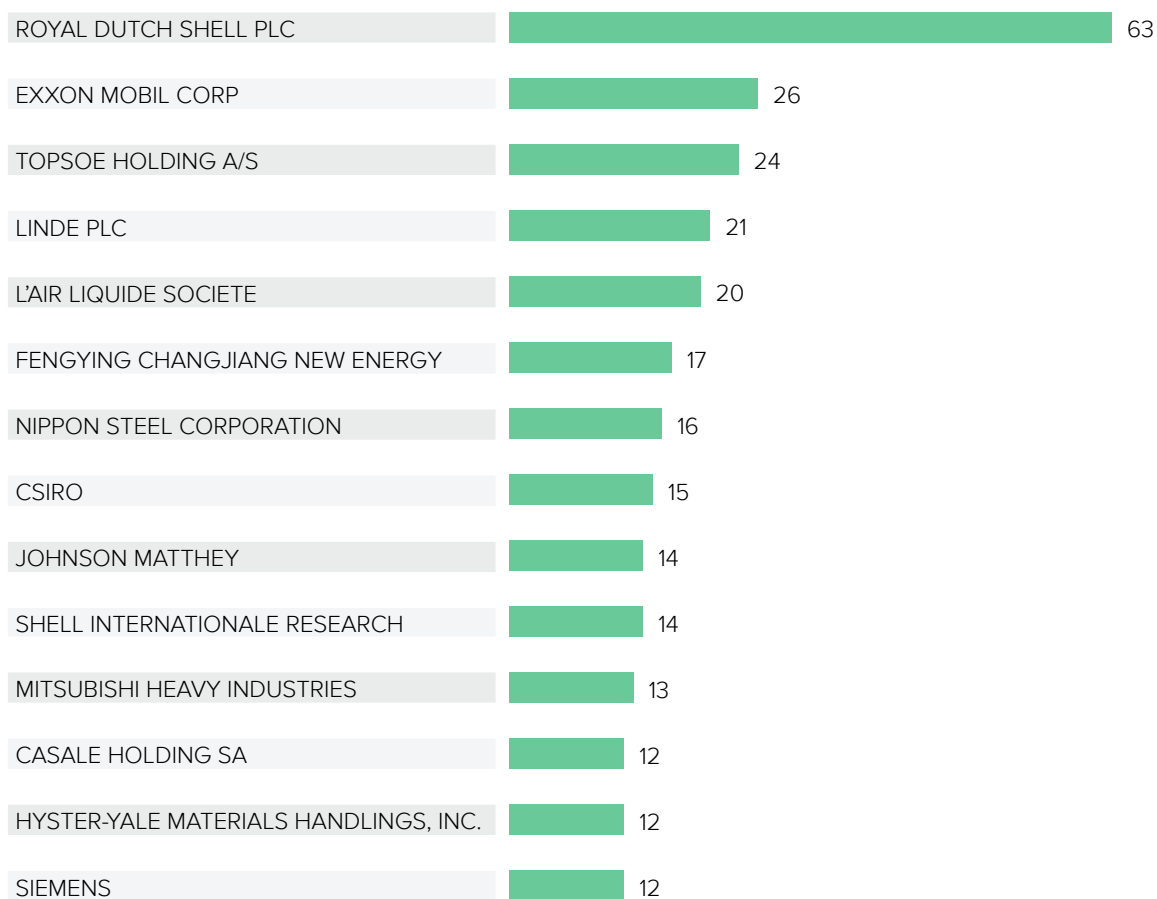
²²Department of Industry, Science, Energy and Resources (2021) State of Hydrogen <https://www.dceew.gov.au/sites/default/files/documents/state-of-hydrogen-2021.pdf>

Global applicants filing in Australia

Figure 9 shows the top global applicants filing patents across all hydrogen technologies in Australia. The top ranked applicant, Royal Dutch Shell PLC (with 63 patent families) corresponds to the Netherlands being highly ranked by country of origin for patents filed in Australia (Figure 8). The same is true for Exxon Mobil Corp from the United States of America (with 26 patent families). This indicates that Australia is a location of commercial interest for major businesses in this sector.

CSIRO ranks as the eighth highest-filing patent applicant in Australia and is also the highest ranked Australian applicant filing globally. The CSIRO work program is currently targeting three impact areas: next generation hydrogen production; novel carrier pathways; and ensuring we have the capability to make the environmental, social, and economic case for hydrogen energy²³.

Figure 9: Hydrogen technology patents filed in Australia, by applicant, 2010-20
 Source: PATSTAT 2021 Spring Edition



²³ CSIRO Hydrogen Energy Systems <https://research.csiro.au/hydrogenfsp/>

Case Study — AquaHydrex

US10087536 — Breathable electrode structure and method for use in water splitting

With the purpose of ‘Green hydrogen for a net zero future’, AquaHydrex’s development in the field of water splitting exemplifies an Australian inventor, university and business who successfully collaborated to research, commercialise, and export their ideas.

AquaHydrex was established in 2012 from the Australian Research Council (ARC) Centre of Excellence for Electromaterials Science (ACES), with venture capital investment from True North Venture Partners. The AquaHydrex water splitting technologies were the culmination of years of research at ACES nodes at the University of Wollongong (UOW) and Monash University, as well other ARC-supported projects at Monash University. UniQuest partnered with UOW and Monash University to develop the business plan and raise capital for AquaHydrex based on IP held by Monash University and UOW²⁴.

In 2015, AquaHydrex opened a facility in Colorado²⁵. By 2016, the company had launched its first products aimed at the industrial hydrogen market in Australia and went on to create 20 new Australian jobs for a highly skilled workforce²⁶.

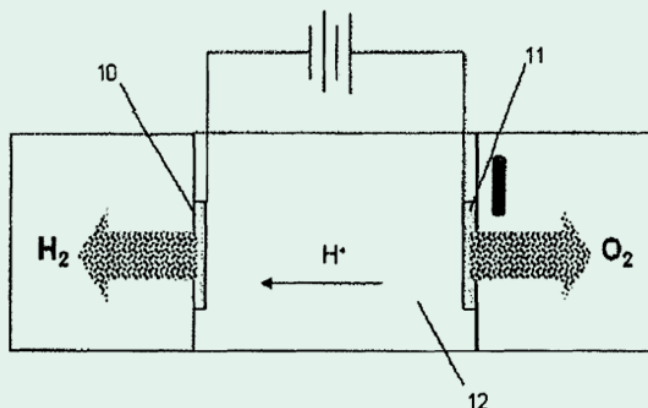
The improvement of the electrolysis process defined in [US10087536](#) is a water splitting cell with an electrode that has a hydrophobic gas-permeable porous membrane. This diffuses gas out of the cell and allows the removal of the gas from the

reaction at the electrode without substantial bubble formation, thus increasing the efficiency of the water splitting cell.

Patent [US10087536](#), granted in the United States of America on 12 September 2018, was initially filed as a PCT application ([WO2013185163](#)) with IP Australia on 12 June 2012 by Monash University together with three Australia-based inventors: Bjorn Winther-Jensen (Associate Professor, Monash University, later Professor at Waseda University, Japan, followed by a career in the private sector), Douglas MacFarlane (Sir John Monash Distinguished Professor, School of Chemistry, Monash University), and Orawan Winther-Jensen.

The Monash University patent was acquired by AquaHydrex in 2016. National patent applications were later filed in Australia, Japan, Korea, Russia, Brazil, Canada, Mexico, and the United States of America. This shows how Australian innovation has been developed and exported, helping to progress global developments in the generation of hydrogen. AquaHydrex is listed as a key player in the global green hydrogen project pipeline by the International Renewable Energy Agency, which predicts future global cumulative water electrolyser capacity in this sector rising from less than 1GW in 2019 to 25GW by 2030²⁷.

Case study Figure 1c: Gas and ion movements in a full breathing cell.



²⁴ Monash University (n.d.) AquaHydrex – Splitting water <https://www.monash.edu/industry/why-work-with-us/success-stories/aquahydrex>

²⁵ AquaHydrex (2022) Company <https://AquaHydrex.com/company/>

²⁶ ACES (ARC Centre of Excellence for Electromaterials Science (2021) <https://electromaterials.edu.au/case-studies/AquaHydrex-enabling-green-hydrogen/>

²⁷ IRENA (International Renewable Energy Agency) (2020) Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5oC Climate Goal, International Renewable Energy Agency, Abu Dhabi https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

TECHNOLOGY ANALYSIS

Technology overview

Analysing the technical content of patents can provide insights into specific technologies. These insights highlight areas of commercial interest and can be used to inform research and commercialisation strategies.

