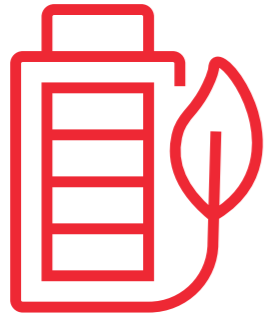


Hydrogen and ammonia for power



Sustainable production, storage, distribution and use of hydrogen (H₂) and ammonia (NH₃) for heat and electricity generation. Hydrogen and ammonia are potential low or zero emission, zero-carbon alternatives to fossil fuels and electric batteries. Applications for hydrogen and ammonia as a fuel source include aviation and marine transport, long distance road transport and heating.

Key Sectors

- Agriculture
- Energy & Environment
- Construction
- Defence & Defence Industry
- Manufacturing
- Mining & Resources
- Transport & Logistics

Estimated impact on national interest	Low	Med	High
Economic Prosperity			X
National Security			X

Key Australian Government Actions	Example Outcomes	Underpinning Science	Example Applications
<p>Initiatives</p> <ul style="list-style-type: none"> • National Hydrogen Strategy • National Hydrogen Roadmap • Australian Renewable Energy Agency (ARENA) – projects • Modern Manufacturing Strategy – clean energy priority • Clean Hydrogen Industrial Hubs Program • Clean Energy Finance Corporation (CEFC) • Low emissions partnerships with Germany, Singapore, Japan and the United Kingdom • Quad clean energy partnership <p>Regulations</p> <ul style="list-style-type: none"> • Australian Energy Market Act 2004 (Cth) • Renewable Energy (Electricity) Act 2000 (Cth) • Road Vehicle Standards Act 2018 (Cth) • Australian Energy Market Agreement 	<ul style="list-style-type: none"> • Reduced carbon and methane emissions from increased utilisation of alternative fuels • Improved stability of the electricity grid • Diversified and stabilised energy supply • Improved supply chain resilience of fuel supply from increased local production of alternative fuels • Reduced transportation and logistics costs from locally produced fuels • Diversified export resources 	<p>ANZ Standard Research Classification Category</p> <ul style="list-style-type: none"> • Analytical chemistry • Inorganic chemistry • Macromolecular and materials chemistry • Physical chemistry • Automotive engineering • Chemical engineering • Electrical engineering • Electronics, sensors and digital hardware • Fluid mechanics and thermal engineering • Materials engineering • Mechanical engineering • Resources engineering and extractive metallurgy • Atomic, molecular and optical physics • Classical physics • Condensed matter physics 	<p>Readiness Level – Now</p> <ul style="list-style-type: none"> • Some electric vehicles, including cars, buses, fork lifts, construction vehicles, through the use of hydrogen fuel cells • Dual-powered (hydrogen/diesel) farming equipment • Diesel-electric submarines, such as the German Type 212 • Industrial chemical feedstock • Hydrogen-fuelled gas turbines for power production • Hydrogen rocket fuel for space travel <p>Readiness Level – 2–5 years</p> <ul style="list-style-type: none"> • Blending hydrogen in the gas network • Hydrogen internal combustion engines • Ammonia as a carrier for hydrogen • Ammonia-fuel blends for combustion engines • Large-scale hydrogen fuel cells for factories • Green ammonia production <p>Readiness Level – Beyond 5 years</p> <ul style="list-style-type: none"> • Conversion of the gas network to using hydrogen • Fuel for mining vehicles, long distance trucks, trains • Fuel for cargo and container ship • Ammonia internal combustion engines • All-ammonia fuel cells

Australia's place in the world

China has the highest research impact in this field, significantly ahead of the second-ranked United States. Australia ranks 9th for research impact, led by the University of New South Wales and Curtin University which both feature in the top 50 international institutes.

Venture capital (VC) investment has increased at around 28% p.a. from 2016–2020, with the United States having the highest amounts of VC investment. Canada, the United Kingdom, Israel and the Russian Federation make up the top 5 countries for VC investment. Australia has the 10th highest amount of VC investment globally.

Patents in this area have been increasing by around 3% p.a. since 2015. China dominates the number of patents in this area, with almost 3 times the amount of the second-placed United States. Australia ranks 19th.

As articulated in the 2019 National Hydrogen Strategy, the Australian Government recognises the importance of hydrogen in the country's energy mix as an emerging power source. Australia has the opportunity to be world leading in its use of hydrogen and ammonia for power, both in terms of its research and potential export to overseas markets. Continual research and investment to more effectively extract and store hydrogen, as well as its safe export, could place Australia as a key export partner for countries with energy needs.

Opportunities and Risks

The growth of technologies to extract hydrogen and ammonia as power sources presents not only opportunities for exports to existing and emerging markets, but for promoting Australia as a reliable source of hydrogen. Hydrogen is increasingly being considered in other countries' energy mixes as a clean source of energy that can contribute to green energy targets. For example, Japan has set an ambitious target of 800,000 hydrogen fuel cell vehicles by 2030, with South Korea committing to 630,000 hydrogen fuel cell vehicles by 2030. Australia currently has 16 hydrogen projects underway, with a further 10 projects at an advanced stage of development planning. These investments could generate more than 8000 jobs, many in regional Australia, and contribute \$11 billion to GDP by 2050.