Here, patents relating to hydrogen technologies have been divided into three main categories:

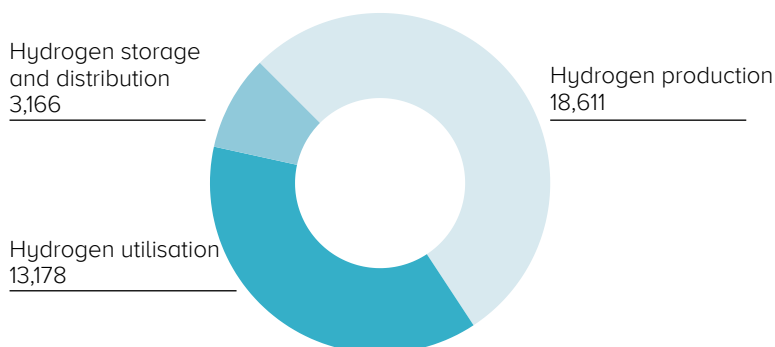
- Hydrogen production
- Hydrogen storage and distribution
- Hydrogen utilisation.

Further sub-categorisation corresponds to the

National Hydrogen Research, Development and Demonstration Technical Repository (CSIRO)²⁸. The technology categories are not mutually exclusive, meaning that a patent family may be counted in more than one technology category.

Figure 10 indicates that hydrogen production is the major focus area of patenting in hydrogen technologies accounting for over 50% of patent families filed globally in this sector. Further definition of the categories is explained in each of the following category sections.

Figure 10: Hydrogen technology filings by main category, 2010-20
Source: PATSTAT 2021 Spring Edition



Hydrogen production

Hydrogen production technologies define alternate methods of sourcing and producing hydrogen. Hydrogen production research and development improves the efficiency and lowers the cost and environmental impact of energy production. Hydrogen production is required in different environments globally with differing sources used for the energy production e.g., water splitting and fossil fuel conversion.

This report focuses on six hydrogen production technology categories:

- **Electrolysis:** hydrogen splitting (extraction) from water using electricity
- **Fossil fuel conversion:** hydrogen extraction and conversion from fossil fuels
- **Biomass and waste conversion:** hydrogen extraction from biomass or waste
- **Biological hydrogen production:** biological systems that produce hydrogen
- **Photochemical and photocatalytic:** use of light to produce hydrogen
- **Thermal water splitting:** hydrogen splitting from water using heat.

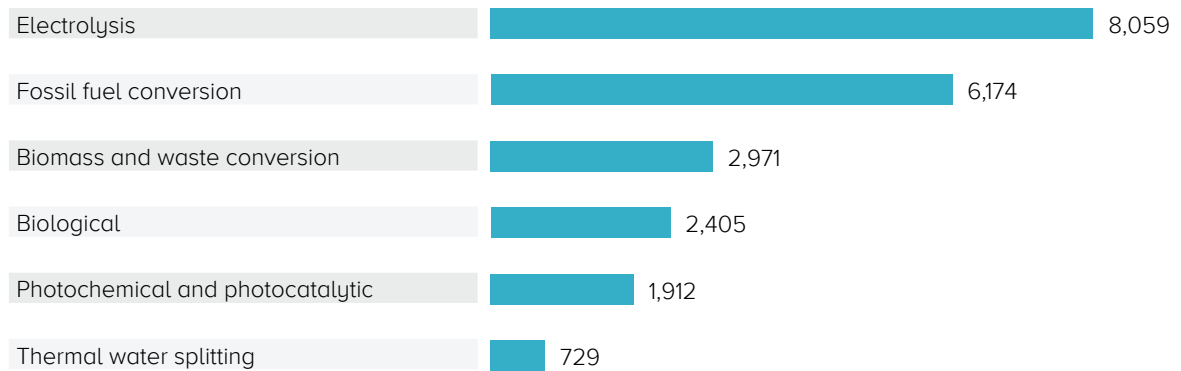
²⁸ CSIRO (2019) Hydrogen Research, Development and Demonstration: Priorities and Opportunities for Australia
<https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/hydrogen-research-and-development>

Patent filings

Figure 11 shows that electrolysis is the major category of hydrogen production patent filing. Australian filing of hydrogen electrolysis patents is analysed further in the Technology Focus section of this report.

Electrolysis and fossil fuel conversion are also shown as major categories of patent family filing in hydrogen production by the patent insight report *Innovation trends in electrolysers for hydrogen production*²⁹ published by the European Patent Office (EPO) and the International Renewable Energy Agency.

Figure 11: Hydrogen production technology patent family filings, 2010-20
Source: PATSTAT 2021 Spring Edition



²⁹EPO and IRENA (2022) Innovation trends in electrolysers for hydrogen production
https://www.epo.org/news-events/news/2022/20220512.html?mtm_campaign=epo-newsletter&mtm_source=epo-newsletter&mtm_keyword=epo-newsletter-09&mtm_medium=newsletter&mtm_group=email

Patent origin

Countries show different trends in their focus on hydrogen technologies. This can be a result of differences in political, geographical or energy requirements.

Table 2 shows the number of patent filings in the hydrogen production technologies by country of

origin since 2010. The data indicates that China's hydrogen production technology concentrates on electrolysis and fossil fuel conversion. Fossil fuel conversion and electrolysis dominate filings by the United States of America, with electrolysis technology also leading filings from Japan.

Table 2: Hydrogen production technology patent family filings, by patent origin, 2010-20
 Source: PATSTAT 2021 Spring Edition

Origin	Biological	Biomass and waste conversion	Electrolysis	Fossil fuel conversion	Photochemical and photocatalytic	Thermal water splitting
CHINA	1,543	1,274	4,253	3,666	1,215	402
UNITED STATES	565	806	1,128	1,744	356	183
JAPAN	174	332	1,134	300	236	34
REPUBLIC OF KOREA	137	200	829	322	113	32
TAIWAN	134	128	607	264	95	45
GERMANY	78	215	344	282	57	65
FRANCE	39	101	146	237	15	5
NETHERLANDS	21	115	55	195	49	26
UNITED KINGDOM	61	70	115	169	24	10
CANADA	51	76	88	138	21	14
SAUDI ARABIA	4	49	35	147	44	35
INDIA	17	72	27	112	17	14
RUSSIAN FEDERATION	10	28	78	90	1	1
AUSTRALIA	12	30	60	33	20	14
ITALY	19	21	54	46	9	6

Top applicants

Patent applicants also show hydrogen technology focus areas in their patent portfolios. This can be a result of the interests of the country in which they operate, and the services they offer.

Table 3 shows that China Petrochemical Corporation has a strong, world-leading focus on fossil fuel conversion that appears to heavily drive their total number of patent families (928 out of 1,313 across all hydrogen technology sectors). The Chinese Academy of Sciences and Panasonic Corporation lead global patent filings on electrolysis.

Table 3: Hydrogen production technology patent family filings by applicant, 2010-20

Source: PATSTAT 2021 Spring Edition

Applicant	Biological	Biomass and waste conversion	Electrolysis	Fossil fuel conversion	Photochemical and photocatalytic	Thermal water splitting
CHINA PETROCHEMICAL CORPORATION	86	40	21	928	2	2
CHINESE ACADEMY OF SCIENCES	85	72	133	152	91	26
SAUDI ARABIAN OIL COMPANY	4	50	29	186	41	17
PANASONIC CORPORATION	2	9	101	6	39	4
CHINA NATIONAL PETROLEUM CORPORATION	6	10	2	138		
ROYAL DUTCH SHELL PLC	9	56	3	77	1	1
LINDE PLC		43	10	80		3
ENEOS HOLDINGS		65	15	45		
HE JUTANG		2		120		
SOUTHEAST UNIVERSITY	23	28	19	39	8	2
L'AIR LIQUIDE SOCIETE				107		1
TOSHIBA CORPORATION	1	7	83	1	14	
TIANJIN UNIVERSITY	7	11	40	9	29	9
HONEYWELL INTERNATIONAL INC	4	28	6	61		2
IFP ENERGIES NOUVELLES	2	28	9	56	1	1
EXXON MOBIL CORP	4	20	2	67	1	1
TAIJUAN UNIVERSITY OF TECHNOLOGY	13	6	27	33	10	3
SOUTH CHINA UNIVERSITY OF TECHNOLOGY	15	8	3	39	16	6
TSINGHUA UNIVERSITY	27	13	31	12	3	

Hydrogen storage and distribution

Hydrogen storage and distribution technologies involve increasing hydrogen density, allowing storage at atmospheric pressures and transportation at ambient temperatures, and improving safety. Hydrogen storage and distribution occurs in varied environments with differing needs.

Patent filings

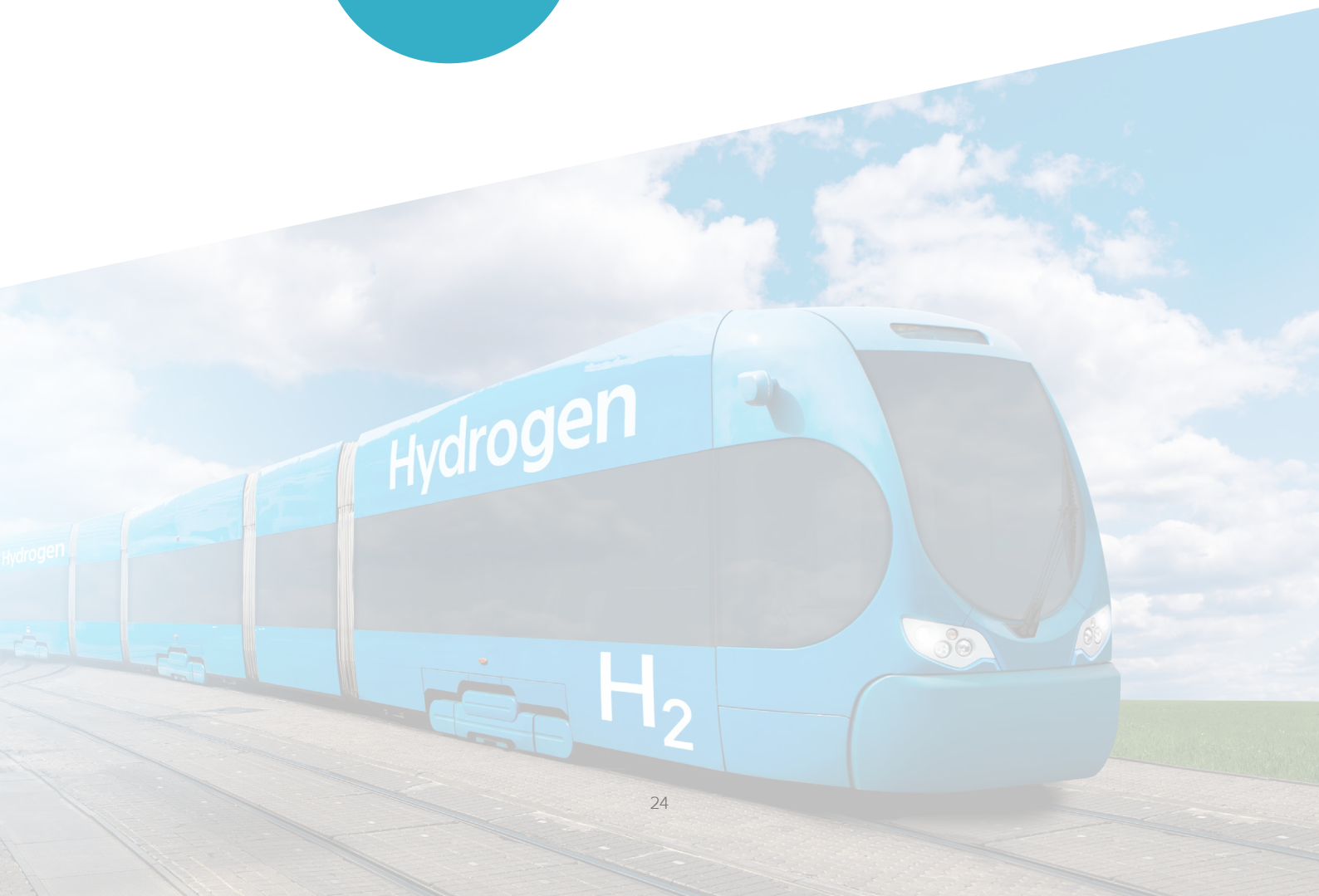
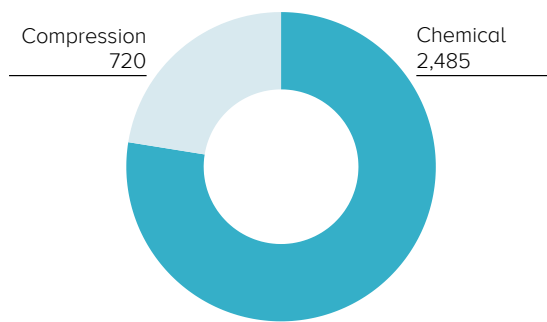
Figure 12 shows that chemical storage patents are more prevalent than compression storage patents. Filings over time indicate that compression storage

The report focuses on two hydrogen storage and distribution technology categories:

- **Chemical:** hydrogen in a chemical carrier
- **Compression:** high density hydrogen in a compressed or liquefied form.

patent filings are also undergoing reasonable growth.

Figure 12: Hydrogen storage and distribution technology patent family filings, 2010-20
Source: PATSTAT 2021 Spring Edition



Patent origin

Table 4 shows that all countries have more patent filings related to chemical carrier than compression

hydrogen storage, with China leading in both technology areas.

Table 4: Hydrogen storage and distribution technology patent family filings, by patent origin, 2010-20
Source: PATSTAT 2021 Spring Edition

Origin	Chemical	Compression
CHINA	1,055	245
UNITED STATES	547	146
JAPAN	434	106
REPUBLIC OF KOREA	198	131
GERMANY	229	96
FRANCE	115	31
TAIWAN	115	18
UNITED KINGDOM	78	22
RUSSIAN FEDERATION	48	1

Origin	Chemical	Compression
CANADA	39	8
SWITZERLAND	21	13
NETHERLANDS	28	5
INDIA	25	5
BELGIUM	28	2
AUSTRIA	22	8
ITALY	24	5
AUSTRALIA	22	4

Top applicants

The country-level focus on chemical carrier over compression hydrogen storage changes at the company level. Table 5 shows that the top two ranked applicants have a focus on compression

storage and then the next four applicants focus on chemical carrier storage. Motor vehicle companies have a focus on compression storage.

Table 5: Hydrogen distribution and storage technology patent family filings, by applicant, 2010-20
Source: PATSTAT 2021 Spring Edition

Applicant	Chemical	Compression
TOYOTA MOTOR CORPORATION	27	41
HYUNDAI MOTOR COMPANY	16	47
LINDE PLC	24	18
CHINESE ACADEMY OF SCIENCES	34	6
L'AIR LIQUIDE SOCIETE	24	13
TIANJIN NORMAL UNIVERSITY	34	
KIA MOTORS CORPORATION	6	28
CEA (COMMISSARIAT A L'ENERGIE ATOMIQUE)	26	4

Applicant	Chemical	Compression
PANASONIC INTELLECTUAL PROPERTY	21	8
GENERAL MOTORS COMPANY	11	16
BASF SE	26	
ZHEJIANG UNIVERSITY	25	
HONDA MOTOR COMPANY	1	24
BMW (BAYERISCHE MOTOREN WERKE)	12	13
TOKYO ELECTRON LIMITED	24	

Hydrogen utilisation

Hydrogen utilisation technologies are the end uses for hydrogen power. These technologies improve efficiency, reduce cost, and lower emissions as illustrated in WIPO’s patent landscape report on hydrogen fuel cells in transportation³⁰. Like hydrogen distribution and storage, hydrogen utilisation occurs in varied environments with differing needs.