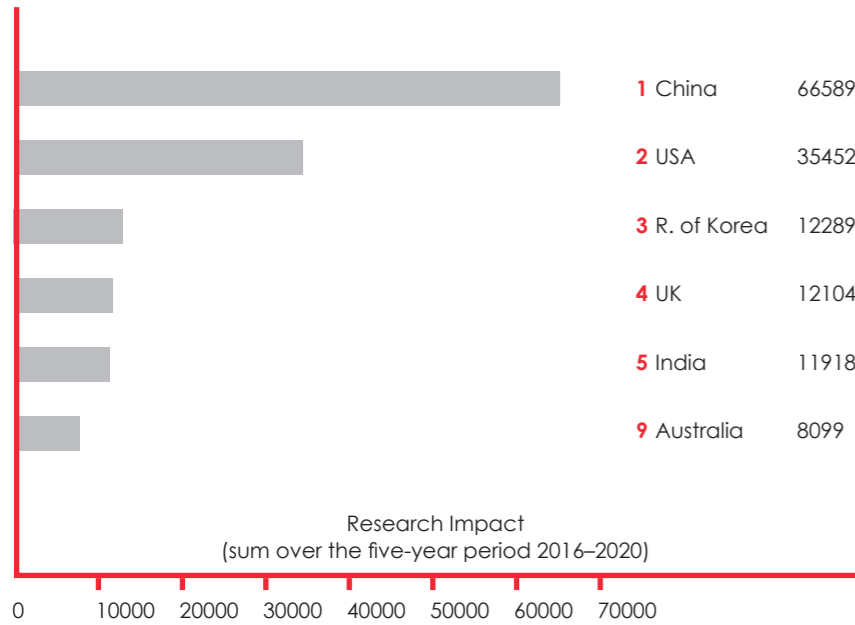
Diversifying our export mix to include hydrogen and ammonia as a source of fuel and power for current and emerging markets may help reduce Australia's reliance on traditional natural resources, such as coal. This could build Australia's economic resilience to price fluctuations and geopolitical actions which may not be in Australia's economic interests. Production of hydrogen and ammonia as clean, alternative sources of power may adversely affect other Australia exports, most notably coal. It may also affect other exports such as liquefied natural gas, which is a current source of (non-clean) hydrogen fuel.

Domestic commercialisation of hydrogen and ammonia is dependent on the competitiveness of energy pricing, especially as non-renewable power sources currently provide lower electricity generation costs. Furthermore, Australia's electricity grid has not yet been adapted to generate power from hydrogen or ammonia. Further investment in our capabilities, as well as adaption of the electricity grid, is required to lower costs, encourage domestic consumption and increase the competitiveness of Australian-sourced hydrogen. There is also further opportunity to alleviate national security and energy risks through the decentralisation of power production and increased source diversity.

As alternative fuels are increasingly adopted as sources for heat and electricity, countries may use hydrogen, for example, as a strategic, geopolitical asset. Attempts to undermine the use or export of hydrogen may create both an economic and strategic risk for Australia – particularly if Australia seeks to position itself as a key regional supplier of hydrogen. However, this risk can be mitigated through the reinforcement and facilitation of free trade, as well as export to a variety of trading partners and markets.

Research Impact (RI)

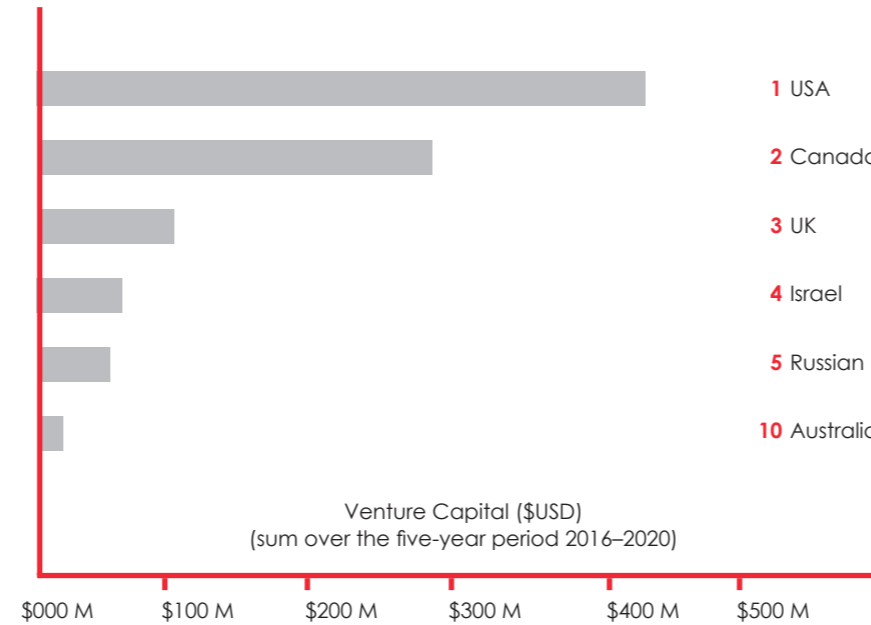
China has the highest research impact well ahead of the United States, with Australia ranked 9th. Total volume of published research has decreased at around 1% p.a. over the five-year period 2016–2020, with 25% of research involving international collaboration.