The report focuses on six hydrogen utilisation technology categories:

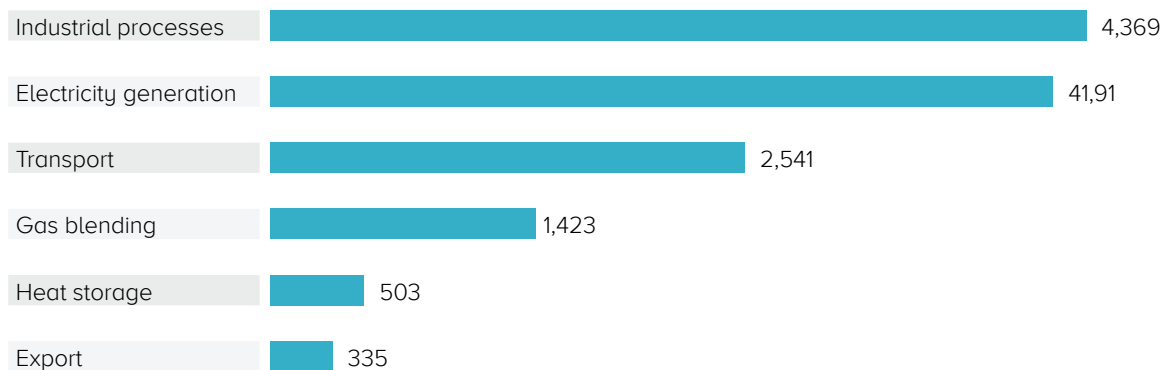
- **Industrial processes:** hydrogen used in industrialised processes
- **Electricity generation:** hydrogen-generated electricity
- **Transport:** hydrogen-powered transportation
- **Gas blending:** hydrogen blending, separation, pipeline materials, metering, and appliance testing
- **Heat storage:** hydrogen used in thermal storage systems
- **Export:** hydrogen export, including international shipment and logistics.

Patent filings

Figure 13 shows that industrial processes and electricity generation are the major areas of patent filings for hydrogen utilisation. Industrial processes include technologies relating to steel processing,

combustion, synthetic fuels, and methanol production, all of which are initiatives intended to reduce carbon production in industrial processes.

Figure 13: Hydrogen utilisation technology patent family filings, 2010-20
Source: PATSTAT 2021 Spring Edition



³⁰ WIPO (2022) Patent Landscape Report: Hydrogen fuel cells in transportation
<https://www.wipo.int/publications/en/details.jsp?id=4604>

Patent origin

Table 6 shows that China and Japan lead the world in patent filings in hydrogen utilisation technologies. The countries have clearly different

areas of specialisation: China is focused on industrial purposes while Japan is focused on electricity generation.

Table 6: Hydrogen utilisation technology patent family filings, by patent origin, 2010-20
Source: PATSTAT 2021 Spring Edition

Origin	Electricity generation	Export	Gas blending	Heat storage	Industrial processes	Transport
CHINA	1,090	262	433	241	3,128	1,140
JAPAN	2,126	10	157	107	157	467
UNITED STATES	625	66	535	84	859	367
REPUBLIC OF KOREA	366	16	67	29	116	170
GERMANY	108	8	173	34	140	252
TAIWAN	119	18	39	15	232	139
FRANCE	63	2	154	12	78	55
UNITED KINGDOM	62	1	69	5	79	49
RUSSIAN FEDERATION	25	4	7		120	34
CANADA	35	2	31	2	75	25
NETHERLANDS	22	3	70	11	39	11
INDIA	24	2	36	1	41	9
SWITZERLAND	20		15	6	32	18
SAUDI ARABIA	18		43	1	13	8
AUSTRALIA	8	11	8	2	29	21
ITALY	12	2	21	5	29	9

Top applicants

Table 7 shows that, as seen for other hydrogen technology areas, there is a company-level specialisation in patent applications in different hydrogen utilisation technologies. Applicants from China (i.e., the top two global filers of patent

applications in hydrogen utilisation technologies) are focused on industrial processes, while applicants from other countries are primarily interested in electricity generation.

Table 7: Hydrogen utilisation technology patent family filings, by applicant, 2010-20
Source: PATSTAT 2021 Spring Edition

Applicant	Electricity generation	Export	Gas blending	Heat storage	Industrial processes	Transport
CHINA PETROCHEMICAL CORPORATION	1	5	17	5	318	1
CHINESE ACADEMY OF SCIENCES	71	7	24	6	127	5
TOTO LTD.	236					
TOYOTA MOTOR CORPORATION	81		5	7	3	71
NGK SPARK PLUG CO. LTD.	123		1			4
NGK INSULATORS LTD.	126			1		1
PANASONIC INTELLECTUAL PROPERTY	94		11	6	1	6
PANASONIC CORPORATION	104			9	1	4
L'AIR LIQUIDE SOCIETE	2	1	102	3	8	1
LINDE PLC	2		94	1	9	9
MITSUBISHI HEAVY INDUSTRIES LTD	95		6	2	3	1
OSAKA GAS CO. LTD.	100		4	1		1
HONDA MOTOR COMPANY	86					19
ENEOS HOLDINGS INC	65		7	4	1	27
NISSAN MOTOR CO., LTD.	85		1	1		14
KYOCERA CORPORATION	97					2

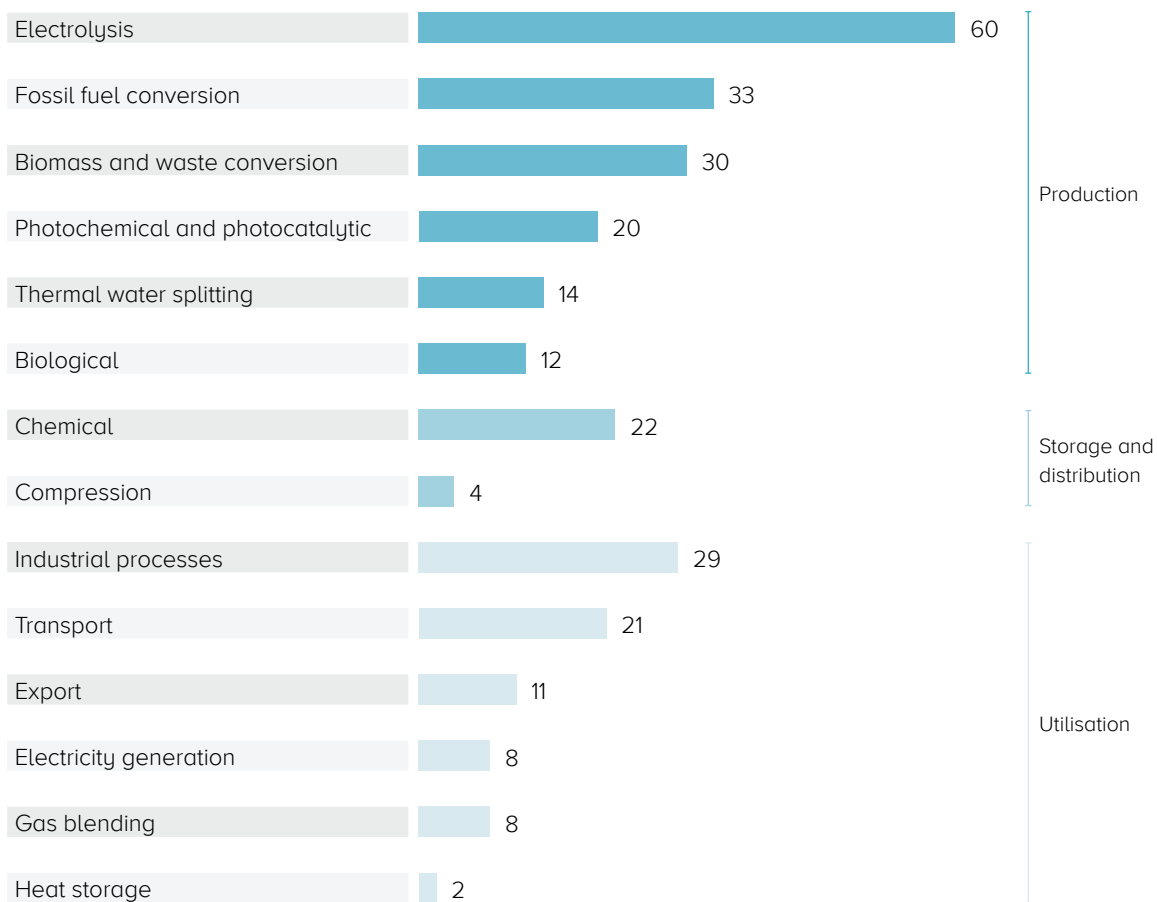
Patent technologies originating from Australia

Australian based applicants show their own focus areas for hydrogen technologies. Figure 14 shows that the greatest numbers of patent filings originating from Australia are in the areas of electrolysis, fossil

fuel conversion, and biomass and waste conversion. This indicates that Australia’s primary focus is on the initial production of hydrogen.

Figure 14: Hydrogen technology patent families filed by Australian applicants, by technology category, 2010-20

Source: PATSTAT 2021 Spring Edition

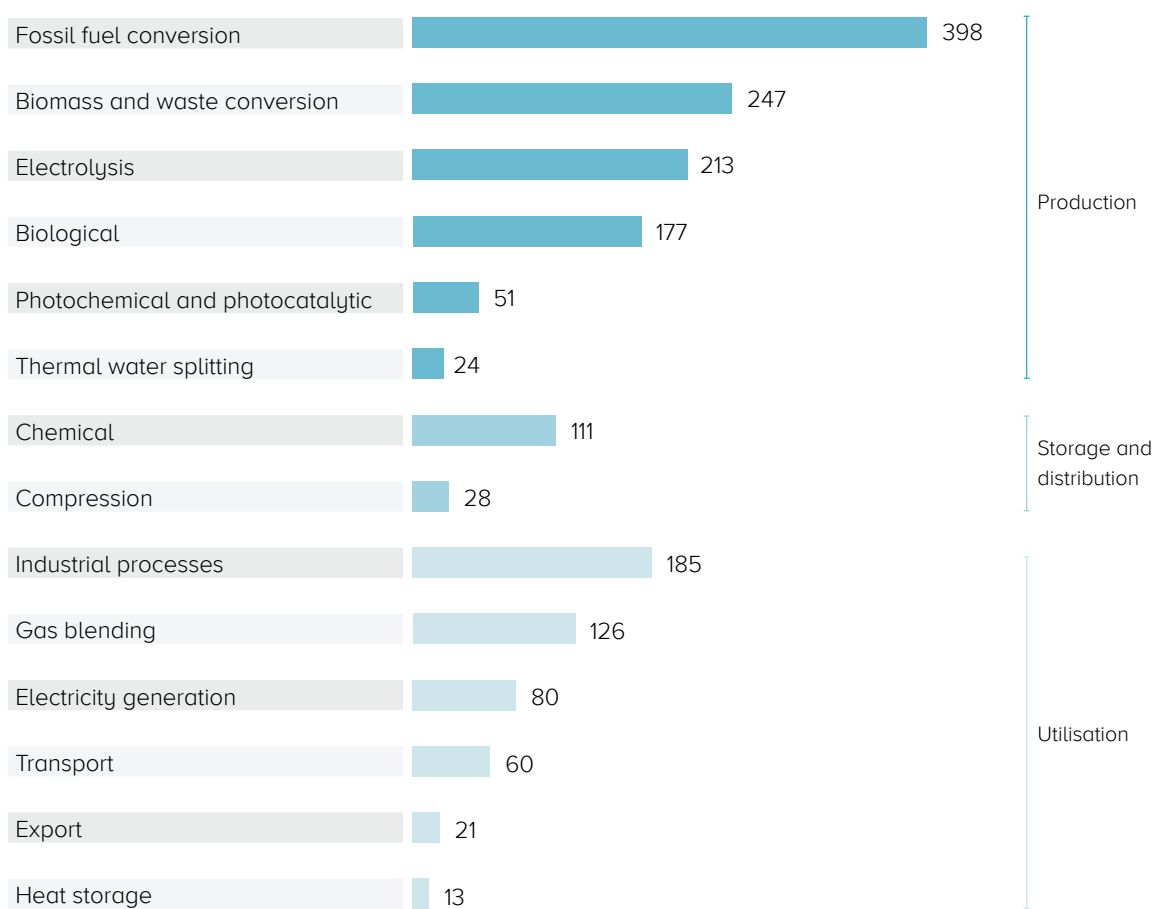


Patents filed in Australia on hydrogen technologies

Patents filed in Australia by overseas or Australian applicants indicate the technologies that have demonstrated market and investment potential in Australia.

Figure 15 shows that the greatest focus is on hydrogen production technologies - fossil fuel conversion, biomass and waste conversion, and electrolysis, paralleling the areas of innovation specialisation shown by patent filings originating from Australian applicants (see Figure 14).

Figure 15: Hydrogen technology patent families filed in Australia, by technology category, 2010-20
Source: PATSTAT 2021 Spring Edition



TECHNOLOGY IN FOCUS: ELECTROLYSIS

Electrolysis in Australia

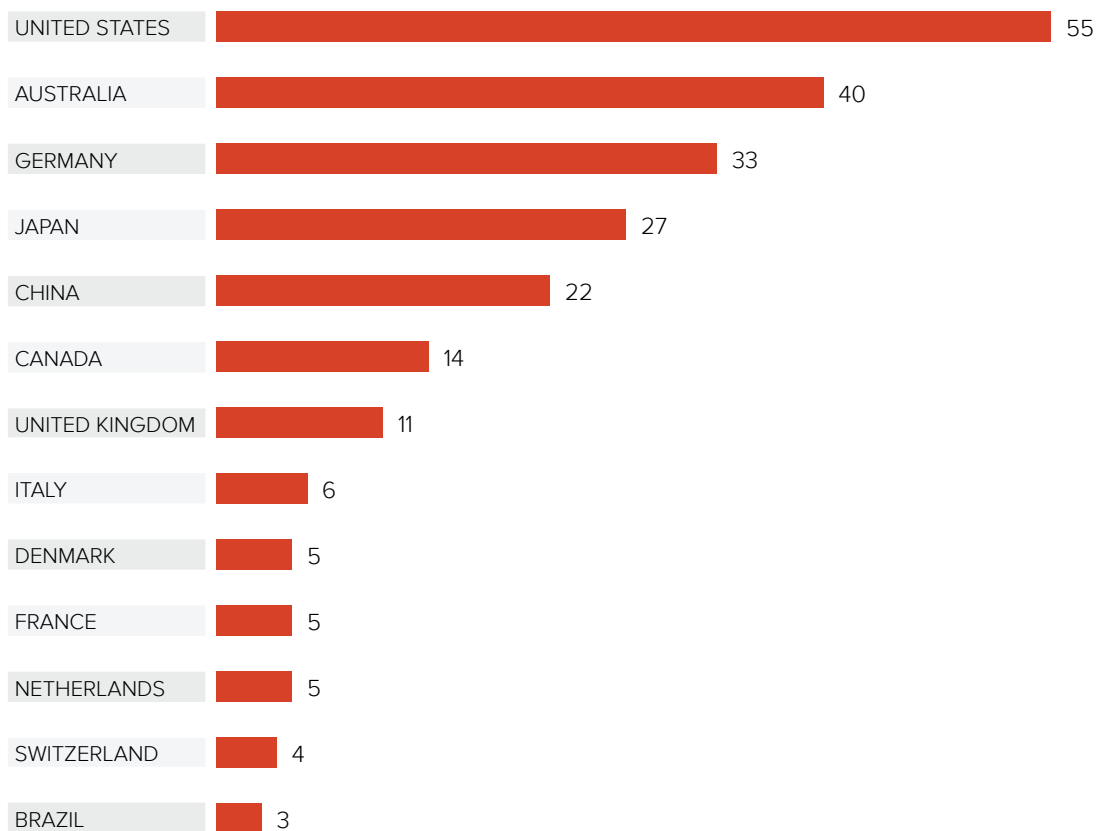
Hydrogen electrolysis is the process of using electricity to decompose water into oxygen and hydrogen gas and is one of the most promising alternatives to store energy from renewable energy resources³¹. It was shown in Figure 14 that electrolysis is the major area of filing, and innovation specialisation, by Australian applicants in hydrogen technologies.

Figure 15 showed that electrolysis is also in the top three areas of patent filings in Australia. However, Australian applicants account for less than 1% of the global patent filings in electrolysis technologies,

indicating that Australia has the capability but is a minor player in one of the most protected hydrogen technology areas. As a destination market, Australia received just under 3% of global patent filings in electrolysis, indicating that Australia is a market of interest for international applicants.