The research impact provides an indication of the productivity of a country or institution. Here, productivity was assumed to be represented by the volume of publications (i.e. scholarly output) as an indicator of the resources & facilities, and the level of interest in the publications as an indicator of quality.

VC Investment

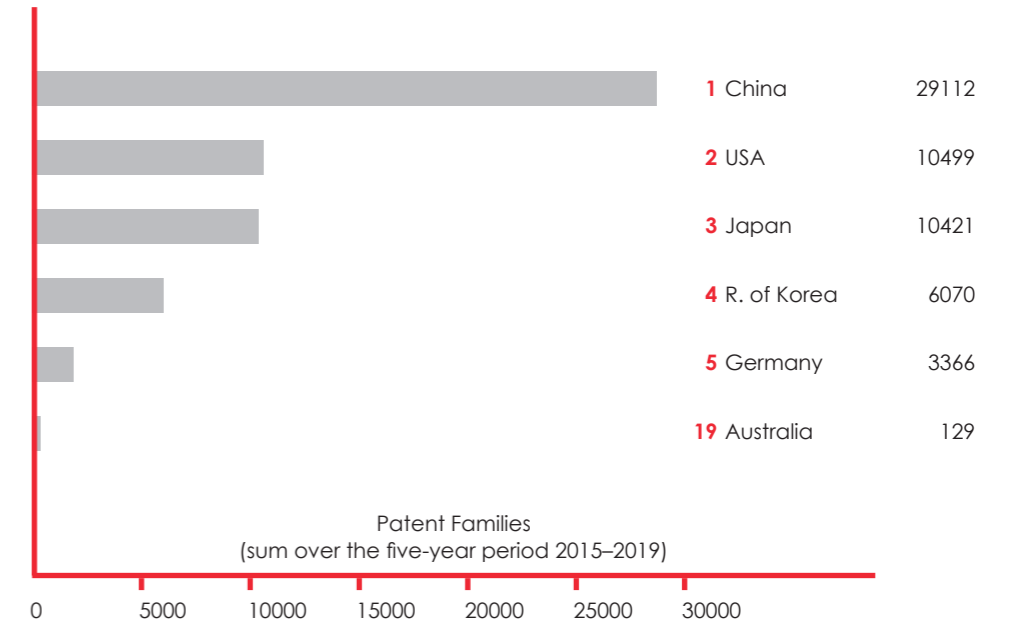
The United States has the highest venture capital (VC) investment, ahead of Canada and the United Kingdom. Australia is ranked 10th for VC investment in this area. Investment in this area has been growing at 28% p.a. since 2016.



Data from Crunchbase. The Crunchbase database provides a partial view of the global VC landscape. However the quantity, quality and richness of the data are considered to be statistically significant, and indicative of global trends.

Patents – International

Most patents for this technology were filed by Chinese applicants or inventors, with almost three times the number of the United States. Overall patent applications have been increasing at 3% annually since 2015. Australia ranks 19th.



Research Institutions – International

China dominates the top international institutions with 6 in the top 10. The United States, France and Malaysia make up the remainder of the top 10 international institutions.

Rank	Top International Institution	Research Impact
1	Chinese Academy of Sciences China	8742
2	United States Department of Energy United States	4504
3	French National Centre for Scientific Research (CNRS) France	4297
4	Tianjin University China	3934
5	Tsinghua University China	3847
6	University of Science and Technology of China China	3447
7	Argonne National Laboratory United States	2953
8	Universiti Kebangsaan Malaysia Malaysia	2547
9	Harbin Institute of Technology China	2479
10	University of Chinese Academy of Sciences China	2459

Research Institutions – Australia

Within Australia, the University of New South Wales leads research impact, and is ranked 18th internationally. Second ranked Curtin University ranks 35th internationally.

Rank	Top Australian Institution	Research Impact
1	University of New South Wales	2130
2	Curtin University	1600
3	University of Queensland	847
4	Royal Melbourne Institute of Technology University	675
5	Monash University	558
6	Swinburne University of Technology	455
7	University of Technology Sydney	358
8	Deakin University	283
9	University of Wollongong	280
10	University of Sydney	211

Patents – Australia

Top 5 Australian Patent Applicants	Patent Families
NewSouth Innovations	9
CSIRO	7
Aquahydrex	3
Hydrexia	3
Kohodo Hydrogen Energy	3

Patents filed by Australian businesses, 2015–2019.