Figure 16 shows that the United States of America is the biggest filer of electrolysis patents in Australia followed by Australian filings.

Figure 16: Electrolysis patents filed in Australia, by applicant's origin, 2010-20
Source: PATSTAT 2021 Spring Edition



³¹ Kuman SS and Himabindu V (2019) Hydrogen production by PEM water electrolysis – a review, Material Science for Energy Technologies vol. 2(3), p. 442-454
<https://www.sciencedirect.com/science/article/pii/S2589299119300035>

Figure 17 shows the wide variety of applicants filing hydrogen electrolysis patents in Australia, from Hsin-Yung Lin (a Chinese inventor-applicant) to large multinational technology companies such as Siemens.

Figure 17: Electrolysis patents filed in Australia, by applicant, 2010-20
 Source: PATSTAT 2021 Spring Edition

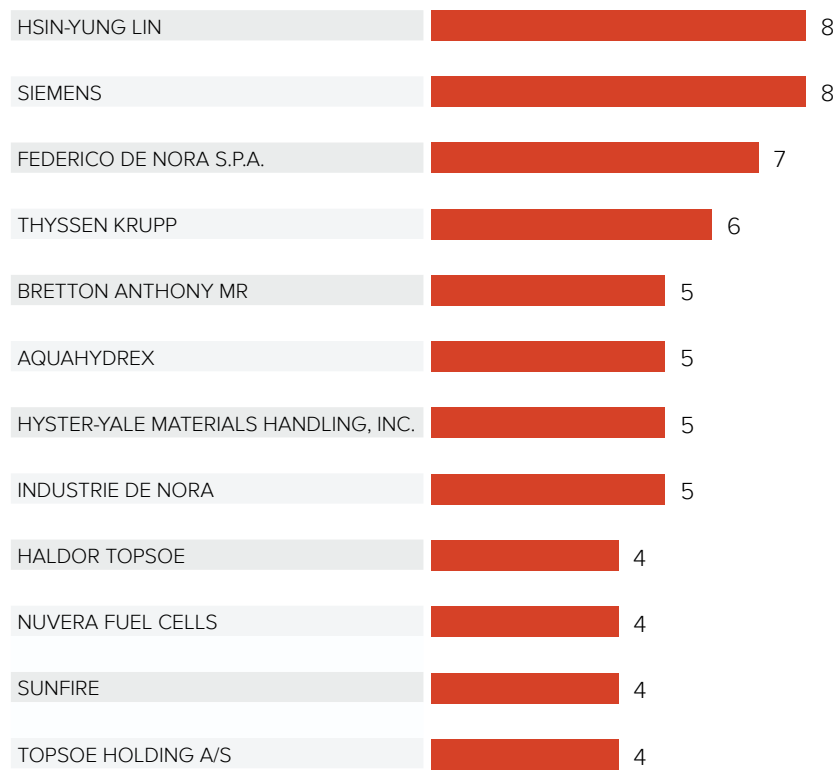
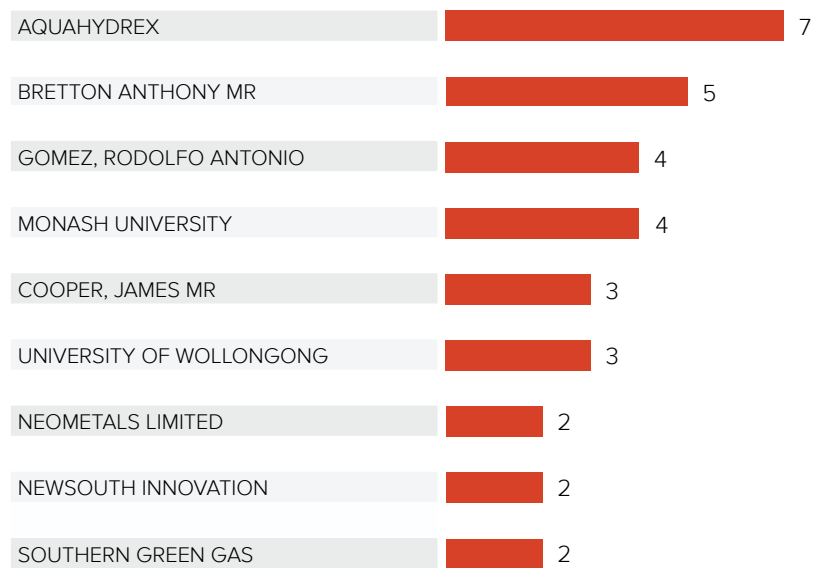


Figure 18 shows that AquaHydrex is the top Australian filer of patents in the field of hydrogen electrolysis in all markets. The Case Study - AquaHydrex highlighted one of AquaHydrex's

patent filings in electrolysis. Table 1: (above) provides an overview of the top Australian filers including AquaHydrex.

Figure 18: Electrolysis patents filed globally by Australian applicants, 2010-20
Source: PATSTAT 2021 Spring Edition



Case Study — Electrolysis

AU2017391757 — Hydrogen production from seawater

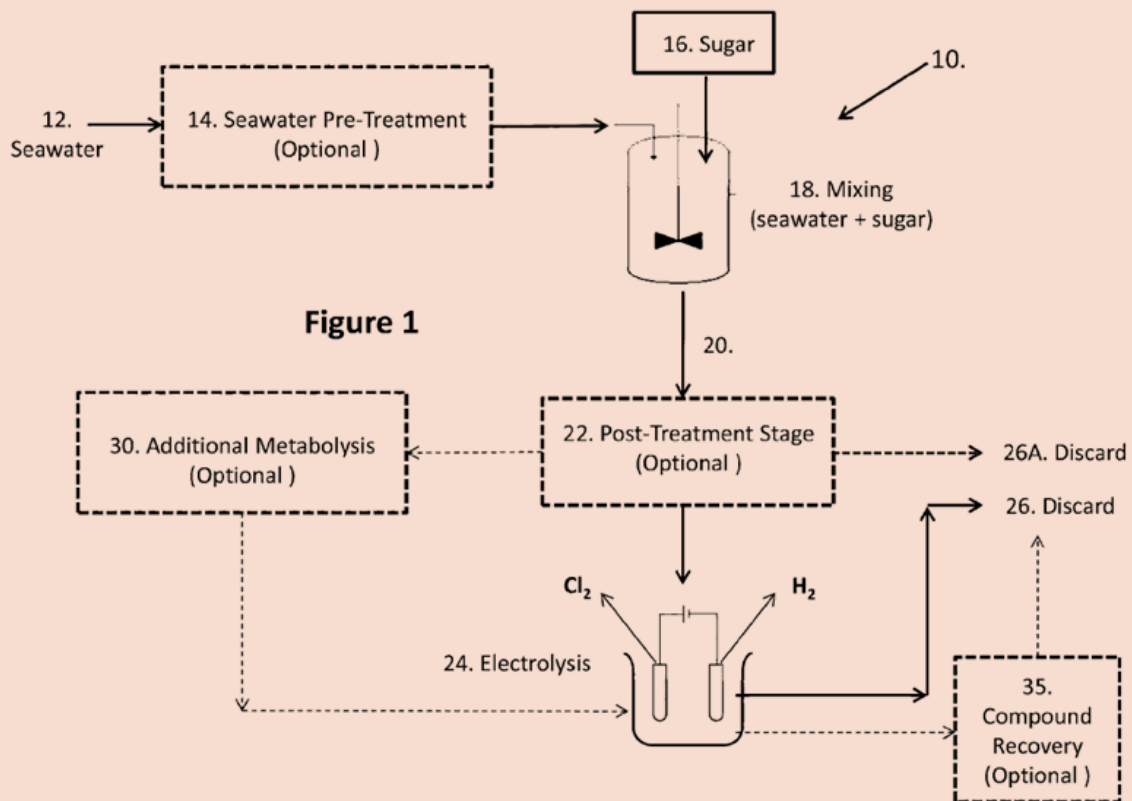
Sea-Nergy Pty Ltd is an Australian based company developing methods of producing carbon negative renewable hydrogen from seawater³². With global interest in renewable energy and water security, this development by an Australian applicant demonstrates Australia’s capability to improve the electrolysis process through looking at the system as a whole and finding alternate and more abundant water supplies. The progress of this patent internationally also illustrates the potential to export Australian innovations into countries that have well-developed hydrogen economies.

The improvement in the electrolysis process defined in [AU2017391757](#) is the method of producing a precursor compound using seawater. The method disclosed involves mixing a predetermined amount

of sugar with seawater for a sufficient period to allow the conversion of the sugar to a carboxylic acid, which is then used as the precursor in hydrogen electrolysis. The ability to produce hydrogen from seawater is defined in the application as a surprising discovery; and has the environmental benefit of not impacting fresh water supplies.

Patent [AU2017391757](#), granted by IP Australia on 19 October 2018, was initially filed as an Australian provisional application with IP Australia on 3 January 2017 by Jason Scott Evans who then transferred the application to the company Sea-Nergy Pty Ltd for the accepted application. The application has subsequently filed as a PCT application ([WO2018126292](#)), entered National Phase in the Republic of Korea, and has been granted in Japan.

Case study Figure 1: schematic flowsheet of producing hydrogen from seawater



³² <https://static1.squarespace.com/static/56c6c5b8ab48de588bfff3c8/t/5849e4378419c22ce7619d51/1481237577956/Greater+Geraldton+Investment+Opportunities+Program+2016+FINAL+%281%29.pdf>



CONCLUSION

This report set out to explore patents in hydrogen technologies and to shed light on innovation trends as environmental and sustainability awareness grows. We identified 32,885 unique patent families filed globally since 2010 relating to hydrogen, including 193 patent families originating from Australian applicants.

Hydrogen technologies have seen an increase in global patenting activity since 2010, with 3,929 filings in 2018 alone. Recent growth has been predominantly driven by China, with over 50% of patent families originating there. We also observed a slight decline in patent families originating from Japan, while patenting from the United States appears steady.

China is also the largest filing destination with many Chinese applicants only patenting in China. In contrast, entities from the United States and Europe often choose to protect their inventions worldwide. Chinese companies are prominent among the top applicants, with some having filed large numbers of patent families in short periods of time.

Australia is the eighth largest global filing destination for hydrogen technologies, with many companies from Europe and the United States of America choosing to file applications here. The major Australian players include CSIRO, AquaHydrex, Monash University and Hydrexia.

Australian applicants specialise in electrolysis, which accounts for 31% of patent families filed by Australians. In terms of the Australian market, patent families in fossil fuel conversion account for 32% of the patent families filed into Australia, making it Australia's most protected hydrogen technology field.

This report identifies Australians who are actively working in different fields of hydrogen technology, and the accompanying interactive visualisations³³ allow the reader to 'drill down' into the underlying data and discover relevant individuals and companies. This type of information can help identify expertise in areas that could help to build Australia's hydrogen capability and inform strategic research and policy decisions to build Australia's national energy capability.

Overall, this patent analytics report on hydrogen reveals a sector with strong growth and potential to build Australian capability. This would benefit the broader Australian economy in the context of intense global interest and also secure our energy future and supply chain resilience. This report provides evidence to inform decision-makers to ensure that Australians benefit from secure national energy capability.

³³IP Australia (2021) Patent analytics on hydrogen technologies
<https://www.ipaustralia.gov.au/tools-and-research/professional-resources/data-research-and-reports/publications-and-reports/2022/09/30/hydrogen-technology-patent-analytics>



Hydrogen LH₂



APPENDIX A: DEFINITIONS

Patents, applications, and publications

A patent is a right that is granted for any device, substance, method, or process that is new, inventive and useful. Australian patent rights are legally enforceable and give the owner, or patentee, exclusive rights to commercially exploit the invention in Australia for a period of up to 20 years. In this report, an application refers to a single patent filing.

A patent application is usually published within 18 months of its earliest filing date (also known as the priority date). We consider that the priority date is most relevant to our analysis as it is the closest date to that when the invention occurred.

There are two major routes for filing a patent application: the international route and direct filing. The international route involves filing a PCT application, which establishes a filing date in all 156 contracting states. Subsequent prosecution at national patent offices, referred to as national phase entry, is made at the discretion of the applicant. A patent can only be enforced once it has been granted, and a PCT application must enter the national phase in each country to proceed toward grant. Alternatively, applications can be filed directly in the countries of interest, without using the PCT system.

Patent families

Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity, regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention. We determine patent families based on INPADOC database definition, with a unique family ID for patents that share a common priority document. The number of patent families is typically used

as a metric. There are some exceptions when reporting individual applications, as each application represents a legal right in an individual country. When analysing applicants, related commercial entities are grouped by a singly, harmonised name. When individual publication numbers are quoted, we have chosen a representative publication from the patent family, typically US or WO English language documents.

Classification

Patents are hierarchically classified by technology into the hierarchical International Patent Classification (IPC) or Cooperative Patent Classification (CPC) systems. The CPC began in 2013 and provides

significantly more depth to the hierarchy of the IPC. For more information on the coverage of the CPC, see the CPC Annual Reports.

Patent status determination

A patent application is considered as 'being sought or in force' when it has not lapsed (due to expiry or non-payment of renewal fees), been revoked or withdrawn. A family is designated as 'being sought or in force' if it contains at least one application that is 'being sought or in force'. The PATSTAT database is used to define the legal events 'Application

Discontinuation' and 'IP Right Cessation'. These are considered to make an application lapsed, expired, or withdrawn. Applications without these events are considered as 'being sought or in force'.

Country of origin

Many records in the PATSTAT database (around half) do not have any associated country code information for applicants/inventors. In previous patent analytics studies, null data has generally been excluded from the country of origin analysis. In this patent analytics report, we have used other data available in PATSTAT to provide additional insights for patent families that do not have applicant origin data available. This method of country code assignment leverages all data from the entire PATSTAT database, and not only country codes information from a subset of the data extracted for a specific technology area.

The country of origin of a patent family is assigned using a three-step process.

1. Where country code is available for applicant data, this is used as the country of origin.
2. If the country code is 'null' and the applicant's name is associated with a standardised or cleaned version of their name (e.g., the

PATSTAT standardised PSN name), there may be several versions of an associated applicant name with several entries for country code. A count of the total number of applications applied for with each country code is used to determine the most representative country and that is applied. This is an independently developed technique analogous to the technique detailed by the European Commission by Pasimeni (2019)³⁴.

3. If the country code for the standardised name is 'null', or where no applicant details are recorded for the patent application, then the first application authority is used. This is the country that the earliest priority document was filed into for the patent family, and it is used as a country of origin. This authority is the first by date where the authority is a country, and not an international body. For international applications, the receiving office is used where possible.

Who are Australians?

In this analysis, a patent family is considered to have been filed by an Australian if any one of the patent applicants (generally companies, universities, or research institutes) or inventors has listed an Australian address.

As a result of this definition, this analysis includes patent filings from some entities that are not Australian. These non-Australian entities are included for those filings where they either:

- Have co-filed patents with Australian applicants or
- Have listed Australian inventors as working for, or in collaboration with, them.

Information on these filings and collaborations identifies dissemination of Australian knowledge and expertise. Such knowledge, and who holds it, is discussed in this report. Full details of all patent families are included in the accompanying interactive visualisation.

³⁴Pasimeni, F. (2019) SQL query to increase data accuracy and completeness in PATSTAT, World Patent Information, vol. 57, p.1-7. <https://www.sciencedirect.com/science/article/pii/S0172219018300875?via%3Dihub>



APPENDIX B: SEARCH STRATEGY

Searching patent information to identify relevant records for analysis requires a stepped approach to identify broad categories of relevance, and then specific records within them that meet the technology brief.

The following details outline the search and analysis process conducted.

Data extraction and analysis

We used five phases of data extraction and analysis.

- Phase 1: Development of a search strategy (below).
- Phase 2: Data mining using the DWPI database accessed via Derwent Innovation. The unique patent publications relating to hydrogen were identified and used to extract information related to their INPADOC family from PATSTAT 2021 Spring Edition.
- Phase 3: Data cleaning, focusing on consolidating applicant names and ensuring the return of correct records.
- Phase 4: Data captured in the search that was not directly related to hydrogen were excluded from the analysis.
- Phase 5: Data analysis using Power BI Desktop for calculation and visual presentation of patent metrics.

Search strategy

Hydrogen production

All hydrogen production searches use a base of keywords and IPC/CPC symbols related to hydrogen production.

- 1.1 (PY>=(2010) AND PY<=(2021)) AND ((CTB=((H2 or Hydrogen) near2 (PRODUCE or Production or Producing OR MANUFACTUR* OR GENERAT*)) AND AIC=(C25B000102 or C25B000104* or H01M0004242 or H01M0002300* or C25B000303)) OR CTB=((H2 or Hydrogen) near2 (PRODUCE OR Production or producing OR MANUFACTUR* OR GENERATION or Generate or generating)) near5 (ELECTROLYSIS* OR ELECTROLYTIC* OR ELECTROLYSER* OR ELECTROLYZER*));
- 1.2 (PY>=(2010) AND PY<=(2021)) AND (CTB=((H2 or Hydrogen) near2 (PRODUCE or producing OR production OR MANUFACTUR* OR GENERAT*)) OR AIC=(C01B000324 or C01B22031235 or C01B220302*)) AND (CTB=((Fossil or METHANE OR CH4 OR carbon ADJ dioxide or natural ADJ gas or oil or coal) Near3 (REFORM* or crack* or gasificat* or thermo_chemic* or pyrolysis or autothermat*)) OR (AIC=(C10J* or E21B0043295 OR C10G* or C10K0001*) AND CTB=(Fossil or METHANE OR CH4 OR carbon ADJ dioxide or natural ADJ gas or oil or coal)));
- 1.3 (PY>=(2010) AND PY<=(2021)) AND (CTB=((H2 or Hydrogen) near2 (PRODUC* OR MANUFACTUR* OR GENERAT*)) OR AIC=(C01B220302* or C01B22030861 or C10J23001238 or C01B22030238 or C01B22030233)) AND (CTB=((Biomass or biogas or waste or refuse) Near3 (Conver* or gasificat* or pyrolysis* or reform*)) OR AIC=(C10J23000916 or C10J2300092* or C10J23000946 or C10G000340 or C10G2300101* or C10B005302 or C01B00032*));
- 1.4 (PY>=(2010) AND PY<=(2021)) AND (CTB=((H2 or Hydrogen) near5 (PRODUC* OR MANUFACTUR* OR GENERAT*)) OR AIC=(C01B0003063 or C25B000104 or C01B0003068 or C01B0003042 or Y02E006036)) AND (CTB=((Water or H2) near5 (split* or seperat*))) AND (AIC=(Y02E00104 or Y02E001040 or Y02E001060 or F24S*) OR CTB=(Heat* or high_temp* or Thermal or solar));
- 1.5 (PY>=(2010) AND PY<=(2021)) AND CTB=((H2 or Hydrogen) near2 (PRODUC* OR MANUFACTUR* OR GENERAT*)) AND (AIC=(C12P3*) OR CTB=(Biologic* or Bio_hydro* or Biophotolysis or Dark ADJ ferment* or Microbial ADJ electrolysis or Photoferment* or Anaerobic ADJ digest*));
- 1.6 (PY>=(2010) AND PY<=(2021)) AND CTB=((H2 or Hydrogen) near9 (PRODUC* OR MANUFACTUR* OR GENERAT*)) AND (AIC=(Y02E001050 or C25B000155 OR H01M0014005 or C25B000321) OR CTB=(photo*)) AND (AIC=(C25B000104*) OR CTB=((Water or H2O) near3 (split* or react*)));

Hydrogen storage and distribution

All hydrogen storage and distribution searches use a base of keywords and IPC/CPC symbols related to hydrogen storage or distribution.

- 1.1 (PY>=(2010) AND PY<=(2021)) AND (CTB=((H2 or Hydrogen) near9 (stor* or distrib* or hold* or contain*)) OR (CTB=((H2 or Hydrogen)) AND AIC=(F17C*)) OR AIC=(Y02E006032 or Y02E006034 or F17C2221012 or C01B00030005)) AND (AIC=(Y02E006016 or F17C0001007 or B65G5* or F25J0001001 or H01M000804201) AND CTB=(compress* or underground or liquef* or solidif* or pressur* or network or pipelin* or cryo*));
- 1.2 (PY>=(2010) AND PY<=(2021)) AND (CTB=((H2 or Hydrogen) near5 (chemical* near5 (stor* or distrib* or hold* or contain*))) OR AIC=(Y02E006032 or Y02E006034 or F17C2221012)) AND (CTB=(SYNTHESES* OR AMMONIA OR Hydrides or chemical or Dimethyl ADJ either OR NH3 OR PHYSISORP* OR (PHYSI* ADJ W ADJ SORP*) OR (METAL* near3 HYDRID*) OR (ORGANIC* near3 COMPOUND*) OR (ORGANIC* near3 SOLUTION*) OR (ORGANIC* near3 LIQUID*) OR METHAN* OR CH4 OR (PROTON* near3 BATTER*)) OR AIC=(C01B00030015 or C01C000102 or C01B0003047 or C01B000324 or C01B00030026 or C01B0003003* or C01B0003004* or C01B0003005* or C01B0003006*));

Hydrogen utilisation

All hydrogen utilisation searches use a base of keywords and IPC/CPC symbols related to hydrogen utilisation.

- 1.1 (PY>=(2010) AND PY<=(2021)) AND ((CTB=((H2 or Hydrogen) AND (blend* or intergrat*)) AND (AIC=(F17C2221012 or G01N0033005 or G01N00274045 or B01D0053* or F17D1*) OR CTB=(gas adj meter* or pipeline adj material* or seperat* or appliance ADJ test*))) OR AIC=(B01D225616 or F25J00030252));
- 1.2 PY>=(2010) AND PY<=(2021) AND ((CTB=((HYDROGEN OR H2) near5 (motor or engine)) OR AIC=(F02B2043106)) AND (CTB=(Transportation or VEHICLE* OR CAR OR CARS OR TRUCK* OR TRAIN* or aviation or UAV or refuel* or steel ADJ embrittlement ADJ test* or Polymer ADJ electrolyte ADJ membrane ADJ fuel ADJ cell) OR AIC=(B60F* or B61C* OR B62D0047* or B62D0049* or F02D001902 or H01M225020 or Y02T009040)));
- 1.3 PY>=(2010) AND PY<=(2021) AND (((CTB=(turbine or fuel_cell*) OR AIC=(H01M8* or F02C*)) AND CTB=(hydrogen or H2)) OR AIC=(Y02E006050)) AND CTB=((Electric* near5 (generat* or produc*)) AND (AEMFC or PEMFC or AFC or Ammonia or Alkaline ADJ anion ADJ Exchange ADJ membrane or Microbial or solid ADJ oxide or unitised ADJ reversible or polymer ADJ electrolyte ADJ membrane or Alkaline or molten ADJ carbonate or phosphoric ADJ acid or direct ADJ methanol));
- 1.4 (PY>=(2010) AND PY<=(2021)) AND CTB=((H2 or Hydrogen) AND ((INDUST* OR COMMERCIAL*) near5 (process* or manufact* or produc*))) AND (AIC=(C21B* or C21B* or C22C0038* or F23* or F02B00431* or F02C or C10L or C10G or C07C003104) OR CTB=((Methanol near3 (MAK* OR MANUFACTUR* OR PRODUC* or Process*)) or steel* or synthetic ADJ fuel* or combustion or ((carbon ADJ dioxide or CO2) near3 reduc*)));
- 1.5 PY>=(2010) AND PY<=(2021) AND CTB=(H2 or hydrogen) AND CTB=((Export* or Import or imported or importing or internation*) near9 (Logistic* or market* or countr* or transport* or ship*));
- 1.6 PY>=(2010) AND PY<=(2021) AND ((CTB=(H2 or Hydrogen) AND AIC=(F28D00200056 or F28D0020003 or Y02E006014)) OR CTB=((H2 or Hydrogen) Near9 (heat ADJ stor* or thermal ADJ batter*)));

Search syntax

* denotes a wildcard, for any suffix or prefix variation when placed at the end or start respectively

*n (e.g., *2) denotes a wildcard with between zero and n characters

CTB indicates the titles, abstracts, and claims were searched

AIC indicates that patent classifications were searched

PY indicates the publication year.

